

Creativity

Understanding Innovation in
Problem Solving, Science, Invention, and the Arts

Robert W. Weisberg

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Preface

In my last book on creativity, written over 10 years ago, I noted in the preface that it was an exciting time to be studying creativity, and I think that that statement is even more true today. The study of creative thinking has undergone what one might call a mini-boom in recent years, with an increasing stream of important work, both empirical and theoretical, being produced. We have accumulated an ever-expanding database of information that can serve as the foundation for thinking about the processes underlying creativity and the characteristics of creative people. In addition, the field has taken steps toward maturity, as evidenced by the increasing numbers of sophisticated models that have attempted to integrate and explain findings across disparate areas.

These recent advances have been presented in several recent edited handbooks, by Sternberg (1999), by Runco (1997), and by Shavinina (2003), which present cutting-edge chapters on various aspects of creativity written by experts. However, those developments have not been summarized and evaluated in an overall manner for students and researchers. There is thus a real need in the study of creativity thinking: There has been a growth in research without a comprehensive review of that research that will be useful for advanced students and scholars. The present book is designed to meet that need; it provides a comprehensive historically based review of research and theory concerning creative thinking, at the level of an advanced undergraduate or graduate-level course. I also believe that the presentation of material is comprehensive enough to make the book useful for scholars and researchers.

My plan in writing this book, as noted, has been to present a broad-

ranging historically based survey of research and theory concerning creativity. There is also a second purpose behind this project. I take what can be called a “cognitive” perspective on creativity—a view advocated also by Perkins (1981) and Simon and his coworkers (Newell & Simon, 1972; Simon, 1986), among others—which proposes that creative products of all sorts are brought about by our ordinary cognitive processes, such as those involved in our day-to-day problem-solving activities. From the point of view of the researcher studying creativity, there may be no difference in the processes that bring about a great scientific or artistic advance and those underlying someone’s making a new salad from leftovers in the refrigerator. Much of the mystery that we sometimes feel about creative thinking and creative people is the result of our ignorance about the phenomena in question. When one examines creativity from the perspective of the cognitive psychologist, one finds that many groundbreaking creative advances are comprehensible without assuming that anything ordinary is occurring in the way of thought processes. This conclusion can be contrasted with views that propose that there are extraordinary aspects of the person who is able to produce significant new works. Those postulated extraordinary aspects vary from theory to theory, but they include ways of thinking (“divergent” thinking, or leaps of insight, or unconscious thinking) or personality characteristics (“openness to experience”; psychoticism).

I have tried to be even-handed in my presentation of the facts, but I have not been reluctant to inform the reader of the interpretation of those facts that I felt was most useful. I saw my first responsibility as an unbiased presentation of the relevant information. That presentation could then be followed by the presentation to a now informed reader of possible interpretations of that information. The reader can then assess any theoretical claims from a knowledgeable position. I have tried to use my overall orientation to structure the presentation of the material while at the same time giving competing views a fair hearing and allowing readers to decide for themselves which interpretation to accept for the present. I have also criticized what I see as various shortcomings in my own view, again to assist the reader in making an informed independent judgment as to what to believe.

One unique aspect of this book concerns the “data” that are presented concerning creativity. In my own research, in addition to carrying out traditional laboratory studies of undergraduates solving simple problems, I have also examined historical case studies of the development of creative products (e.g., Weisberg, 2006). Examples have included the development of the double-helix model of DNA, the invention of the airplane and the lightbulb, and the development of *Guernica*, one of Picasso’s most famous paintings. I believe that case studies provide readers with compelling ex-

amples of how creative thinking functions at its best, and that they can provide us with “data” relevant to the scientific study of creative thinking, including creative thinking in the arts. I have used case studies as an important source of information concerning how the creative process works when it is functioning at the highest levels. In this book I present a wide range of case studies to which I constantly refer as I work my way through discussions of various phenomena. As noted earlier, this tactic allows the reader to approach material from a knowledgeable perspective, which allows him or her to play a more active role in the learning process.

While it is impossible for an author to judge the quality of his or her work, there is no doubt that this is my biggest book on creativity. There is a larger set of topics covered in this book than in my earlier ones. For example, the coverage of invention has been expanded, with information about various aspects of Edison’s career, and the material on scientific creativity is also covered more broadly and deeply. Musical creativity is also covered in more detail. There is also much more known about creativity, which requires more coverage. Beyond my own perspective, a number of other theories of creativity are covered in detail, research relevant to each theory—positive and negative—is discussed, and the relative merits of the various theories are evaluated, using what one might call a “compare and contrast” method. In conclusion, I believe that this book represents a unique addition to the literature on creativity. It presents an integrated review of recent research and theory, from a perspective that enables a fresh look at many phenomena. That viewpoint is supported with research findings, including case studies that are intrinsically interesting as well as not presented elsewhere. Finally, the presentation allows a comparison of several theories that have attempted to explain creative functioning.

The first chapter of the book presents a general introduction to my perspective on creativity. Rather than going directly to a relatively abstract discussion of issues of definition, I then present two case studies of creative thinking at the highest level—Watson and Crick’s discovery of the double helix and Picasso’s creation of the painting *Guernica*—which will illuminate in the best way the functioning of creative thinking, and provide the beginnings of a database from which the reader can assess theoretical proposals that will be presented later. Chapter 2 then serves to provide a general orientation to the area. It presents an overview of the study of creativity, including my particular definition of the relevant terms, which is a bit different from that typically used in the literature. The broad range of research methods used to study creativity is also critically examined. The chapter concludes with a brief introduction to some of the major theoretical perspec-

tives—including my own—that have been used to explain and understand creativity, and which will be discussed in detail throughout the book.

Chapters 3–5 present the details of the cognitive perspective that serves to organize my presentation. Chapter 3 discusses problem solving as an example of creative thinking and introduces many of the concepts used by the cognitive perspective to discuss problem solving, such as searching of problem spaces and the role of analogical transfer in problem solving. Chapter 4 examines the role of expertise in problem solving and in creative thinking more generally. Proposing that expertise is important in creativity immediately raises the question of the role of talent in creativity, and this issue is considered. Recent findings may require us to rethink the notion of talent. Chapter 5 presents a number of case studies from various domains—the arts, invention, and science—to provide support for the cognitive view presented in the earlier chapters. Throughout Chapter 5, the case studies are used as data to test specific aspects of the cognitive view as well as to provide examples of application of the concepts underlying the cognitive perspective.

Chapters 6–11 examine various aspects of the competition to my view; that is, those chapters examine other ways of understanding creativity. Chapter 6 examines the notion of insight in problem solving (and by implication in creative thinking): the idea that solutions to problems sometimes come about as the result of processes that bring about sudden changes in the way the problem is perceived. Those processes are different from those postulated by the cognitive view presented in the earlier chapters. The notion that creative advances come about through a sudden leap of insight has been in psychology for more than 100 years, and I review its development and the current status of its empirical support. Chapter 7 examines the question of genius and madness, the idea that psychopathology may play a role in fostering creative production. This too is an idea that has been around for a long time, and I again examine its history. In addition, this is an area in which increasingly nuanced work has taken place in recent years, and I examine those developments in some detail, since they allow us to move away from the simple idea that madness does (or does not) support genius. The issues are much more complicated but (to me at least) much more interesting.

The cognitive perspective outlined in Chapters 1–5 assumes that creative thinking is the result of ordinary conscious thought, which raises the question of the possible role of the unconscious in creativity. Chapter 8 examines various aspects of the unconscious that have been postulated by researchers as playing a role in creative thinking, and also examines empirical support for those components. Chapter 9 is the first of two chapters examining the psychometric perspective on creativity. This is the general idea that one

can use tests to ascertain important aspects of creative individuals, and thereby determine what it is that allows them to do what they do. Chapter 9 examines tests that have been developed to measure the thinking strategies underlying creative thinking, and examines the support for the idea that there is a critical type of thinking underlying creativity and that one can measure that thinking type using “creativity tests.” Chapter 10 examines research that has used tests to isolate critical features of people’s personalities that play a role in creative accomplishment. Finally, Chapter 11 critically reviews three theories that have been proposed to explain creativity. Each of them provides an alternative to the cognitive perspective underlying my presentation, which will allow readers to determine, based on the evidence presented earlier as well as new evidence presented in Chapter 11, which view they believe is most reasonable at this time. The last chapter provides a summary of the discussion in the book and presents suggestions for where we might go in the future.

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This book is dedicated to the memory of my father, who first taught me how to think; to my mother, who keeps me on my toes and who never ceases to amaze me; and to Alana, who is teaching me to wonder all over again.

CHAPTER

1

Two Case Studies in Creativity

Creative thinking brings about new things—*innovations*—ranging from solutions to simple puzzles and riddles to ideas and inventions that have radically altered our world. *Creative people* are those who produce such innovations, and the *creative process* consists of the psychological processes involved in bringing about innovations. Figures 1.1A and 1.1B give examples of some of the more impressive products of creative thinking. In Figure 1.1C are some simple exercises that might result in creative thinking on your part. If you had never seen those puzzles and riddles before, and if you solved one or more of them, then you were thinking creatively when you did so—you produced something new. In this book, we will consider the full range of creativity, ranging from solving simple puzzles to producing the seminal innovations shown in Figures 1.1A and 1.1B. We will examine a wide range of recent research on creativity, as well as theories that have been developed to explain the processes involved when people produce innovations.

There are many reasons why creativity is a critically important topic for psychologists to understand. First of all, our world has been shaped by the products of creative thinkers. All of our modern conveniences—the telephone and other modes of communication, the automobile, the airplane, computers, and so forth—have been brought about through the creative work of inventors and scientists. Our healthy existences and our ever-longer lives are the result of scientific and medical advances, which are the result of creative thinking on the part of scientists in many domains. Much of the richness of our lives—art, music, drama, literature, poetry—is the result of artistic creativity. Society values greatly the products of creative thinking;

CREATIVITY: UNDERSTANDING INNOVATION

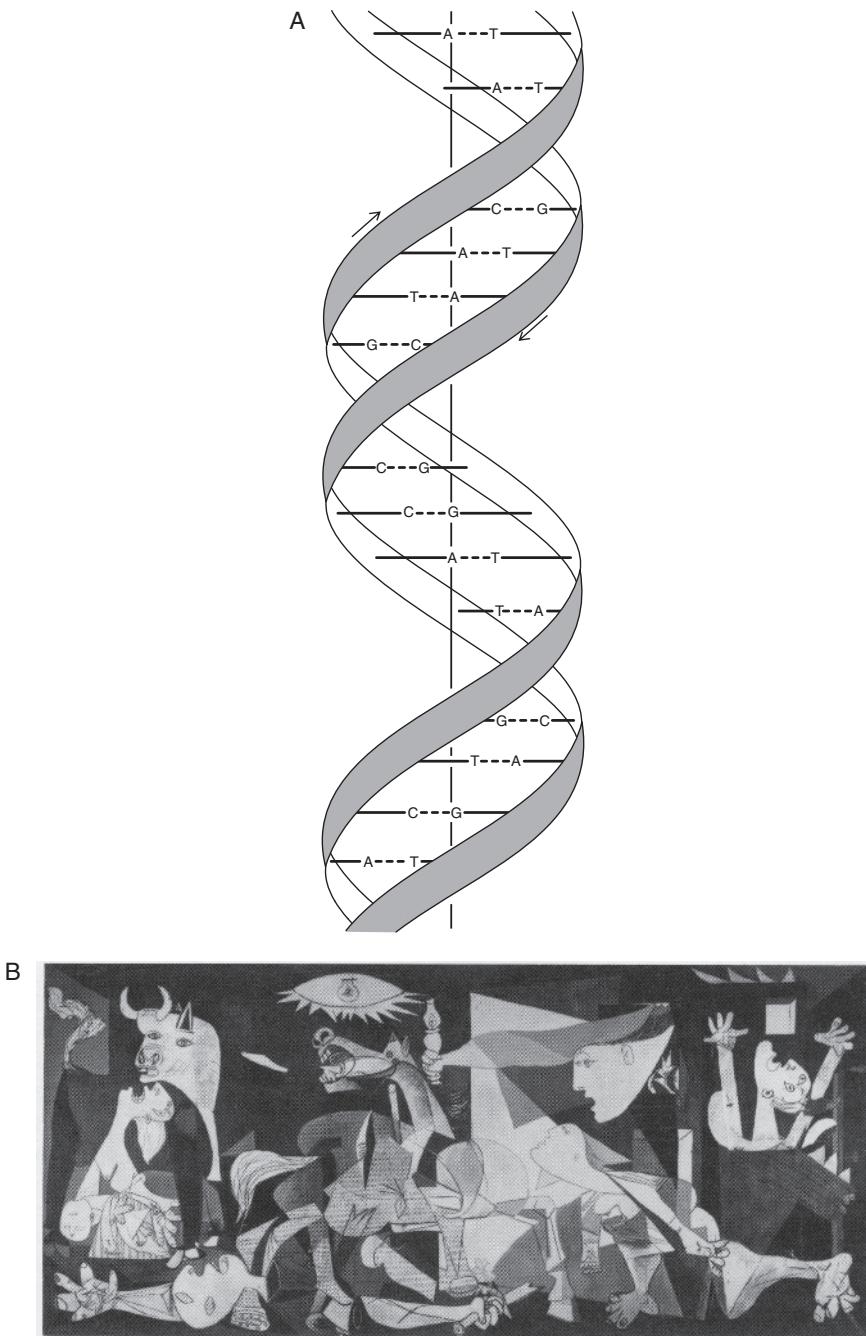


Figure 1.1 Examples of creative thinking (1937): A, DNA: The double helix; B, Picasso's *Guernica*; C, Examples of problems

Two Case Studies in Creativity

C

Balance

You have four indistinguishable coins—two heavy and two light. How can you tell which are which in two weighings on a balance scale?

Solution: Weigh any two coins. (A) If they do not balance, one is heavy and one is light. Repeat with the other two. (B) If they balance, they are both light or both heavy. Replace one coin with one of the two that remain, that will tell you whether the original pair is light or heavy.

Cards

Three cards are lying face down. To the left of a queen is a jack; to the left of a spade is a diamond; to the right of a heart is a king; to the right of a king is a spade. Assign the proper suit to each card.

Solution: Lay out information in an array: Jack of hearts, king of diamonds, queen of spades.

Prisoner

A prisoner in a tower finds a rope reaching halfway to the ground. He divides it in half, ties the two pieces together, and escapes. How? *Initial solution:* The problem is impossible.

Solution: He unravels the rope *lengthwise* and ties the two pieces together.

Basketball game

Our basketball team won last night, 74–55, and yet not one man on the team scored so much as a single point. How is that possible?

Solution: It was our women's basketball team.

Figure 1.1 (continued)

we bestow honors, such as Nobel Prizes, on those who have produced such things, and the stories of their lives and accomplishments fill our history books and encyclopedias. By understanding how creative products are brought about, we may be able to increase the likelihood that innovations will occur, thereby making life better for us all.

In addition, creative thinking is also big business. Our largest and most prestigious corporations, as well as the largest government agencies, are constantly searching for ways to be more innovative, and they pay handsome fees to consultants who will help them achieve new levels of innovation from their employees. Institutions of higher education also take interest in teaching creative thinking. Many university business schools offer courses that are designed to provide business leaders—both those of the future and present-day ones who return for a refresher—with skills that will enable them to solve on-the-job problems. At the grassroots level, one constantly

reads accounts of debates concerning the best way to structure our educational system so that children come out as young adults who are able to think creatively. It is therefore important that we have some idea of how creativity comes about, so that we can make decisions concerning how individuals might be helped in dealing with situations that demand creativity.

Beliefs about Creativity

There are two difficulties in discussing research on creativity. Some people, even people with very deep knowledge of psychological phenomena, come to the subject of creativity with the belief that the topic is so mystical and/or subjective that it could never be captured by psychological methods (Sternberg & Lubart, 1996). In this view, we cannot even define what terms like *creativity* and *creative* mean, so as a consequence we cannot even discuss them coherently, much less study them using scientific methods. I have sometimes been asked by other cognitive psychologists—that is, people whose professional lives are involved in bringing difficult-to-study psychological phenomena under scientific scrutiny—how one could ever study creative thinking. They cannot see how one can bring creativity under scientific investigation. One purpose of this book is to demonstrate how something as seemingly difficult to pin down as creativity can be defined and brought under scientific study.

Other people, from inside and outside psychology, come to the discussion of creativity with the belief that, even if we can define creativity and begin to study it, there is no purpose in doing so, because creativity comes about as the result of almost supernatural powers. In this view, the people who bring about things like those in Figures 1.1A and 1.1B are basically different from ordinary people: They are endowed with gifts that the rest of us do not have. Learning about what they do and how they do it, even if it were possible to do so, might be of some interest in its own right, but it would not tell us much that would be useful. The differences between the creative greats and ordinary people are in this view assumed to be of two sorts. On the one hand, the greats do not think as you and I do, and the differences between “real” creativity and the activities that you and I carry out are so great as to be unbridgeable. The relatively simple problems presented in Figure 1.1C may require some creativity for solution, but those problems are so different from the situations in which great artists, inventors, and scientists work that entirely different cognitive processes must be involved. So the processes involved when you and I solve such problems would not tell us much about “real” creativity. Second, there are

Two Case Studies in Creativity

assumed to be critical differences in personality structure between creative and ordinary individuals, and those differences are assumed to play a role in making some people creative.

Most psychologists who have developed theories on creative thinking and creative persons take a different perspective on these issues. Although many psychologists believe that creative thinking depends on specific thought processes, they also believe that those processes can be carried out to some degree by all of us. Those who produce great creative advances might be *better* creative thinkers, but the same thought processes are available to or present in all of us. Similarly, if there is a specific set of personality characteristics that are related to creative achievement, those characteristics are assumed to be present to some degree in many if not all of us; they are simply present to a higher degree in those who produce great creative achievement. According to this perspective, then, creative capacity may to some degree be present in all of us (e.g., Amabile, 1996; Csikszentmihalyi, 1996; Eysenck, 1993; Guilford, 1950; Sternberg & Lubart, 1995).

There is also a minority view in psychology (e.g., Perkins, 1981; Newell, Shaw, & Simon, 1962; Weisberg, 1980, 1986, 2003), to which I subscribe, that proposes that the thought processes underlying the production of innovations are the same thought processes that underlie our ordinary activities. From this perspective, the term *creative thinking* is misleading at least and perhaps a misnomer, because one thinks creatively by using ordinary thinking; one just uses that ordinary thinking to bring about innovations (see also Klahr & Simon, 1999). This does not mean that there is no such thing as creativity, however. There is no doubt that scientists, artists, and inventors, for example, bring forth innovations. It is just that those innovations are based on the ordinary thought processes that we all carry out.

One task of this book is to review a representative sample of the various theories of creativity proposed by psychologists and to examine their structure, the predictions that are derived from them, and the evidence for and against them. A further task of this book will be to show that there is a relatively close relationship between creative thinking and other forms of cognition, such as problem solving, reasoning, and the use of memory. That is, the view motivating the presentation in this book is that creative thinking is not different from ordinary thinking—the thinking that we use in carrying out our day-to-day activities. I will show also that the differences in personality and other psychological characteristics between creative individuals and ordinary people may not be very large, and, furthermore, those differences may not be crucial in making creative people creative.

Two Case Studies in Creativity

In this first chapter, I will discuss two examples of creative thinking at its highest: Watson and Crick's discovery of the double-helix structure of DNA, the genetic material (Figure 1.1A), and Pablo Picasso's creation of *Guernica*, his great antiwar painting (Figure 1.1B). Those two case studies will provide us with "data" of a sort we will have occasion to refer to many times as we consider theorizing concerning creative thinking. At various points in this book, we will discuss the Beatles, Edison, Darwin, the Wright brothers, and Mozart, among other creative thinkers, and the case studies presented in this chapter will provide an introduction to this method. The data from case studies such as those presented here, in conjunction with other results, such as those from laboratory studies of creativity, will allow us to bring an educated perspective to the sometimes conflicting claims made by theories of creativity.

The two case studies to be discussed—one from science and one from the arts—are relevant to the question of what differences may exist between the creative processes in those two domains. At first glance, it seems that we are talking about two different things when we talk about creative thinking in the arts versus the sciences. We use different terms to describe the process in the two domains: We talk about artists *creating* their works (Picasso created *Guernica*), but we talk about *discoveries* in science (Watson and Crick discovered the double-helix structure of DNA). There seem to be basic differences in our beliefs concerning the relation between the person and the product in the arts versus the sciences. It is obvious that, if there had never been Picasso, then there would be no *Guernica*. Similarly, no Beethoven, no Beethoven's Fifth Symphony. Artistic creativity seems to be an inherently subjective process, as the artist produces something that would not have existed save for the effort of that person. DNA, on the other hand, exists independently of Watson and Crick. If there had been no Watson and Crick, DNA would still have been there, waiting to be discovered, and at some point it would have been discovered. Scientific discovery, in this interpretation, is an objective process: Objects, events, and facts available to all of us are what scientists discover. As we work through the two case studies, I will try to make note of aspects of each that point to similarities, rather than cut-and-dried differences, between creative thinking in science and the arts. Artistic creativity is not as subjective, nor is scientific creativity as objective, as one might think.

Creativity in Science: Discovery of the Double Helix

In 1953, Watson and Crick published the double-helix model of the structure of DNA, which has had revolutionary effects on our understanding

and control over genetic processes. As one example of the impact of Watson and Crick's work, there has in recent years been much controversy over the possibility that scientists have succeeded or will soon succeed in cloning human beings. This possibility is but one of the remarkable developments that can be traced directly back to the discovery of the double helix. Geneticists, biologists, and other scientists, including Watson and Crick's teachers, had for more than 50 years been pursuing the question of the composition and structure of the genetic material (Olby, 1994). Watson and Crick succeeded in formulating a model of the structure of DNA after approximately one and a half years of work, and several misdirected attempts. Other research groups were at that time also working on the structure of DNA, and Watson and Crick were not the first to publish a possible structure, but theirs was ultimately judged to be correct (Judson, 1979; Olby, 1994).

DNA was a discovery of wide sweep, which involved a large number of contributors. Examining this discovery will provide information concerning how scientists become focused on the questions that they study. What, if anything, does the creative individual know that leads him or her to the important questions, the answers of which will change our world? Studying the discovery of DNA also will allow us to address the critically important question of how different scientists, while studying the same phenomenon, wind up taking different approaches, so that one is successful while the other is not. That is, we will begin to gather information on what, if anything, separates the individual who produces the important scientific discovery from the one who does not.

Historical Background

DNA was discovered in the middle of the nineteenth century, and by the early twentieth century it had been shown to be present in all cells (Stent, 1980, p. xiii). DNA is made up of a number of different components: a phosphate group, constructed around phosphorus; a sugar; and four different nitrogen-rich bases, adenine, cytosine, guanine, and thymine, abbreviated as A, C, G, and T. (See Figure 1.2.) One phosphate, one sugar, and one base form what is called a *nucleotide*, the basic unit out of which DNA is constructed. There are four different nucleotides, differing only in their bases. Thousands of nucleotides, strung together, form the complete DNA molecule. So the basic structure of DNA could be described as a *polynucleotide*, built out of a set of building blocks that repeat again and again.

It was not until the late 1940s that researchers began to agree that DNA was the genetic material. Although DNA is found almost exclusively in the chromosomes, which are the sites of the genetic material, there is more protein than DNA in chromosomes, which led to the belief that protein

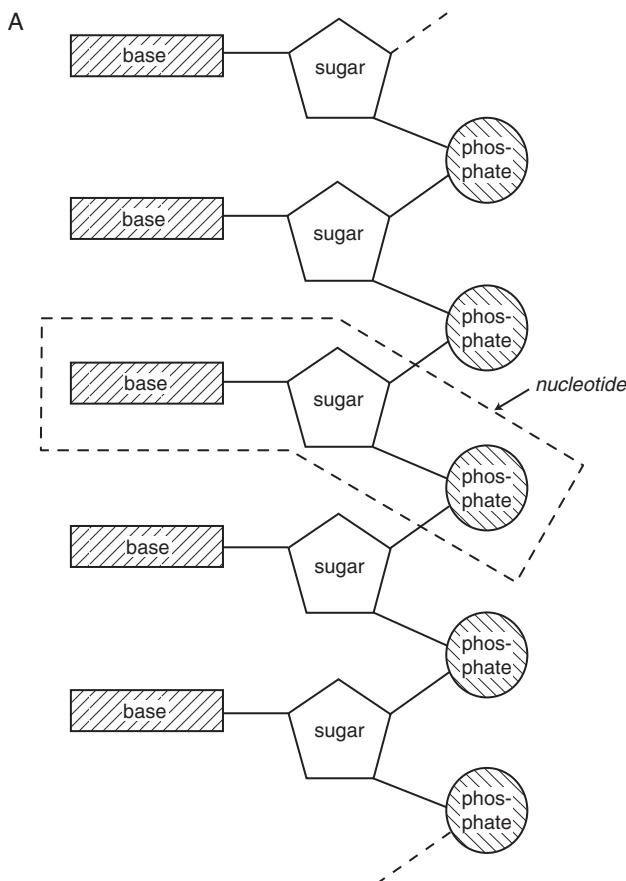


Figure 1.2 DNA information: A, Nucleotides; B, Chemical structures of the four DNA bases as they were often drawn about 1950.

might be the critical material. In addition, it was also thought originally that DNA was a relatively simple molecule, too simple to carry out the tasks required of genetic material (Olby, 1994). It was initially believed that the DNA molecule was simply a *tetranucleotide*, that is, that the complete molecule consisted of one of each of the four nucleotides, and nothing else. It was soon shown that the molecular weight of DNA was much larger than only four nucleotides, but researchers then assumed that the large molecule simply consisted of the four nucleotides repeating monotonously in the same sequence. In both those analyses, DNA was relatively simple in structure. The function of the genes is to direct synthesis of proteins, which are complex molecules. It seemed to follow from this that the genes would have to be complex as well. Therefore, DNA with its simple tetranucleotide

Two Case Studies in Creativity

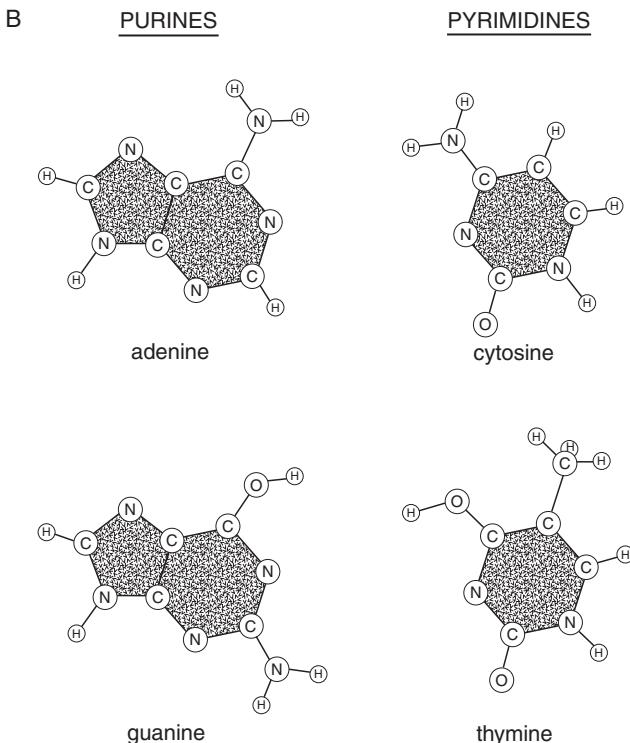


Figure 1.2 (continued)

structure could not serve that purpose. It was assumed by some that DNA was present in the nucleus only to serve as a “stretcher,” so that the protein genes could be straightened out to carry out their functions.

In the 1940s, several different sorts of evidence pointed to DNA as the genetic material. In 1928, Griffith had shown that injection of purified material from virulent pneumococcus bacteria (that is, bacteria that caused illness—in this case, pneumonia) into heat-killed bacteria that were benign (i.e., that no longer produced pneumonia) could *transform* those benign bacteria into virulent ones (Olby, 1994). Most important, this transformation could also be passed down to subsequent generations, which indicated that the genetic material of those benign bacteria had been altered. The critical question then centered on the chemical composition of the extracted material, or “transforming substance,” and in 1944, Avery and colleagues identified it as DNA. Furthermore, since the transformation could be passed down genetically, identifying DNA as the transforming substance indicated that DNA might be the genetic material as well.

Also during this decade, a study by Hershey and Chase examined the

mechanisms whereby viruses attacked and killed bacteria, in order to gather information about the composition of the genetic material (Olby, 1994). When a virus attacks any organism, including a bacterium, it takes over the reproductive mechanism of the host organism's cells and uses them to reproduce itself. A virus is essentially genetic material encased in a shell. Hershey and Chase used radioactive phosphorus (which is incorporated into DNA) and radioactive sulfur (which becomes part of protein) in order to produce strains of viruses with different radioactive "signatures." They then traced the fate of those radioactive chemicals after the marked viruses had infected bacteria. In a methodological innovation that became legendary, the researchers used a kitchen blender to separate the infected host bacteria from the shells of the viruses that were attached to them. The results indicated that when viruses attack bacteria, the viral DNA is introduced into the host bacteria, while the shell of the virus, which is made up of protein, stays outside the host. The protein shell seemed to serve as a kind of hypodermic that injected the viral DNA into the host. This result provided strong support for the idea that DNA was the material carrying the genetic information from the virus to the bacteria.

Finally, in a series of chemical studies of DNA, Chargaff showed that the tetranucleotide hypothesis of the structure of DNA was incorrect (Olby, 1994). He analyzed the relative proportions of the various bases in DNA from different organisms. The results, shown in Table 1.1, contradicted the tetranucleotide hypothesis in two ways. First, within each species, the proportions of the various bases were not equal, and second, the ratios of the various bases differed in different species. So there was much more variability in DNA than researchers had believed, perhaps enough variability for the DNA molecule to function as the carrier of the genetic code. Another interesting finding reported by Chargaff was that, even though the proportions of the bases differed from species to species, in each species there seemed to be equal proportions of A and T, as well as equal proportions of G and C.

Table 1.1 Chargaff's data on the chemical composition of DNA from different species (Chargaff's ratios)

Species	Base composition (%)			
	A	T	G	C
Human (liver)	30.3	30.3	19.5	19.9
Bacterium (tuberculosis)	15.1	14.6	34.9	35.4
Sea urchin	32.8	32.1	17.7	18.4

This pair of findings, which became known as “Chargaff’s ratios,” turned out to be significant in the construction of the double helix.

As a result of this constellation of findings, by the 1950s many researchers, although not all, had come to believe that DNA rather than protein was probably the genetic material. Watson (1968, p. 31) notes this when he comments on meeting Crick, “Finding someone . . . who knew that DNA was more important than proteins was real luck.” Once Watson had met Crick, the central question for the two of them concerned the way the DNA molecule was structured.

As we can see, it is not always obvious to scientists what the important questions are in a discipline. Some first-class researchers were pursuing the study of the structure of the proteins in the cell nucleus as the basis for understanding the structure of the genetic material. Those individuals obviously had no chance of discovering the structure of DNA. So when Watson says that he was lucky to have found a kindred spirit in Crick, we can understand the significance of that statement, and we can ask where that commonality of interest came from. One sometimes sees it stated (e.g., Getzels & Csikszentmihalyi, 1976; see also chapters in Runco, 1994) that individuals who make creative discoveries have an ability or intuition—a skill sometimes called *problem finding*—that allows them to find a critically important problem to work on, where other less-creative individuals see nothing of importance. The latter individuals therefore spend time and effort studying problems that may lead nowhere, or at least will lead to less important results. So the question of how Watson and Crick focused on DNA, to which we now turn, is one with broad implications.

Watson Gets to Cambridge

Watson and Crick’s collaboration began in autumn 1951, when Watson joined the staff of the Cavendish Laboratory at Cambridge University, where Crick was working on his PhD (see Table 1.2). Watson already had a PhD in genetics; Crick had been trained as a physicist before World War II, but he was then working toward a PhD in biology, studying the structure of hemoglobin using X-ray diffraction techniques. Even though Watson and Crick had never met, they had intellectual links. Watson had received his PhD in genetics at Indiana University, working under the direction of Salvador Luria, who, along with Max Delbrück and Alfred Hershey (of the Hershey-Chase kitchen-blender experiment discussed earlier), was one of the founders of the “phage group” (see Figure 1.3). This was a group of scientists who were interested in studying bacteriophages, viruses that devour bacteria, in order to understand the genetic mechanisms in all organisms. *Phage* comes from the Greek for *eat*; the kitchen-blender study

Table 1.2 DNA Timeline

Date	Research team and activity	
	Watson and Crick	Wilkins/Franklin/Pauling
<i>1951</i>		
Spring	Watson attends conference; sees Wilkins's X-ray photo.	Wilkins presents X-ray photo at conference.
July		Wilkins visits Cambridge, tells Crick DNA was probably helix.
Fall	Watson joins Cavendish.	
Mid-September		Franklin: X-ray pictures of DNA; fibers made wetter stretched and yielded a new pattern (B form); Wilkins and Stokes: photos showed "helical features."
October 31	Cochran and Crick: helical X-ray pattern theory.	
November 9–11	Wilkins visits Cambridge; Wilkins: DNA helical.	
November		Franklin's notes prior to colloquium: structure helical in both states; presents evidence.
November 21	Watson attends Franklin's colloquium, takes no notes, misses much of what she says.	
November 22	Watson reports to Crick what he remembers from Franklin's colloquium. Mistakenly recalls amount of water (in B form). Crick: only a few structures are compatible with Crick/Cochran theory of helices.	
November 26–28	Begin building chain-inside models. 3 chains fit density data; "hole" for water; held together by Mg ⁺ ions.	

Two Case Studies in Creativity

Table 1.2 (continued)

Date	Research team and activity	
	Watson and Crick	Wilkins/Franklin/Pauling
November 28	King's group comes to see model; points out problems. Franklin: backbones outside; too little water.	
1952		
Early in year		Wilkins letter to Crick: phosphates outside.
April 10–19		Franklin: new A-form pictures—it is not a helix.
May 1	Franklin tells Watson that DNA is not helical.	
May 1–6		Franklin: new B-form X-rays (49 & 53); clearly helix.
Spring	Watson learning crystallography. TMV photo: helix.	Wilkins, convinced by Franklin that A form not helical, decides B is not either; stops work in frustration.
Late spring	Crick tells Franklin A-form photo might be misleading.	
May 24–27	Chargaff visits, explains results.	
July 18		Franklin announces “death” of DNA helix.
Summer		Franklin, with Gosling, begins Patterson synthesis of A form (analytical approach).
November 26		Pauling, using density measurements, calculates number of chains to be 3; result surprises him.
End Nov.		Franklin writes up work, describes unit cell of molecule.

(continued)

Table 1.2 (continued)

Date	Research team and activity	
	Watson and Crick	Wilkins/Franklin/Pauling
December 15		Committee (including Perutz) visits King's.
December 25		Pauling invites colleagues to see 3-strand model of DNA.
1953		
January 2		Pauling submits note on DNA to <i>Nature</i> .
January 19		Franklin models figure-8 structure.
January 28	Pauling's manuscript arrives; model seems incorrect.	
January 30	Watson goes to King's with Pauling's manuscript, sees Franklin's B-form photo (51), decides that 2-strand models are not ruled out by density data.	
February 2		Franklin: "Objections to figure-8 structure" in notebook
February 4	Watson builds models; 2 fruitless days on chains inside.	
February 5	Watson tries 2-chain-outside model; easy without bases.	
February 10	Crick sees Franklin's report, deduces anti-parallel chains (based on his thesis), led to 2 chains. Watson & Crick build backbones with 36° rotation; Watson provides deductive evidence for 2 chains.	Franklin working on helix for B form.
Feb. 16(?)–19	Watson reads on bases; DNA held together by H bonds; builds "like-with-like" model.	

Two Case Studies in Creativity

Table 1.2 (continued)

Date	Research team and activity	
	Watson and Crick	Wilkins/Franklin/Pauling
February 20	Like-like torn to shreds by Donohue; wrong tautomers.	
February 23		Franklin: helix of B form to probable helix of A
February 28	Watson discovers base pairings by manipulating models on desktop.	

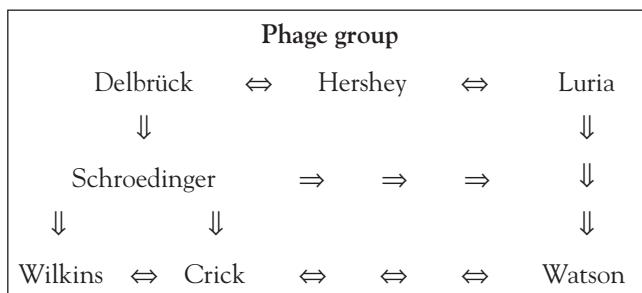


Figure 1.3 Intellectual links between Watson, Crick, and Williams

of Hershey and Chase was a study of the mechanisms of reproduction of bacteriophages. Delbrück was a physicist who had moved into biology in search of new research areas (Olby, 1994). He had also convinced other physicists of the importance of biological questions, and a number of other physicists followed him into biology after World War II.

In 1944, Erwin Schrödinger, a physicist and one of the founders of quantum mechanics, published a book called *What Is Life?* in which he discussed how the then-unknown genetic material might be structured and how it might transmit information and direct the reproduction and other activities of cells. He proposed that the genetic material might be constructed out of small units that repeated over and over in various combinations, with the various combinations serving as letters in a kind of alphabet used to communicate information from the gene to the mechanisms in the cell. Schrödinger was familiar with and influenced by Delbrück's ideas (Stent & Calendar, 1978, p. 26), and his book can be looked upon as a popularization of those ideas. Schrödinger's book was read by many physicists who

then became interested in biological questions in general and genetics in particular, and it was also read by biologists. One such physicist was Crick, and another was Maurice Wilkins, a friend of Crick's who was studying the structure of DNA at King's College, in London, and who, as we will see, played a significant role in the discovery of DNA. Luria and Watson also read Schroedinger's book. These links are shown in Figure 1.3.

Thus, we can understand in a straightforward manner Watson and Crick's common interest in the structure of DNA: It came directly out of their common intellectual heritage. In this case, and in other cases to be discussed later, the problem that turned out to be important and fruitful was almost thrust upon Watson and Crick—and also upon other researchers who played important roles in the story as it unfolded—by the intellectual milieu in which they were raised.

At Luria's suggestion, Watson went to Europe in the fall of 1950 to study the chemistry of the nucleic acids, because Luria felt that acquiring that knowledge would help Watson gain an understanding of how genes function. Watson did not find the work interesting, however, and he was looking for a more stimulating environment in which to work, especially a place that might provide an opportunity to work directly on the question of the structure of the genetic material. In the spring of 1951, Watson attended a conference in Naples, at which Wilkins presented a paper. During his talk, Wilkins projected a slide of an X-ray photograph of DNA (see Figure 1.4), which completely captivated Watson (Watson, 1968). The fact that one could photograph DNA using X-rays meant that one could make a crystal out of it, which in turn meant that DNA must have a regular structure, which might be analyzable without an impossible amount of work. Watson then decided that he would work someplace where it would be possible to carry out X-ray analysis of DNA. There were only a few places where one could carry out such work; one was the Cavendish Laboratory at Cambridge University, which had been world-famous for its X-ray work since early in the twentieth century. Watson was able to arrange an appointment there, and he joined the staff in the fall of 1951.

Watson and Crick's Collaboration

Soon after Watson's arrival at the Cavendish, he and Crick made two early decisions about DNA that were very important in setting them on the path to success. First, they decided to try to build a model of the structure, as shown in Figure 1.1A. Deciding to build a model led to the question of the shape of the molecule. Was DNA a long chain of nucleotides, one attached to the next? Was it a closed ring, with one nucleotide attached to the next until one came back around to the point where one began? Was it shaped

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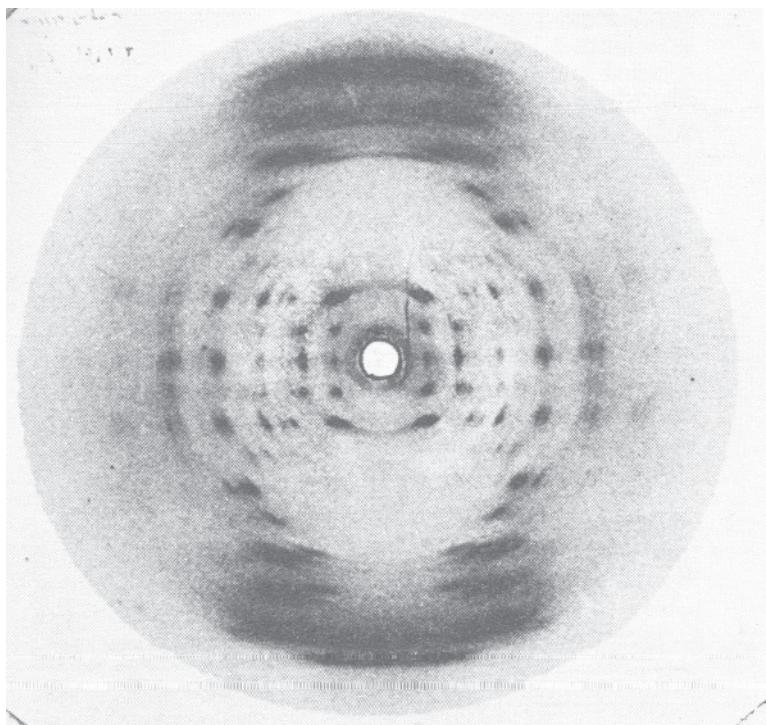


Figure 1.4 DNA X-ray photo

in some other way? One of those choices had to be made; so, in order to initiate their model-building work, Watson and Crick agreed to begin with the working assumption that DNA might be in the shape of a helix. This helical assumption was, of course, correct in general terms, and it, along with the model-building orientation, put Watson and Crick solidly on the path to success. Other researchers who were also working at that time on determining the structure of DNA, including Wilkins, had not decided to build models and/or had not made the assumption that DNA was helical, and they were therefore slower in finding the structure (Judson, 1979).

We are thus faced with another question of critical importance in the understanding of the creative process of Watson and Crick: Where did they get those two critical ideas—that they should build models and that DNA might be helical? Did they have some magical intuition, some creative sixth sense, that led them along the correct path, where others did not know to tread? It seems not. Both of those critical assumptions were based relatively directly on the work of Linus Pauling, a world-famous chemist

who had recently solved the problem of determining the structure of the protein alpha-keratin (Olby, 1994; Watson, 1968), which forms fingernails and hair, among other things. Pauling had proposed that alpha-keratin was helical in shape, and he had built a model of the structure to show how all the atoms fit together. He had also published an unheard-of seven papers in a single issue of a professional journal, in which he and his associate presented the alpha-helix and evidence to support it. Pauling's success had stirred the scientific community, and especially the Cavendish lab, where similar techniques were being used to investigate proteins. It was felt by some, including some at the Cavendish, that Pauling's success was at the expense of and an embarrassment to the Cambridge group.

However, the fact that Pauling could be seen as a rival of the Cavendish group did not stand in the way of Watson and Crick's seeing the potential usefulness of his research methods and ideas in the analysis of DNA. Like DNA, alpha-keratin is a large organic molecule—a *macromolecule*. In addition, alpha-keratin is similar to DNA in one critical way: Proteins are constructed out of large numbers of repeating units, or *peptides*, which are linked together to comprise the large protein macromolecule. Proteins thus are *polypeptides*, a structure similar to the *polynucleotide* structure of DNA. The reason Watson and Crick chose Pauling's work as the basis for their own is easy even for us non-molecular-biologists to understand: The domains are closely linked. We have here a clear example of what can be called *continuity* in creative thinking: Watson and Crick built their work on the past. That is, the new work was continuous with the past. Continuity is also a component of our ordinary thought processes, of course, because in our ordinary thinking activities we are always using what we know as the basis for decision making and behaving.

Wilkins also contributed to Watson and Crick's adoption of the assumption that DNA was helical. Around 1950, Wilkins was carrying out what was probably the most advanced work on DNA in the world (Olby, 1994). He had been studying the properties of DNA in response to light, when he accidentally produced long fibers of DNA. When his assistant exposed those fibers to X-rays, the results were the best diffraction patterns that had been seen, one of which was the photograph that had excited Watson at the Naples conference. From the X-rays, one could deduce the diameter of the molecule and the distance between consecutive bases. However, one could not determine any more specific information about the shape of the molecule or how it was constructed.

A researcher skilled in interpreting such X-rays could also determine that there was an underlying pattern in the structure of the molecule, which repeated as one went along it. Knowing about the double helix, we can un-

derstand that the repetition of the pattern comes about because the helix cycles and comes around to the same place as one travels along the molecule. As an analogy, when you enter a spiral staircase and start to ascend, you will reach a point as you go around at which you will be standing directly above the first step of the staircase, where you began. That is the point at which the structure begins to repeat. Of course, at that time, no one knew why there was a repeated pattern; all that could be seen from the X-ray photograph was that a repetition of some sort occurred. In the summer of 1951, before Watson arrived at the Cavendish, Wilkins had given a talk at Cambridge during which he discussed the possibility that DNA was helical (Judson, 1979; Olby, 1994). At the time, judging by measurements of its density, as well as other data (some of which turned out to be incorrect), he felt that it might be a single strand. In the fall of 1951, after Watson joined the Cavendish staff, he, Crick, and Wilkins met and discussed DNA; they agreed that the molecule was probably helical. By the time of this meeting, Wilkins was leaning toward a theory, based on new data, that there were three strands.

It is important to note here that seeing a helical pattern in the X-ray in Figure 1.4 is not the same as seeing a smile on the face of your friend. That is, the diffraction pattern produced by exposing the DNA crystal to X-rays does not look anything like a helix. There is no visible evidence that can be directly seen as being from a helix. One must understand X-ray crystallography in order to see a helical pattern in an X-ray photograph. One must first make certain assumptions about how the X-ray beam will be broken up by a crystallized molecule of a given shape and structure. Then one can make predictions about what the diffraction pattern will look like, although, as just noted, the pattern will look nothing like a helix. This is a crucially important interpretive skill, and Watson and Crick were in a unique position to develop that skill. Soon after Watson's arrival at Cambridge, Crick, in collaboration with William Cochran, another member of the Cavendish staff, had carried out theoretical work concerning the mathematics of the interpretation of helical X-ray diffraction patterns, which proved to be critically important in enabling Watson and Crick and others to interpret and make sense of X-ray data (Judson, 1979; Olby, 1994; Watson, 1968).

This point is relevant in a broader way for our understanding of scientific creativity: More than simple observation is involved in scientific research. Scientists often draw conclusions from very indirect evidence, so their knowledge and comprehension are critical to their success. This is a step away from the notion of science as the simple discovery and study of objective facts. One could say that the helical shape of the DNA molecule was not an objective fact, in the sense that it was not sitting there to be observed. One might go even further and say that it was a “created fact.”

On the Origins of New Ideas

So, if one asks where new ideas come from, in this case the answer is that the new ideas used by Watson and Crick—the idea of building a model of DNA and the idea that the structure might be a helix—came about first of all through the adoption and extension of already-existing ideas that had been developed by someone else (Pauling) in dealing with a similar problem in a closely related area. This view was also supported by Wilkins, a researcher respected by both Crick and Watson. We can also see continuity in Wilkins's thinking about DNA: He used experimental techniques on DNA—the response of the fibers to light—that had been used by earlier researchers in the study of other large organic molecules.

It is also interesting to note that when Watson and Crick adopted the working assumption that DNA was helical, they changed the structure of their problem. That is, now they did not have to sift without focus through data and ideas in order to find something that might give them direction. Rather, they were now examining all available information from the perspective of the assumption that DNA was helical, which means that concepts and ideas were directing their work. The situation is similar to working on a jigsaw puzzle with a picture of the completed puzzle as opposed to working without one. The latter is the position that other researchers were in at about that time; that is, they had many pieces of data, and the task was to determine, in a necessarily piecemeal manner, how they fit together. Once Watson and Crick had adopted the helix assumption, they could look at each piece of data and ask, "What, if anything, does this tell us about the structure of the helix?" The relative difficulties of the two sorts of problems seem obvious. In addition, adopting the helical assumption led Watson and Crick to raise questions about the available data. That is, they questioned whether some pieces of data were accurate, because those data conflicted with the helical idea. Other researchers, who lacked the helical assumption, were forced to treat all pieces of data as equal—as we shall see—and that sometimes led them astray.

Adopting Pauling's method and his conclusion did not settle all the issues facing Watson and Crick, however. Before they could start to build a model, they had to make several further decisions. Experimental evidence, based primarily on X-ray pictures of DNA taken by Wilkins, was consistent with the idea that DNA might be a helix, but that evidence did not specify how big it was. The X-ray evidence could be used to calculate the diameter of the molecule, but more details than that were impossible to ascertain. Therefore, Watson and Crick did not know exactly how many strands or *backbones* the helix contained. As we now know, DNA contains two strands (it is a *double helix*), but when Watson and Crick started working, evidence

indicated only that the molecule was thicker than a single strand. There might have been two, three, or four strands, for example, as shown in Figure 1.5A. The number of backbones in the model that they planned to build was the first decision to be made.

The second concerned where to put the *bases*, the four different compounds (A, C, T, and G) that we now know form the rungs of the spiral staircase of DNA, and which carry the actual genetic information (see Figure 1.5B). The specific sequence of bases determines which proteins are constructed by the cell, which is how the specific genetic information gets translated into the physical structure of the organism. When Watson and Crick started their work, the location of the bases was not known; they could have been inside the helix—that is, between the backbones—or protruding from the outside, with the backbones in the center, as shown in Figure 1.5B.

Another question that could not be answered at the time concerned the specific angle or pitch of the spiral of the helix. Once can visualize a helix by imagining a spring, as shown in Figure 1.5C. The spring can be either tight, so that the spiral is almost flat in cross-section, or stretched open, in which case the angle of the spiral formed by the backbones is steep. This angle is called the *pitch* of the helix, and it was unknown at the time Watson and Crick began their work. Finally, the specific way the backbones were structured was not known; it was assumed that they were structured as in Figure 1.2A, with one nucleotide linked to the next, but the details were not known. So, before Watson and Crick could carry out specific model building, they needed several additional pieces of information.

Franklin's Colloquium

On November 21, 1951, Watson attended a colloquium, or professional talk, given at King's College by Rosalind Franklin, who was also carrying out research on the structure of DNA (Judson, 1979; Olby, 1994; Watson, 1968). Franklin was a knowledgeable crystallographer, but her experience had previously been limited to studying the structure of coal. The study of DNA was her first exposure to biological molecules. Franklin and her assistant had recently produced X-ray photographs of DNA after it was exposed to humidity. This was a task that Wilkins had been trying to carry out earlier, but it was Franklin, with her deeper experience with X-ray diffraction techniques, who was successful at it. Those photographs of what was called the wet or B form of DNA were especially informative to the knowledgeable researcher, producing an exposure pattern that was strongly supportive of a helical structure (see the X-shaped pattern in Figure 1.6, a further example of the indirect nature of scientific “facts”). We shall shortly see more evidence

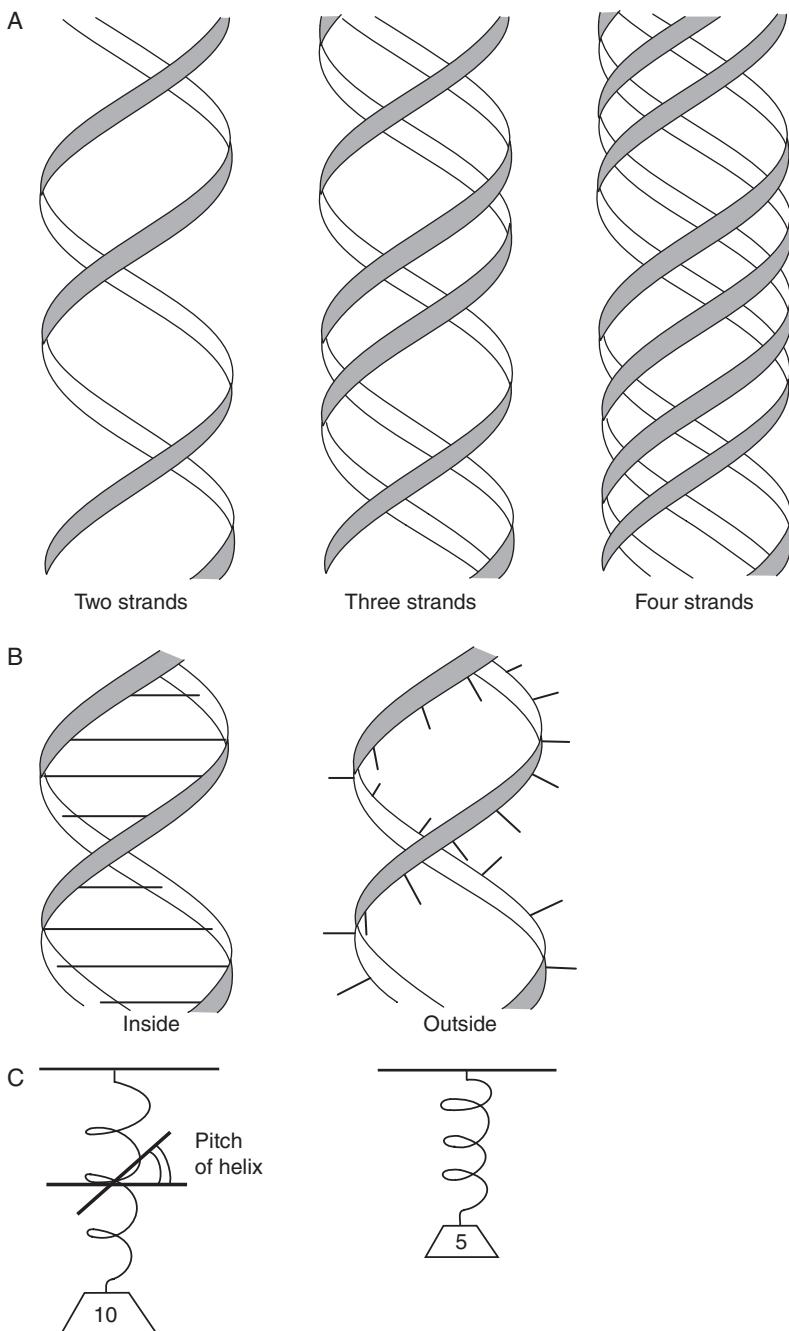


Figure 1.5 DNA: A, Multiple-strand helices; B, Possible positions of bases; C, Pitch of helix

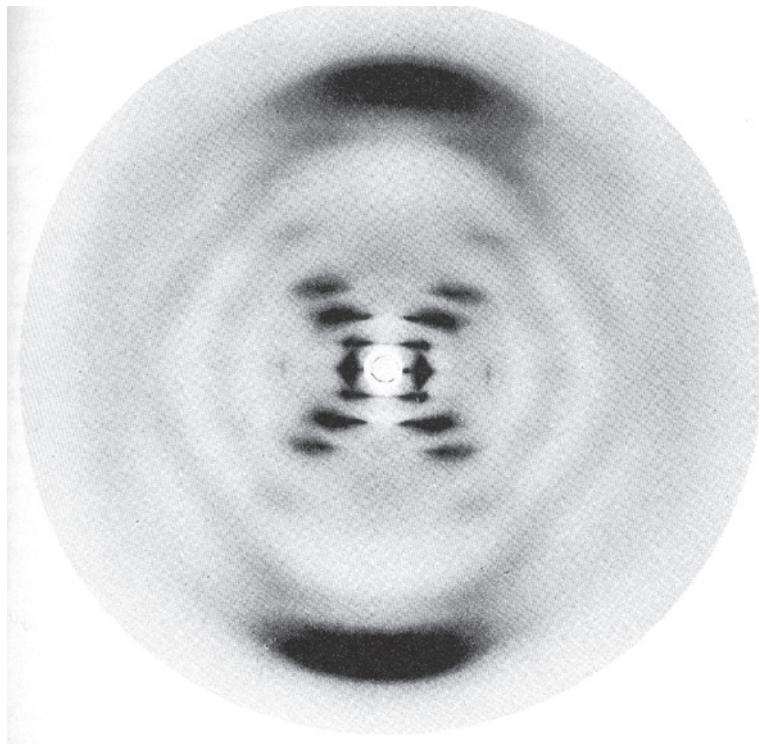


Figure 1.6 Franklin's B-form X-ray

of Franklin's success. At this colloquium, Franklin discussed her most recent work on DNA. Franklin had not been at King's for very long, and relations between her and Wilkins were not good. When Franklin came to King's, she thought her assignment was to carry out research on the structure of DNA. However, Wilkins believed that that was his task, and therefore he felt that she was an interloper who was trying to push herself into his research area. This resulted in some hard feelings between the two and some resentment toward her from Watson and Crick.

In her talk, Franklin presented recent results of her research on DNA. There is a fascinating subtext concerning this presentation. In her notes for the talk, which have been preserved, Franklin discussed how her X-ray data and other results constrained the structure of DNA, which she described as a large helix. She also noted how much water DNA absorbed on exposure to humidity. In relating the content of Franklin's talk to Crick, Watson told him nothing about Franklin's ideas concerning the helical structure of DNA (Judson, 1979; Olby, 1994; Watson, 1968). This is somewhat surprising,

since nothing had been said earlier about Franklin's believing that DNA was a helix, so one would think that Watson would have been struck by her describing the molecule as a helix. Olby, in discussing Watson's omission, speculates that he might not have perceived such comments by Franklin as adding anything new to what he and Crick were already thinking about and what they had also discussed with Wilkins. In addition, Watson usually did not take notes when he attended talks, relying instead on his memory, as he did at Franklin's talk, and this might have affected what he could report. Also, Watson was new to the type of analysis being carried out by Franklin and Wilkins at King's (and also at the Cavendish), and he later said that much of what Franklin reported went over his head.

I have another interpretation, based on no additional information, of Watson's failure to report to Crick what Franklin wrote in her notes about the helical structure of DNA: Perhaps she decided not to make those ideas public at the talk. (It should be noted that Olby briefly considers this possibility and rejects it; see Olby, 1994, p. 351.) There are several reasons why I believe that this speculation is not completely without base. Wilkins did not recall Franklin discussing helices (Olby, 1994, p. 351), although he was not certain about it. It seems to me very unlikely that Watson would have either ignored or forgotten a discussion by Franklin of the structure of a DNA helix. Since she had never made such claims in public before, they would surely have captured Watson's attention, especially since he specifically went to King's to hear her talk. Since at that time Franklin was not on good terms with Wilkins and other members of the staff at King's, she might have felt that her ideas would not meet with a sympathetic hearing or that they might help others advance their work, both of which she might have wanted to avoid. In any case, what Watson seems to have taken away from the King's talks was some information about the density of DNA, as well as some information concerning how it behaved when exposed to moisture. Since at that time he was not very sophisticated in interpreting X-ray-diffraction photographs, he did not get much useful information out of Franklin's B photo.

Consideration of Franklin's colloquium adds another fascinating plot line to the story of the discovery of double helix. In the fall of 1951, Franklin seemed to have moved far down the path to the double helix, perhaps even farther than Watson and Crick. And yet, she did not formulate the structure; Watson and Crick did. Why was she not successful? We will discuss this question once we work our way through Watson and Crick's story, because it provides important information concerning the factors that separate the "greats" from the "near greats."

The Triple Helix

When Watson reported his recollections of Franklin's talk to Crick, the latter concluded that only a small number of helical structures would fit both the data and Crick and Cochran's theory concerning how the X-ray pattern should look: structures of two, three, or four strands. Here is another example of the indirect nature of some scientific facts. Drawing on what they knew from experimental work, including Franklin's, and from discussions with other investigators, most importantly Wilkins, in November 1951 Watson and Crick first built a three-strand model of DNA—a triple helix—with the bases on the outside (see Figure 1.5). That is, in the two critical decisions they had to make—number of backbones and location of the bases—they made incorrect choices. However, each of those choices was reasonable at the time (Judson, 1979; Olby, 1994; Watson, 1968). One piece of evidence to support the idea of three strands, for example, was the calculated density of DNA. From the X-ray photos, the overall dimensions of the molecule could be determined. The weight could also be determined, so one could divide the weight by the volume calculated from the dimensions to determine the density of DNA. If one knows the density of the molecule and if one makes some assumptions about the structure, one can draw conclusions concerning the number of strands it must contain. The evidence concerning density turned out to be incorrect, which meant that the conclusion concerning number of strands was also incorrect, but Watson and Crick could not know that when they built the triple helix.

Thus, Watson and Crick used calculation and deductive logical reasoning to develop their new triple-helix structure. This is another example of creative thinking using components we all use in our ordinary thinking. In the case of the triple helix, at least, we do not need to call on any exotic thought processes to understand what Watson and Crick produced.

Placing the bases on the outside of the helix was done for different sorts of reasons, but again ones that followed from what Watson and Crick knew at the time. One reason Watson and Crick put the bases on the outside of the helix, rather than between the backbones, was that they could not figure out how to fit the bases inside the rigid backbones (Watson, 1968). The bases are of different sizes (see Figure 1.2B), so in order to fit base pairs inside the helix, the backbones would have to bend back and forth, and this would not make for a rigid structure, which they knew that DNA was. Putting the bases outside eliminated this problem. There was another hurdle to putting the bases inside. Molecules sometimes appear in nature in more than one form, called *tautomeric forms*. Crick believed that at least some of the bases might appear in more than one form, which meant that the num-

ber of possible base combinations was even larger than they had originally believed, which made even more remote the possibility of constructing a uniformly shaped molecule with the bases inside. Again, putting the bases outside eliminated this difficulty. Here too we have several examples of creative thinking based on logic.

Placing the backbones at the center of the triple helix raised a problem, however, because the phosphates would be negatively charged and would repel each other, meaning that the molecule would blow apart. In order to hold together the three strands of the helix, Watson assumed that magnesium ions served to link them. The positively charged magnesium ions would serve to hold together the chains of the helix. This idea was based on an analogy to other molecules, where magnesium played such a role (Judson, 1979; Olby, 1994). There were two potential problems with this assumption. There was no evidence of magnesium in DNA, and there was no evidence of ions in DNA with the +2 charge of magnesium ions.

The triple helix, then, was a creative response to the information available to Watson and Crick at that time, and it demonstrates several aspects of the creative process. It is also interesting to note that at about this time Bruce Fraser, a physics student at King's, built a triple-helix backbones-inside model of DNA, similar to that of Watson and Crick (Judson, 1979; Olby, 1994). Franklin's response to Watson and Crick's model was that any modeling was premature, because not enough data were available.

Triple Helix to Double Helix

The same week that the triple-helix model was constructed by Watson and Crick, the King's group was invited to see it. The meeting was a disaster for Watson and Crick, because they were informed of many problems with their new model (Judson, 1979; Olby, 1994; Watson, 1968). First of all, the magnesium ions postulated by Watson to hold the backbones together would probably, according to the King's group, be surrounded by water due to the ions' charge, and therefore the magnesium could not hold the strands together. Second, it turned out that Watson had drastically misrecalled the report by Franklin of the amount of water in the molecule after exposure to moisture, and the correct amounts changed their calculations and made parts of the structure unlikely. Finally, at this meeting Franklin presented arguments for the backbones' being on the outside of the structure. Her evidence came from information from her X-ray photos, among other sources. As a result of this meeting and the embarrassment it brought to the Cavendish lab, Watson and Crick were told by Dr. Lawrence Bragg, the lab's director, not to work on DNA and to leave that area to the King's group.

So, as we will see frequently in studying creative work, Watson and Crick's

first attempt was a failure. It took more than a year, from late fall 1951 to early 1953, before they formulated the correct model of DNA. During that time, Watson and Crick kept thinking about DNA, although more privately, and Watson learned how to carry out crystallography and to read X-ray photos, which would be critical to their success. Most important, he took X-ray photos of tobacco mosaic virus (TMV), a virus that attacks tobacco plants, and produced evidence that TMV was helical in structure. In this way Watson acquired expertise in reading helical patterns in X-rays. Watson and Crick also acquired several important pieces of information, some of which directed them away from the triple helix, and others of which pointed to the double helix. One example of information that led away from the triple helix came about because Watson was not convinced by the King's group that using magnesium ions to hold the structure together was a problem. He tested a sample of DNA for the presence of magnesium and found none, which ended that possibility. Watson and Crick also found that three-strand models could not be made to fit together without violating some basic laws of chemistry. Unless they had missed something, this led to another dead end, which also indicated that a three-strand model was probably wrong (Judson, 1979; Olby, 1994; Watson, 1968).

At the end of January 1953, Watson and Crick saw a copy of a paper published by Pauling and his associate Robert Corey that contained a proposed structure for DNA. Watson and Crick read the paper with trepidation, because they assumed that Pauling, with his record of past successes in similar areas, had solved the problem (Judson, 1979; Olby, 1994; Watson, 1968). To their surprise, they saw that Pauling's model was a triple helix, at least superficially like their own earlier model. Watson and Crick also saw relatively quickly that its chemical structure was incorrect, and Watson got confirmation of this conclusion from organic chemists at Cambridge. The fact that Pauling was incorrect gave Watson and Crick a little time to work, but not much, because they assumed that as soon as Pauling learned of the problems with his model, which would not take very long, he would correct it.

On Friday, January 30, 1953, more than a year after being forbidden to work on DNA, Watson visited King's with a copy of Pauling's paper. He met with Franklin and then with Wilkins. The meeting with Franklin was unpleasant, according to Watson (Judson, 1979; Olby, 1994; Watson, 1968), because she asserted that there was no evidence that allowed anyone to conclude that DNA was helical. As we know, she had at least been speculating about such a possibility over a year before, but, as we shall see shortly, things had changed. In addition, she had shown copies of her X-ray photos to Pauling's associate Corey (Olby, 1994, p. 396), so she might have known

what they were thinking about. By this time, relations between Franklin and Wilkins were very poor, and she also felt negatively toward Watson and Crick, which may partially explain her disparaging response. Wilkins showed Watson some new X-ray photos, including a new photo of the B form, taken by Franklin in May 1952 (Franklin's photo 51).

Photo 51 was not only new to Watson but also extremely precise and informative, and he examined it with excitement. There was no doubt in his mind that it was from a helix-shaped molecule. Also, with his newly acquired expertise at reading and interpreting (and, therefore, remembering) X-ray photos, he was able to get much additional information out of the photo, and he made a sketch of it from memory later that evening. Wilkins also told Watson that Franklin had found that exposing the DNA fibers to moisture (going from A to B) resulted in a 20 percent increase in their length. One of the main sources of evidence for the existence of three strands was the amount of water the DNA molecules could absorb, but there were questions about the accuracy of those results, which meant that the case for three strands was not that strong. The new information, along with information from the new B photo, enabled Watson to draw the conclusion that the molecule contained two strands, not three.

There has arisen an interesting question concerning the propriety of this conversation between Watson and Wilkins, which provided information that obviously helped greatly in the development of the double helix. The question is whether Franklin's photo and results were private information, which Wilkins should not have shared. The poor relations that Franklin had at that time with Wilkins and with Watson and Crick raise the question of how much Wilkins should have told Watson (see Sayre 1975, and Elkin, 2003, for further discussion).

The next day, Saturday, January 31, 1953, Watson convinced Bragg, the director of the Cavendish, that Pauling was getting close to determining the structure of DNA and that no one at King's was doing much in the way of modeling the structure (Judson, 1979; Olby, 1994; Watson, 1968). Watson also presented what he and Crick then knew about the structure, and Bragg gave them permission to return to building models of DNA. When Watson and Crick met and went over the new information obtained by Watson the day before, Watson was ready to concentrate solely on two-strand models, but Crick felt that they should not completely abandon three-strand ones. Watson, still concerned about what to do with the bases, then spent two days unsuccessfully trying to construct two-strand models with the backbones inside. Again, he could not get the backbones to fit together without violating laws of chemistry. He then finally gave up on the backbone-inside

structures, which raised two problems: How could the bases be made to fit inside, and how were the two strands connected?

In the second week of February, Watson and Crick obtained another critical piece of information. As noted earlier in the analogy of the spiral staircase, a helix has a repetitive pattern as one moves along it. This repeating component is called the *unit cell* of the structure. Max Perutz, a senior researcher at the Cavendish, gave Watson and Crick a report that the researchers at King's had prepared for an outside committee, of which Perutz was a member, that was charged with evaluating the progress of the research being carried out there. In this report, which was a public document, Franklin discussed the shape of the unit cell of the molecule, which enabled Crick to deduce that the backbone chains were *antiparallel*—that is, they ran in opposite directions—and also enabled him to determine the pitch of the helix. Crick was able to make those critical deductions at least in part because, in his work on hemoglobin (under Perutz's direction), he had been working with a unit cell of the same structure as that reported by Franklin for DNA (Judson, 1979). Thus, he was immediately able to see the consequences of that structure. Those were almost the last pieces of information that Watson and Crick needed.

Constructing the Double Helix

By mid-February 1953, Watson and Crick had built part of a model that had one spiraling backbone but no bases inside. Since the backbones were antiparallel, one chain was all that was necessary, since the structure of the other chain could be determined from it. The development of this model was based on the contributions of many people (Judson, 1979; Olby, 1994; Watson, 1968).

- Watson was the strongest advocate for the two-strand structure.
- The outside backbones were based on Franklin's work.
- Crick contributed the antiparallel structure of the backbones and the pitch of the helix.
- Wilkins had contributed to the general orientation of the work.

Watson and Crick then began to consider specific possible arrangements of the bases inside the backbones, and Watson first tried pairs of the same bases—that is, A with A, C with C, and so forth—as the rungs of the staircase, a scheme that was called *like-with-like* or *like-like*. He found some evidence in the literature, including some work done at the Cavendish, that like-with-like pairing might occur between bases. In addition, sev-

eral of Watson's professors in graduate school had discussed like-with-like pairings in other contexts. So, even though the different sizes still raised problems, Watson thought the possibility was worth looking into. However, the like-with-like structure was torn to shreds by Jerry Donohue, a postdoctoral fellow at the Cavendish who had received his PhD in Pauling's laboratory and had published with Pauling. Donohue shared the office with Watson and Crick (and also, in a further twist, with Pauling's son Peter, who was also a researcher at the Cavendish). Donohue informed Watson that the forms of some of the bases that he was using in his model, which he had gotten from a reference book, were the wrong tautomeric forms and would never be found in nature. That meant, if Donohue was correct, that Watson's tentative structure was impossible. Since Donohue came with the highest-quality credentials, there was no question of the accuracy of his observation. In addition, Crick noted that Watson's like-with-like plan went against the shape of the crystal found by Franklin and also did not fit Chargaff's findings concerning base ratios (see Table 1.1). So that like-with-like model was rejected.

Watson then set out to try to find different pairings that would fit. Crick has recalled their agreeing at this point to try to pair the bases following Chargaff's ratios (that is, pairing A with T and C with G), but Watson has indicated that he does not remember there being that specific a plan (Olby, 1994, pp. 411–412). On a Saturday morning in February 1953, Watson used cardboard models of the bases, in the tautomeric forms suggested by Donohue, to try to determine how they might fit together in the center of the helix. He moved them about on his desktop like pieces in a jigsaw puzzle. Here is his account of what happened (Watson, 1968, pp. 123–125).

When I got to our still-empty office . . . , I quickly cleared away the papers from my desk top [sic] so that I would have a large, flat surface on which to form pairs of bases. . . . Though I initially went back to my like-like prejudices, I saw all too well that they led nowhere. . . . [I] began shifting the bases in and out of various other pairing possibilities. Suddenly I became aware that a[A-T] pair held together by two hydrogen bonds was identical in shape to a[G-C] pair held together by at least two hydrogen bonds. All the hydrogen bonds seemed to form naturally; no fudging was required to make the two types of base pairs identical in shape. . . . Upon his arrival Francis did not get more than halfway through the door before I let loose that the answer to everything was in our hands.

Those pairings (A-T and C-G) turned out to be the same overall size, so the problem of the different-sized rungs for the spiral staircase was eliminated.

Thus, the final piece of the model came about by moving cardboard pieces around on a desktop in what one might call trial and error. It is important

to note, however, that this final step by trial and error was possible only because the whole structure was almost complete. I have sometimes seen Watson and Crick's discovery of the double helix labeled as the result of trial and error (e.g., Simonton, 1999), but that overlooks two facts that are important to keep in mind. First, only the very last step—fitting the bases together—occurred through what could be called trial and error. Second, that trial-and-error step was possible because the backbones had already been constructed and the locations of the bases had already been decided upon, and neither of those steps came about through trial and error. In addition, calling this last step trial and error may lead one to think of Watson as simply blindly putting the bases together in every possible combination, but that is not what happened. The various possible configurations that the pairs of bases could form with each other were limited by the chemical structures of the bases: Only certain spatial configurations were likely, based on the necessity that the bases be held together by hydrogen bonds.

The situation faced by Watson before this last discovery was analogous to having a jigsaw puzzle completed except for one or two pieces. One might try to fit those last pieces in by trial and error, but that is only possible because almost all the work has already been done. In addition, even if one used trial and error, one would not put the pieces in blindly, with one's eyes closed; one would place them in the orientations in which they would most likely fit. So Watson was not blindly pushing models of bases around without thought; there was a plan behind even those last steps.

Conclusions: Watson and Crick's Discovery of the Double Helix

Watson and Crick's model of DNA was one of the great discoveries of twentieth-century science and has had great effects on our lives in many ways. However, from the perspective of cognitive processes, nothing extraordinary was involved in bringing it about. This case study demonstrates that one must keep separate the importance of a product, which may be extraordinary, and the thought processes that brought it about, which may be very ordinary. As we have just seen, Watson and Crick took what was known and used that as the basis for building a possible model of DNA. When their first model proved incorrect, they went back to work, and over more than a year acquired new information and expertise that allowed them to ultimately produce the correct structure.

The Double Helix: Why Not Franklin, Wilkins, or Pauling?

Examination of the story of Watson and Crick's discovery of the double helix leaves us with a set of related questions: Why didn't Franklin or Paul-

ing discover the double helix? And why were Watson and Crick the ones who did? The question of what separates the successful from the unsuccessful thinkers has broad implications for understanding the creative process. Franklin's situation is particularly interesting, since, as we have seen, at the time of her colloquium—that is, in November 1951, more than a year before Watson and Crick finalized their model—Franklin believed that DNA was a helix, and she had discussed relatively specific aspects of the molecule. She was ahead of Watson and Crick at that time, so why did she not carry her thinking through to the double helix? Similarly, we know that Watson and Crick based their work on that of Pauling, which might lead one to the expectation that Pauling had a leg up in theorizing about DNA. Since his general orientation and some of the specifics of his method had served Watson and Crick well, one might expect that Pauling, as the originator of that orientation and those methods, would have had an advantage over them. Here too the answer to the question has potentially broad implications.

Why Not Franklin or Wilkins?

In her notes for her November 1951 colloquium, Franklin had laid out evidence for a spiral structure for DNA. She cited many sorts of evidence, ranging from a probable lack of stability in a straight untwisted chain to the pattern of spots on her X-ray photos. So she seems to have been far along the road to the double helix. Why did she not take those last few steps, which Watson and Crick did, using some of her data?

In April 1952, Franklin took some photos of the A (dry) form of DNA, and one of those photos, of very good quality, led her to the belief that the A form of DNA was not a helix. That photo had an asymmetrical spot in it that Franklin believed could not have occurred if the structure were a helix. Based on an analogy with earlier work on alpha-keratin by William Astbury, a well-known researcher of the previous generation, she concluded that the change between the A and B forms of DNA resulted in basic changes in the structure of the molecule, so the A form might be very different from the B form (Judson, 1979). On July 18, 1952, she wrote as a joke a black-bordered note announcing the death of the DNA helix and stating that Wilkins would speak at the funeral. She spent much of the next year trying to work out the structure of the A form based on that photo, using very complicated and tedious methods of traditional crystallography, and it was not until early in 1953 that she became convinced that that photo had been misleading her. Franklin had also convinced Wilkins that the A form of DNA was not a helix, and he then carried that conclusion one step further and decided that the B form might not be helical either. He then stopped work on DNA for several months in frustration.

One reason for Franklin's concentration on the methods of crystallography rather than Pauling's model building was that she was concerned that there might be more than one model structure that could fit the data available from studies of DNA. That is, if one built a model that was consistent with those data, how could one be sure that there were not other models, perhaps of an entirely different structure, that would also fit the data? This sense of caution, combined with her inconsistent findings, led her to methods that she felt confident in using. In a professional meeting in late spring of 1952, Franklin told Crick about the evidence that she considered compelling against a helix structure for the A form. Crick told her that a helical molecule might still produce the irregularities in structure that she had found. Thus, he was not sure that her data supported the antihelical conclusion that she was drawing, and therefore he was not convinced that he should change his orientation.

In his maintaining his helical orientation in the face of Franklin's potentially conflicting data, Crick was behaving in a manner similar to the way Pauling had worked in analyzing the alpha-helix (Judson, 1979). In that case too there had been a datum that indicated that the structure was not helical, but Pauling had ignored that information, assuming that it was not critically important to the analysis of the structure. It turned out that he was correct, and that datum was not inconsistent with a helix, which made Crick (as well as Watson, who also discussed that issue with Franklin) a bit skeptical when faced with data that stood out from an otherwise consistent pattern. Franklin, in contrast, was at that point convinced by her results, perhaps because they were her results. In addition, in early 1953, when Franklin had progressed far enough in her crystallographic analysis that she felt comfortable beginning to model, the results initially led her to an incorrect structure, a figure-eight configuration. So Franklin was unsuccessful at least in part because she had data that led her away from the correct structure, data she took very seriously. Wilkins was also influenced by Franklin's results. It is also notable that just about the time that Watson and Crick completed their model, Franklin had almost completed a paper in which she described a double-helix structure of DNA (Elkin, 2003), so at the end she was very close to the correct structure, and probably would have produced it had not Watson and Crick published their model when they did.

Why Not Pauling?

Pauling's lack of success was obviously not owing to reluctance to theorize in a bold manner or disbelief that DNA was helical. Rather, his failure was probably due to a lack of access to the most accurate information concern-

ing the molecule (Judson, 1979; Olby, 1994). For example, he was basing much of his model building on X-rays of DNA taken by Astbury in the 1940s, which were problematic in two ways. First, they did not provide precise information about the structure: They were blurry, so that specific parameters were difficult to determine. Second, and not unrelated, it turned out that Astbury's X-rays combined the A and B forms of DNA, although at that time it was not known that two forms existed. Thus, part of the reason that Astbury's X-rays were hard to read was that they combined the two forms. The density measurements that Pauling was using, which led him to conclude that three strands were involved, also were based on Astbury's work, and we have seen that those measurements were incorrect. If Pauling had had access to Franklin's B-form photo 51, he might have made more progress.

Why Watson and Crick?

The development of the double helix is outlined in Figure 1.7, which points out how the various components of the final model came about. In the figure, a number of the critical components of the double helix are listed in the right-hand column, and the development of that component is shown from left to right. Examination of the components indicates that Watson and Crick were successful for several reasons. First, they built their theorizing on the work—both the theory and the empirical findings—of others, and that work was relevant to DNA. In addition, Watson and Crick both brought unique expertise to the enterprise, so that each was able to make a contribution to the final product that perhaps no one else in the world could have made at that time. Examples are Crick's use of the unit-cell information to deduce the antiparallel chains, based on his particular expertise in that domain, and Watson's use of the change in length in the $A \leftrightarrow B$ transformation to deduce that two chains were involved, again based on his particular expertise.

Thus, one can conclude that Watson and Crick were the first to specify the structure of DNA because they were uniquely capable of putting together the necessary pieces of information. They were also in an environment that provided several critical corrections to possible mistakes (e.g., Donohue and the tautomeric forms of the bases).

Artistic Creativity: Development of Picasso's Guernica

The cognitive processes underlying the discovery of the structure of DNA seem to be comprehensible in a straightforward way. However, one might wonder if one can carry out an analysis of creative thinking in the arts in

TIMELINE =>	COMPONENT
	Pauling's method ⇒ Model building as method of attack
	Pauling's alpha-helix ⇒ Helical shape of molecule
(Incorrect) density	⇒ 3 chains (2 chains fall short of density) ⇒ Problems with triple helix; Franklin's A ⇔ B length change and A-form density ⇒ Watson's reasoning ⇒ 2 chains
Problems with sizes and tautomeric forms of bases	⇒ Chains inside ⇒ Franklin's photo 51 + Donohue's opinion about tautomeric forms ⇒ Problems with bases-inside models + Franklin's opinion + Franklin's photo 51 + Donohue's opinion about tautomeric forms ⇒ Chains outside
Franklin's unit cell discussed in her report	⇒ Same space group in Crick's research ⇒ Crick's deduction ⇒ Chains antiparallel
Mg ⁺ ions in triple helix	Antiparallel chains + repeat from X-rays + shape of nucleotides ⇒ 36° Pitch of helix
Watson's "like-like"	⇒ torn to shreds by Donohue ⇒ Watson manipulating shapes on his desktop ⇒ H bonds holding bases and chains together ⇒ Complementary base pairings ⇒ H bonds holding chains together

Figure 1.7 Timeline: History and development of components of DNA

a comparable manner. Scientific investigation seems to have at its base a logical or analytic method of working, which might make it relatively easy to study in a systematic manner. Actually, careful analysis indicates that the discovery of the double helix of DNA did not proceed in a strictly logical manner. When Watson and Crick began, they *assumed* that the general model-building method of Pauling might be useful, and they also *assumed* that Pauling's discovery of the helical structure of one organic molecule might be relevant to DNA. When one makes the assumption that a piece of information or method of working that has been useful in one situation will be relevant to another situation, that is not a strictly logical process. That is, it does not follow logically that, since alpha-keratin is a helix, DNA is also a helix. This might appear to be a reasonable hypothesis, at least to some people, but it is not logically necessary that it be true. Thus, creative thinking in science is perhaps less strictly structured and logical than we might have thought.

Even if we agree that creative thinking in science is not strictly logical, however, the thought processes underlying artistic creativity still might be too quick, too fragile, perhaps too emotionally laden, too intuitive or illogical, to ever be captured by analysis of the sort just performed. However, I have carried out a case study of Picasso's creation of his great painting *Guernica* (Weisberg, 2004; see Figure 1.1B), which indicates that it may be possible to analyze and capture the thought process underlying artistic creativity. *Guernica*, a landmark of twentieth-century art, was painted in response to the bombing during the Spanish Civil War of the Basque town of Guernica, in northern Spain (Chipp, 1988, Chap. 3). The bombing was carried out on April 26, 1937, by the German air force, allied with Generalissimo Francisco Franco, who became the Spanish dictator after his forces won the Civil War. There seems to have been little strategic value to the town, and when news of the bombing reached the world over the next few days, the destruction of the town and killing of innocent people horrified the world.

Early in 1937, Picasso had been asked by the Spanish government (i.e., those in opposition to Franco), who were losing the Civil War, to provide a painting for the government's pavilion at an international exhibition (a world's fair) to be held in Paris in June 1937. By the end of April, Picasso had already begun a painting, but one that had nothing whatever to do with the political situation in Spain: It depicted an artist and a model in the artist's studio, a subject that Picasso used again and again throughout his career (see Figure 1.8). When reports of the bombing reached Paris, Picasso changed his plans and produced a painting that has been universally hailed as one of the great antiwar documents of our time. Picasso's painting, begun on May 1 in response to news reports of the bombing, was completed in about

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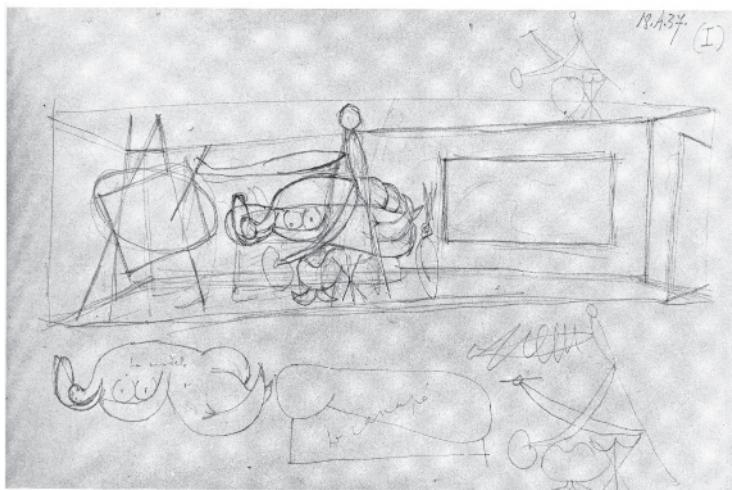


Figure 1.8 Picasso, *The Studio* (18 April 1937)

six weeks, in a burst of creative activity. *Guernica* quickly became an international symbol of resistance to fascism. In his will, Picasso stipulated that the painting was to be loaned to the Museum of Modern Art in New York City and to be sent to Spain when democracy was restored. That occurred in 1981, after Franco's death, and the painting then returned to Spain like a hero and was put on display in Madrid.

When one examines *Guernica* as an antiwar statement, there is something missing: There is no war in the painting (Chipp, 1988). There are no soldiers, no planes dropping bombs, no rifles or cannons, no tanks. There are several animals, four women, a baby, and a broken statue. In the left-hand portion of the painting, a bull stands over a mother whose head is thrown back in an open-mouthed scream; she holds a dead baby, whose head lolls backward. Below them, a broken statue of an ancient warrior (the only human male presence and the only kind of soldier in the painting) holds a broken sword and a flower. Next to the bull, a bird flies up toward a light. In the center of the painting, a horse, stabbed by a lance (again, a hint of warfare), raises its head in a scream of agony. In the upper center, a woman leans out of the window of a burning building, holding a light to illuminate the scene. Beneath the light-bearing woman, another woman with bared breasts hurriedly enters the scene from the right. At the far right, a woman on fire falls from a burning building. Picasso uses those characters to make us feel that something terrible has happened, but he does not present the event directly. Another striking aspect of the painting is that it has no color; it is monochromatic—painted in black, white, and shades of gray. This

physical darkness in the painting serves to present a psychological mood of darkness, highlighted by a few bright objects, into which we are drawn. The painting is also massive in size, measuring almost 12 feet by 26 feet, which adds to the strong effect that it has on viewers.

When one tries to analyze how new ideas in art come about, one must go “underneath” the paintings that hang in museums or are pictured in art books, because a finished painting tells us little about its birth. However, creative works do not come out of nothing: Especially for large-scale creative works—for example, scientific theories, symphonies, novels, or large paintings—there are several potential sources of information that can help us understand how the work developed. First, creative thinkers, including painters, often carry out preliminary work, thinking about what they might do before they commit to doing anything; artists often carry out this preliminary thinking by producing *sketches* of various sorts. Those sketches, if available, can tell us where the artist began and how the painting reached final form. Obviously, not everything an artist thinks about is put down in sketches, but, at the very least, sketches can give us an estimate of the relationship between the artist’s early ideas and the final product. Picasso produced many preliminary sketches for all his major works, including *Guernica*. Even more valuable from our perspective, he dated and numbered the preliminary works for *Guernica*—a total of 45 works—because he thought that others might be interested in how he progressed. In 1937, Picasso was perhaps the most famous artist in the world, and he was correct concerning others’ interest in his methods. Today, some 70 years later, people still examine the sketches for *Guernica* (as we are doing here).

The Preliminary Sketches

When news of the bombing reached Paris, Picasso dropped work on the studio painting and began work on *Guernica*, producing his first preliminary sketches on May 1; the last sketch is dated June 4. He began work on the painting itself on approximately May 11, and the completed work was put on display early in June. There are two different types of preliminary sketches for *Guernica*. Seven *composition studies* present overviews of the whole painting; the remaining sketches, *character studies*, examine characters individually or in small groups. Samples of preliminary sketches are shown in Figure 1.9. The preliminary sketches provide us the opportunity to get inside Picasso’s creative process.

Picasso worked on the sketches for *Guernica* over a period of a little more than a month; for ease of exposition, that overall period can be summarized into three periods of work: the first two days (May 1–2); an additional six days, commencing about a week later (May 8–13); and a final two weeks of

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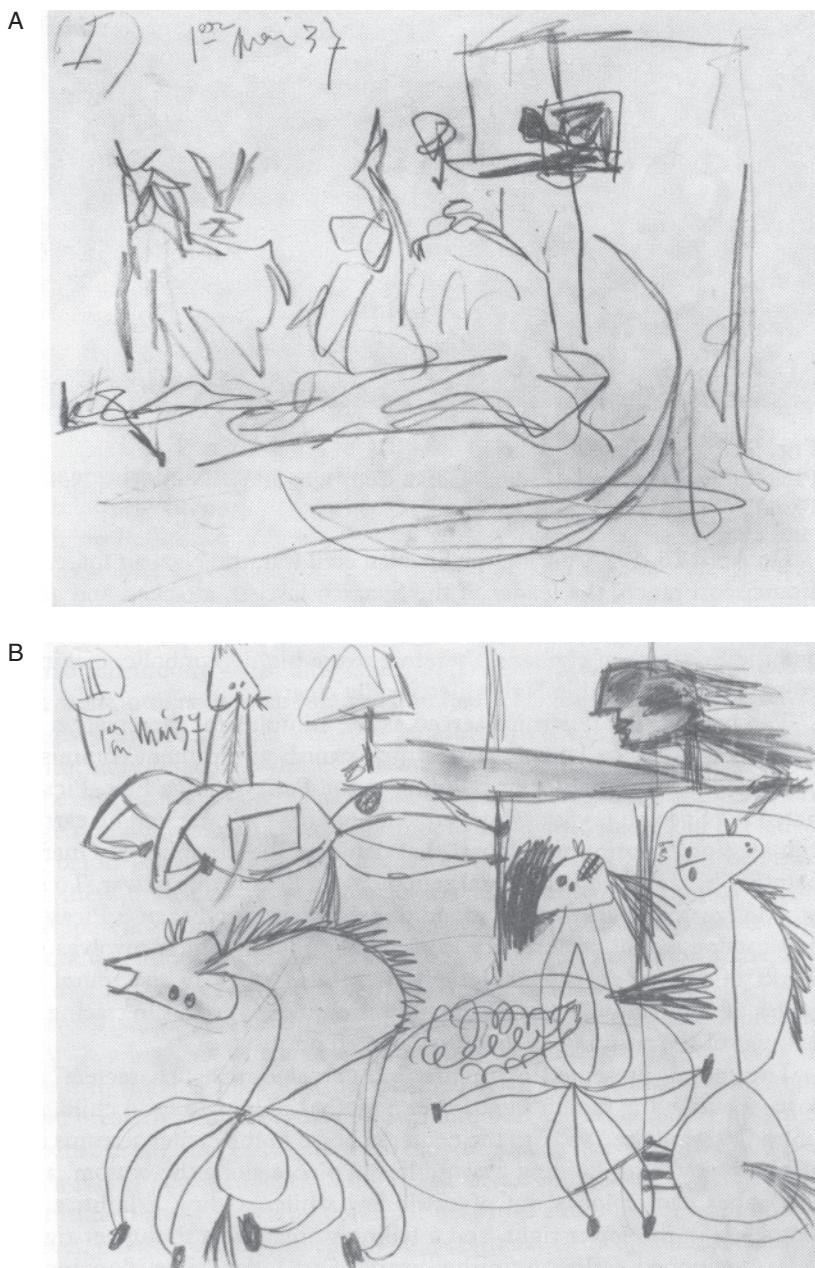


Figure 1.9 Examples of preliminary sketches: A–B

C



D



Figure 1.9 (continued) C, Composition study; D, Picasso's falling man

work, which began about a week later (May 20–June 4). As can be seen in Table 1.3A, the first two days resulted in composition studies and studies of the horse, the central character physically and arguably the central character psychologically in the painting. In the second period, the composition studies are fewer, and other characters appear. In the last period, there are no composition studies, and peripheral characters (e.g., the falling person)

E

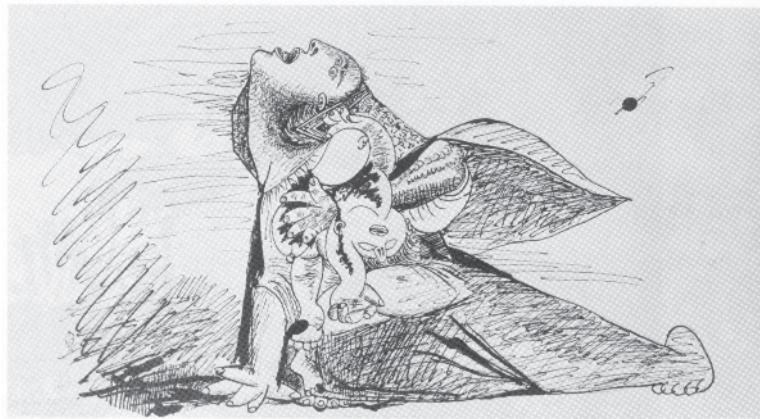


Figure 1.9. (continued) E, Picasso's mother with dead child

Table 1.3 Summary of Picasso's preliminary sketches for Guernica

A. All preliminary works tabulated by three periods of work

Period	Composition	Horse	Bull	Mother and child	Woman	Hand	Falling person	Man	Total
1 (May 1–2)	6	5	0	0	0	0	0	0	11
2 (May 8–13)	2	4	2	5	1	1	0	0	15
3 (May 20–June 4)	0	2	2	2	8	1	3	1	19

B. Composition sketches versus all others

Period	Composition	All others	Total
1 (May 1–2)	6	5	11
2 (May 8–13)	2	13	15
3 (May 20–June 4)	0	19	19
Total	8	37	45

C. Composition sketches + horse + bull versus all others

Period	Composition + horse + bull	All others	Total
1 (May 1–2)	11	0	11
2 (May 8–13)	8	7	15
3 (May 20–June 4)	4	15	19

are seen for the first time. This pattern can be made clearer by combining categories of sketches, as shown in Tables 1.3B and 1.3C. These results indicate that Picasso spent the bulk of his early time working on the overall structure of the painting and on the main character, and then moved on to other aspects of the painting. Thus, analysis of the temporal pattern in the whole set of sketches indicates that Picasso was systematic in working out the structure of *Guernica*, and he had it more or less completed before he went on to the specifics of the painting.

Deciding on an Idea: Analysis of the Composition Studies

We have seen that Picasso was systematic in working out the overall structure of the painting; we can now investigate the specifics of how Picasso decided on that structure. By examining the contents of the various composition sketches, we can see if he experimented with several radically different possible structures for the painting, say, or if he had one basic structure in mind when he began to work. As can be seen in Table 1.4, the structure of the painting is apparent in the composition studies produced on the very first day of work. In seven of the eight composition studies, including the very first one, the light-bearing woman is in the center, overlooking the horse. In addition, each of the central characters (horse, bull, light-bearing woman) is present in almost all of the composition sketches, with other characters appearing less frequently. This pattern supports the view that Picasso had at least the skeleton or kernel of *Guernica* in mind when he began to work: *Guernica* is the result of Picasso's working out this kernel idea.

We see here further evidence that Picasso's thought process was relatively constrained from the beginning. Indeed, if the sketches can be taken at face value as the record of Picasso's thought processes concerning the painting, then from the very beginning he considered only one idea.

Antecedents to the Structure of Guernica?

Analysis of *Guernica* as arising from a kernel idea that was available to Picasso from the beginning of his work immediately raises another question: Whence did the kernel idea arise? Chipp (1988), in his extensive discussion of *Guernica*, was struck by the quick gestation of the painting. When Picasso painted *Guernica*, he was in his mid-50s and had been an artist for most of that time. Therefore, he had available a history of his own on which (literally and figuratively) to draw; that history seems to have played a significant role in the creation of *Guernica*, which is closely related to many of Picasso's works from the 1930s. One striking example of a work that presages *Guernica* is *Minotauromacy*, an etching made by Picasso in 1935 (see Figure 1.10). In this composition, a dead woman in a matador's

Table 1.4 *Guernica* composition studies: Presence of various characters

Sketch	Date	Final structure?	Horse	Bull	Light-bearing woman	Mother and child	Mother and adult	Fleeing woman	Fallen woman	Fallen warrior	Flying animal	Wheel	Upraised arm
1	May 1	Yes	X(?)	X	X								X
2a		Yes		X	X								
2b		No	X	X									X
3		Yes	X		X								
6		Yes	X	X	X								X X
10	May 2	Yes	X	X	X						X	X	
12	May 8	Yes	X	X		X					X		
15	May 9	Yes	X	X	X	X							X X
Proportion			.88	.88	.75	.25	.13	0	.13	.38	.38	.13	.13



Figure 1.10 *Minotauromacy* (Etching; 1935)

costume, holding a sword in one hand, is draped over the back of a rearing horse. A minotaur (the half-man half-bull of mythology) raises a hand in front of his eyes to shield them from the light of a candle held by a young woman who is observing the scene. Two other women observe the scene from a window above, where two birds also stand. On the far left, a man is climbing a ladder.

Table 1.5 summarizes a number of correspondences between *Guernica* and *Minotauromacy*, which indicate that *Minotauromacy* contains the same kernel idea and may have served as a source for *Guernica*. In order to demonstrate that those correspondences in Table 1.5 reflect more than chance, however, one needs a “control” painting to compare with *Guernica*. As indicated earlier, just before the bombing of *Guernica*, Picasso was working on a painting of an artist’s studio. He never progressed beyond sketches for that work; one of those sketches was shown in Figure 1.8. If one compares that work with *Guernica*, as shown in Table 1.6, one finds very little overlap in subject matter, especially as regards major characters and structure. This comparison among *Guernica*, *Minotauromacy*, and the *Artist’s Studio* is presented graphically in Figure 1.11.

Furthermore, the strong correspondence between *Minotauromacy* and *Guernica* shown in Table 1.6 and in Figure 1.11 is actually an *underestimation* of the true correspondence. *Minotauromacy*, an etching, was printed from

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Table 1.5 Corresponding elements in *Guernica* and *Minotauromacy*

<i>Minotauromacy</i>	<i>Guernica</i>
Bull (Minotaur)	Bull
Horse—head raised	Horse—head raised (stabbed—dying)
Dead person	Dead person (broken statue)
Sword (broken—in statue's hand)	Sword (in Minotaur's hand)
Flowers (in girl's hand)	Flower (in statue's hand)
Two women above observing Woman on ground holding light	Woman above observing + holding light
Birds (standing in window above)	Bird (flying up toward light)
Vertical person (man fleeing)	Vertical person (burning woman falling)
Sailboat	
	Electric light
	Mother and child
	Woman running in

a drawing made by Picasso on a printing plate, so the scene Picasso drew on the plate was actually reversed from left to right in comparison with the print shown in Figure 1.10. The “vertical person” was drawn on the right, and the bull was on the far left. The light-bearing female also faces in the same direction as the corresponding character in *Guernica*. Thus, not only does *Minotauromacy* contain many characters similar to those in *Guernica*, but the absolute spatial organization of the two works is also similar. This analysis of Picasso’s creative thought process has provided evidence of planning in Picasso’s thought, as well as structure of several sorts, and continuity with the past.

The Link between Minotauromacy and Guernica

Assume for the sake of discussion that when Picasso began to paint *Guernica* he had *Minotauromacy* in mind and used it as a model for the new work. That raises the question of why the bombing of Guernica caused Picasso to think of *Minotauromacy*. There are several links that can be traced between the bombing, *Minotauromacy*, and *Guernica*, which can

Table 1.6 Comparison of elements in Artist's Studio and *Guernica*

<i>Artist's Studio</i>	<i>Guernica</i>
	Bull
	Horse—head raised (stabbed—dying)
	Broken statue
	Sword
	Flower (in statue's hand)
	Woman above observing + holding light
	Bird flying up toward light
	Burning woman falling
Electric light (above and spotlight below)	Electric light above
	Mother and child
	Woman running in
Reclining model	
Artist	
Male spectator	
Easel	
Window	Window

help us understand why Picasso's thinking may have taken the direction that it did. First, the bombing took place in Spain, Picasso's native land, and *Minotauromacy* is a representation of a bullfight, which obviously has deep connections to Spain and to Picasso's experiences there, because he painted bullfight scenes from his very earliest years (Chipp, 1988). *Guernica* also contains the skeleton of a bullfight: a bull and horse, a person with a sword (the statue), and spectators overlooking the scene. In addition, the emotionality of the bombing may have provided a further link to the bullfight, which is an event of great emotional significance for a Spaniard. It may also be of potential importance that when Picasso was growing up in Spain, the bull was not the only victim in a typical bullfight: The horse that carried the *picador* (the lance-carrier, whose task is to drive

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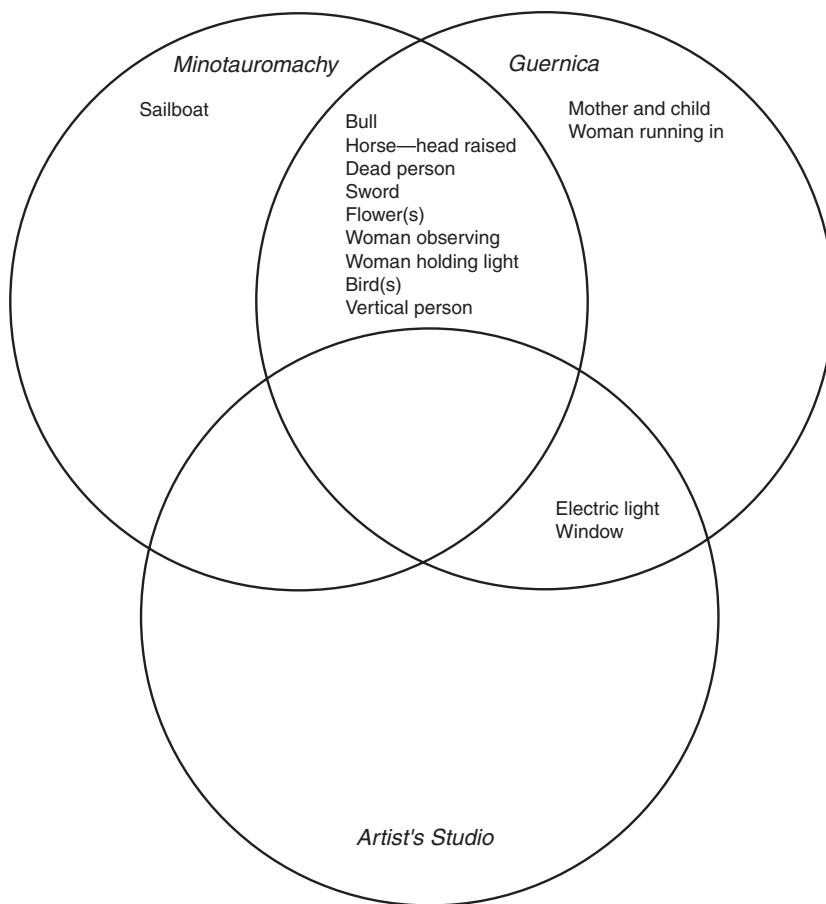


Figure 1.11 Summary of correspondences among Picasso's *Guernica*, *Minotauromachy*, and *Artist's Studio*

the lance into the shoulders of the charging bull) was not protected by padding and was often an innocent victim of the bull's charge. Based on this reasoning, the horse in the center of *Guernica*, whose head is raised in a scream of agony, can be seen as a representation of an innocent victim, and one can understand how that symbolization might have arisen in Picasso's mind.

Thus, *Guernica* and *Minotauromachy* are linked by a web of interrelationships, and it is not hard to understand why the bombing might have stimulated Picasso to think of *Minotauromachy*, which then played a role in directing his further thinking. It is also notable that the links among the various pieces that came together to produce *Guernica* are not particularly exotic. They are simply a complex set of experiences unique to Picasso.

Structure in Development of Individual Characters

We can also use the sketches of individual characters to examine the question of structure in Picasso's thought process. First, did he tend to concentrate on only one character at any given time? Second, if we look at all the sketches that contained one particular character—say, the horse—do we find that aspects of that character are randomly varied from one sketch to the next, or is Picasso systematic in his explorations of that character? As with the development of the overall structure of the painting, Picasso was systematic in his development of the individual characters.

Attention to One Character at a Time

In order to determine whether Picasso tended to concentrate on a given character at a given point in time, we can analyze the sequential pattern over all the sketches (see Table 1.3A). As can be seen, the sketches for the horse were concentrated in the first two periods, the mother and child were most frequent in the second period, and the isolated woman and the falling person were most frequent in the third. Thus, Picasso also was systematic in his working on the individual characters over time.

Development of Individual Characters

If we consider the development of individual characters over the series of sketches, we can also find evidence for structure in Picasso's thought. For several of the individual characters, one can focus on elements that Picasso varied separately. As one example, in the sketches of the horse, Picasso varied the position of the head: up versus down. Another example can be seen in the sketches of the woman: whether her eyes are dry or tearing. A third is whether the woman is alone or with another individual (usually the baby). We can examine each of those components in order to uncover structure in Picasso's thinking as he worked on each character.

If we include composition studies, the horse was sketched a total of 19 times. The position of the head of the horse in those sketches is summarized in Table 1.7A, and a clear differentiation is seen: In the earlier sketches, the head is predominantly down, which changes in the later sketches. A similar pattern is seen in the sketches containing women. Tables 1.7B–D summarize all 20 sketches, both composition sketches and character studies, in which there was at least one woman participating in the action (the light-bearing woman was ignored, as were any dead women). Once again there is a pattern in the presence of the various elements of the women over the two periods of work in which women appeared in sketches. In the early sketches, the woman usually is holding a dead person, whereas in the later sketches she is usually alone (Table 1.7B). Similarly, in the early sketches,

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Table 1.7 Summaries of presentation of the horse and of women in the sketches

A. Position of head of horse summarized over periods 1 and 2

Period	Head up	Head down
1 (May 1–2)	8	1
2 (May 8–20)	2	7

B. Types of women in periods 2 versus 3

Period	Mother and child	Solitary woman
2 (May 8–13)	8	1
3 (May 20–June 3)	2	10

C. Expressions of women in periods 2 versus 3

Period	Open-mouthed	Weeping
2 (May 8–13)	9	0
3 (May 20–June 3)	2	10

D. Relationship between social environment and emotional expressions of women

Type of woman	Open-mouthed	Weeping
Mother and child	8	2
Solitary woman	3	8

she is screaming but tearless; in the later sketches, tears are almost always present (Table 1.7C). Finally, Table 1.7D summarizes for all the sketches the relationship between the facial expression of the woman and whether she is presented alone or with a dead person. When she is alone, she is almost always weeping; when she is holding the dead person, she sheds no tears. Thus, analysis of the character sketches supports the conclusions drawn from analysis of the composition studies: Picasso was systematic in his working out of the elements of *Guernica*.

Antecedents to Characters in Guernica

A further question that can be examined here is whether there were antecedents to specific characters in *Guernica*, comparable to the antecedents of the overall structure discussed earlier, and one can indeed find what seem to be specific connections to characters in *Guernica* from works of other

artists. Two examples will serve to make the point that Picasso's thought process was structured in various ways by art with which he was familiar and that was relevant to the theme of *Guernica*. One particularly distinctive character in the sketches is the falling man in sketch 35 (see Figure 1.9D). Picasso included no men among the actors in *Guernica* (the only male is the broken statue), so the content of this sketch is intriguing. This distinctive individual, with sharply drawn profile, striking facial expression, facial hair, and idiosyncratic placement of eyes, as well as the falling posture with outstretched arms, bears a striking resemblance to the man shown in Figure 1.12A. The latter drawing is from an etching in a series by Francisco de Goya (1746–1828) called *Disasters of War*, which was created more than 100 years before *Guernica*. Picasso had great respect for and knowledge of Goya's works (Chipp, 1988), and it would not be surprising if the events that

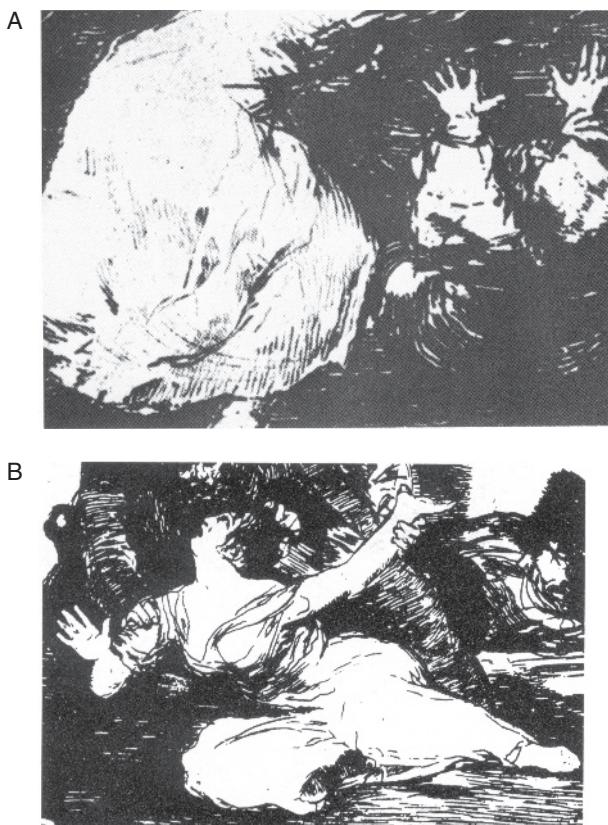


Figure 1.12 Details from Goya's *Disasters of War*:
A, Falling man (No. 41); B, Woman (No. 13)

stimulated Picasso's painting of *Guernica* also resulted in his recollection and use of Goya's work as the basis for his own, especially given the commonality of theme. Picasso changed the man into a woman in the painting, but the falling woman in *Guernica* bears residue of the Goya etching from which she began: Her profile is similar to that of Goya's man, and her outstretched hands with exaggeratedly splayed fingers echo those of the Goya figure.

A second example of a correspondence between one of Picasso's characters and another work from Goya's *Disasters of War* is shown in Figure 1.12B. Picasso's sketch 14 (Figure 19.E) contains a mother and child, and the woman is distinctive in her sharply profiled head thrown back; in her pose, with her outstretched left leg producing a distinctive overall triangular shape; and in the arrangement of her skirt, which is folded between her legs. The woman in Goya's etching is similar in facial profile and expression, and in her posture, with an outstretched left leg producing an overall triangular shape, and her skirt is folded between her legs.

Structure in Picasso's Creative Process: Conclusions

This analysis has provided evidence for what one could call layers of antecedents to *Guernica*. The overall structure, based on the kernel idea seen in *Minotauromacy*, is one level of structure. Within that structure or framework, specific characters are based on other antecedents, meaning that one can trace antecedents nested within antecedents in *Guernica*. If the present analysis is accepted as valid, it means that it has been possible to trace the origins of some microscopic aspects of *Guernica*: for example, the facial expressions and postures of some characters, as well as the appearances of the characters' hands. Thus, the present analysis supports the proposal that creative works may be closely linked to previous works, although how often this occurs and how close the links are remain to be answered through the analysis of other works, both in painting and in other domains (for further discussion, see Weisberg, 1993).

Structure in Creative Thinking: Conclusions from the Case Studies

The most striking point to be drawn from these two case studies is that it seems possible to analyze in a straightforward way the creative thought process—even the creative thought process at the highest levels. In addition, the creative process seems to be highly structured and not very different from the thought processes involved in more mundane activities. There seems to be a large gap between the importance of the products and the ordinariness of the thought processes that brought them about. In both

cases, it was not necessary to introduce any thought processes that seem to go beyond ordinary thinking. For example, in developing the double helix, Watson and Crick used information that came from domains closely related to the one in which they were working. No wide-ranging creative leaps occurred in which ideas from totally unrelated areas were brought together in some sort of magical synthesis. Similarly, Picasso did not leap far afield in creating *Guernica*: He built on his own work from that period of time and incorporated related work by others. The products may in both cases have been extraordinary, but the processes by which they were brought about were not.

Concluding that ordinary thought processes underlie creative thinking does not mean that just anyone could have produced either the double helix or *Guernica* (see also Klahr & Simon, 1999). First, in order to have produced the double helix, one first had to acquire the expertise of Watson and Crick, who, it must be remembered, were two people with two complementary sets of expertise. One had to have their intellectual capacity and to have put in years of hard study. Second, one had to be directed toward constructing models à la Pauling, which may involve ways of thinking and visualization skills that at the very least had to be developed. Concerning *Guernica*, Picasso had been an artist for some 40 years when he painted it, so one would have to have acquired his unique lifetime's worth of expertise; in addition to his skill as a painter, he had a voluminous knowledge about art. Furthermore, in Picasso's work one sees references to classical mythology (the Minotaur) and other bodies of knowledge, meaning that one would have to go beyond painting itself before one could produce works with the broad range of connections that people find in the works of Picasso. Thus, the premise that creative work may not go beyond ordinary thinking processes does not mean that creative work is effortless and that anyone could do it.

These case studies have served to present the orientation that I will take toward the analysis of creativity: I will begin with analysis of the fine structure of the creative thought processes and work outward from there. The case studies just presented also provide the beginnings of a database for us to use in evaluating theoretical claims made about the creative process and about creative people.

Antecedents for New Ideas and the Question of “Real” Creativity

We have seen in these two case studies several examples of a phenomenon that will be seen numerous times in the cases of creative thinking that are discussed in this book: Creative ideas, even those that are radically new, are firmly planted on ideas that came before. There are always antecedents

to any creative idea. The reason that it sometimes looks like an idea comes out of nothing is because we observers are ignorant of the knowledge base of the individual producing the new idea. If we knew what he or she knew, then we could see where the new idea came from. In response to this phenomenon (which, it must be emphasized, we will see again and again, in every case in every domain we examine), some people dismiss the specific examples as not being creative, and assume that we must look for “real” creativity elsewhere. That is, they conclude that Watson and Crick were not creative, or that *Guernica* was not a creative work. Other people conclude that the demonstration of antecedents for ideas means that there is no such thing as creativity: Everyone just rips off ideas from everyone else, and nothing is new.

Both those conclusions, however, are incorrect. First of all, both *Guernica* and the double helix *are* creative products: They were novel. Simply because a new work is related to—or based on, or developed out of—an earlier work does not mean that the new work is not novel. The difficulty comes if one assumes that a creative work must be *completely novel*, which may be an impossible criterion. So, if one lowers one’s (perhaps unreasonable) expectations a bit, and looks for something less than complete novelty, then one sees that we are dealing with creative products here. The second aspect of this problem is the unspoken assumption that there will be cases where complete novelty is to be found and that these are what we should be looking at. However, going beyond the two case studies just reviewed, I believe that *all* creative products are less than completely novel. Although I cannot prove it, it is my belief that one will *never* find a creative product for which there are no antecedents. I will try to get as close as I can at this time to proving that there are no creative products without antecedents, by examining a wide range of products from a wide range of domains, and showing the antecedents for each of them. This may help make people more willing to entertain the idea that there may be no creative products without antecedents.

Are Creative Ideas Just Recycled Old Ideas?

The two case studies discussed in this chapter provide support for what could be called the *foundation view* of the relationship between expertise and creativity: Experience provides the foundation on which the creative process produces innovations. It is sometimes concluded that the foundation view trivializes creative thinking, because accepting the foundation view means that we must also assume that there really is no such thing as creative thinking because no creative products are novel. In response to this objection, I must emphasize that the foundation view does not trivialize creative thinking

by declaring that all new products are simply recycled old ideas. Creative thinkers go *beyond* the past to produce genuinely novel ideas and objects. For example, as we have seen, the double helix model of DNA, although based on Pauling's alpha-helix, differed from that structure in several critical ways. Likewise, although *Guernica* was related to and perhaps built on aspects of Picasso's work and that of others, it was in many ways a novel work.

Additional evidence that the creative process requires more than simple recycling of old ideas can be gleaned from another stream of the DNA story (Judson, 1979; Olby, 1994; Watson, 1968), which was briefly mentioned earlier. As we saw, in an ironic twist, at the time Watson and Crick were developing their model, which was based on Pauling's ideas, Pauling himself formulated an incorrect model, a triple helix, similar to the one initially developed by Watson and Crick. Pauling was not able to correct his model before Watson and Crick published their work on the double helix. If creativity simply involved recycling old ideas, then it is hard to understand how Pauling could have failed, since he was the one who developed the helical notion in the first place (although in another context). Pauling's failure leads to the conclusion that much more must have been involved in the creation of the double-helix model of DNA than simply taking old ideas and using them again. Further evidence for the active thinking involved in creativity can also be seen in the fact that Watson and Crick also first produced a triple helix, which (as we know) they soon realized was incorrect, for several reasons. One problem with the triple helix was that it was difficult to put the atoms in the model in such a way that they fit together as they were supposed to. After further work, they then rejected it in favor of the double helix. Thus, there was much thinking involved in both creating and rejecting the triple helix; it was not simply an old idea recycled.

Revisiting the Question of Artistic Creativity versus Scientific Discovery

We can now turn again to the question of differences in the creative process in science versus art. At the beginning of the chapter, it was suggested that one might look upon artistic creativity as an inherently subjective process, since the artist brings objects into existence as he or she carries out the creative process. Once again: no Picasso, no *Guernica*. On the other hand, scientific creativity is an objective process that deals with objects that exist "out there," independent of the scientist. The scientist does not bring objects into being through the creative process; he or she discovers objects that exist independent of the scientist and of the creative process. Again: With no Watson and Crick, there would still be DNA.

This subjective/objective distinction is not as clear as it seems, however. Crick, for example, has stated that he believes that if he and Watson had not made their discovery others would have done it, probably within a few months of when they did (Olby, 1994). Crick has also asserted his belief that if he and Watson had not published their discovery, which presented the entire structure as a whole, the structure would have been revealed in bits and pieces. In Crick's view, such a presentation of the structure would have had a less dramatic effect on other scientists, and the appearance of the structure would then have been less influential and important than it was. This is an interesting point, because, if correct, it indicates that the same "facts" can be presented in different ways, which can change the influence of a discovery. This leads one away from the simple notion that discovery deals simply with objective facts waiting for us to find them and present them to others. Carrying this line of reasoning further, if we look more carefully at the way we use the terms *discover* and *create*, and at some of the conclusions arising from the case studies just examined, we may conclude that the creative processes in the arts and sciences may be more similar than different.

Multiple Forms of Discovery

Perhaps the simplest and most direct use of the term *discovery* occurs when we talk about a person discovering a dollar on the street. It is not unreasonable to say that anyone—even a child—could have made that discovery, and that the dollar was "waiting" to be discovered. However, we also talk about Columbus's discovering America, and that discovery seems different from discovering a dollar, since not just anyone could have made that discovery. America might have been waiting to be discovered, but it was not visible to Columbus or anyone else in Europe when Columbus made his presentation to King Ferdinand and Queen Isabella of Spain. While any person high up in the rigging of one of Columbus's ships—perhaps even a child—would have sighted approaching land, in order to get those ships and that person into that location, Columbus had to bring special elements to the enterprise. Most important for the present discussion, the discovery of America depended on Columbus's having a theory about the shape of the earth. If he had not had that theory, there would have been no reason for his voyage, and America would not have been discovered then. So, although America was waiting to be discovered, in order for that act to occur it had to be embedded in a complex set of beliefs that served to initiate a complex sequence of actions that culminated in the discovery.

Discoveries, then, can be of several kinds; and Columbus's discovery, although designated by the same word as the child's discovery of a dollar

on the street, turns out to have different antecedents and to be part of a complex set of circumstances. Now we can raise the question of whether the discovery of DNA more was like the child's discovery of the dollar or Columbus's discovery of America, and it seems obvious that it was more like the latter. DNA is not visible to humans, which means that when we talk about seeing DNA itself or seeing that it is helical—from an X-ray, for example—we are not talking about ordinary seeing. Rather, in order to discover the characteristics of DNA, an act comparable to discovering America, one must have a theory as to how the available evidence is to be interpreted. That is why the Cochran-Crick theory of interpretation of X-rays was important in the discovery process: It allowed investigators to "see" things they would not have seen (Olby, 1994). Similarly, we saw that Watson and Crick's adoption of Pauling's helical idea made it possible for them to interpret much information and to ignore other information that became irrelevant. Watson's learning to interpret X-ray photographs also made it possible for him to see things in Franklin's B-form X-ray that he would not have seen several months earlier. Crick's knowledge concerning X-ray crystallography enabled him to interpret the unit cell from Franklin's analysis of the B form of DNA, and so on.

So the process of discovering the double helix required that the investigators bring much to the situation in the way of knowledge and beliefs. The situation seems more subjective than we might have thought, as we have moved away from the notion of discovery involving an objective investigator using objective facts to draw an inevitable conclusion. Let us now look in the same way at the creation side of the creation-discovery distinction; we will see that the dichotomy is not very clear from that side either.

Multiple Forms of Creativity

We use the term *create* in several ways, and although they are similar, they should be distinguished. On the one hand, we talk about God creating the heavens and the earth, which is the paradigmatic case of creation. Divine creation is extraordinary in one critical way: God created the heavens and the earth out of nothing—*ex nihilo*. That would seem to be the epitome of subjectivity in creation. However, human creativity is different from God's creation of the heavens and the earth. Human creation does not occur in a vacuum; human works are not created *ex nihilo* (and perhaps cannot be). We have seen that Picasso was influenced by and built his work on that of others, which means that his creative work was less subjective than one might have thought. That is, his work was embedded in the history of art, with influences stretching back thousands of years (e.g., the myth of the Minotaur). Thus, we do not see the solitary creator producing something out

Two Case Studies in Creativity

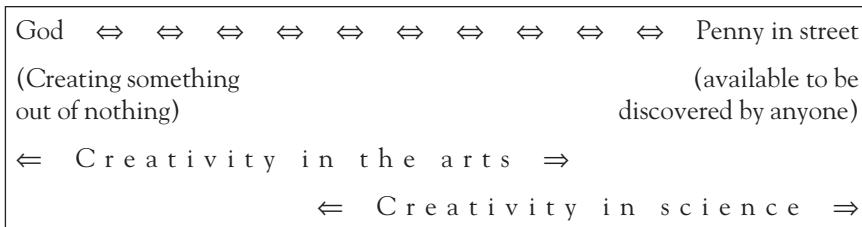


Figure 1.13 Artistic/scientific creativity continuum

of himself independent of what others have done, as the notion of artistic creation might lead one to believe. Just as there is a subjective aspect to scientific creativity, there is an objective aspect to creativity in the arts.

Artistic Creativity and Scientific Creativity: A Continuum

It follows from this discussion that artistic creativity and scientific discovery are not two separate categories of activities. Rather, they overlap in various ways. One can represent this relationship as in Figure 1.13, which puts artistic and scientific creativity on a continuum, with some degree of overlap, in the components just discussed. At one end of this continuum is God's creation, and on the other is the child's discovery of the dollar. Artistic and scientific creativity are seen as occupying more central positions in this continuum, with overlap arising from the role of antecedents and the creator's knowledge in both. From this perspective, it is not absurd to say that Watson and Crick created the double helix, although it seems less acceptable to say that Picasso discovered *Guernica*. (It should be noted, however, that art critics [see, e.g., discussion in Rubin, 1989] have used the term *discovery* to discuss some of Picasso's accomplishments.) This discussion provides support for the belief that one can understand creative thinking in general with one set of theoretical constructs.

Beyond Case Studies: Outline of the Book

We now have a basic background for the study of creativity; examination of two case studies of creativity at its highest has indicated that those examples are amenable to analysis, and that the processes through which innovations come about are comprehensible. This background becomes useful immediately, as we now turn to a broader consideration of psychological studies of creativity. In Chapter 2, I will introduce the study of creativity, examining questions of definition of the relevant concepts and examining the entire range of methods used by psychologists to examine its multiple facets. I have already introduced one theoretical perspective for studying

creativity—the “ordinary-thinking view”—which proposes that creative thinking uses the same processes as our ordinary thinking, and that no new thought processes need be postulated in order to understand how creative advances are brought about. That theoretical view is only one of several different perspectives that psychologists have proposed in order to understand creativity. Chapter 2 will present an introduction to the range of theories of creativity, and subsequent chapters will present specifics of the various theoretical perspectives.

Chapter 3 begins the detailed presentation of the “ordinary thinking” or cognitive perspective, focusing on the relation between problem solving and creative thinking. Chapter 4 examines another component of the ordinary-thinking view, the idea that experience serves as the crucial component on which problem solving and, by extension, creative thinking operate. In Chapter 5, the now fleshed-out ordinary-thinking view will serve as the basis for the analysis of several additional case studies of creative thinking at the highest levels. Those case studies will be drawn from a wider range of domains than those discussed in this chapter, and several of them will represent radical breakthroughs. As such, those case studies will provide a strong test of the notion that ordinary thinking underlies all instances of creativity.

We will then turn to an examination of various aspects of the dominant view in psychology of creativity: the idea that creativity is the result of extraordinary thought processes carried out by extraordinary people. Chapter 6 examines the notion of insight in problem solving, which is the idea that creative ideas sometimes come about through “leaps,” which go beyond what one knows. This view, which has a long history in psychology, challenges the premises that creativity depends on experience and on ordinary problem solving, and so it deserves detailed discussion. Chapters 7 and 8 examine two other examples of the premise that creativity depends on extraordinary thought processes, which is contrary to the view underlying the presentation in this book. Chapter 7 examines the question of genius and madness—that is, the hypothesis that creativity is related to, and may actually be fostered by, psychopathology. Chapter 8 considers the possible role of the unconscious in creativity. In Chapters 9–11, we move considerably beyond the consideration of the creative process to examine the possible broader psychological aspects of creativity. Chapters 9 and 10 present the psychometric perspective on creativity, which emphasizes testing for creative potential and the possible role of personality factors in creativity. Chapter 11 reviews several important recent *confluence* theories of creativity that have attempted to bring together many different components—cognitive, personality, and environmental—in understanding creativity. Chapter 12, the final chapter, presents an overview of the ground we have covered.

CHAPTER

2

The Study of Creativity

We now have considered two examples of creative thinking at the highest level, and it seems from those case studies that one can analyze in a reasonable way the thought processes underlying seminal creative advances in both science and art. We can now put those examples into the broader context of the study of creativity. The present chapter provides a general introduction to the psychological study of creativity, to set the stage for the discussion in the rest of the book.

Outline of the Chapter

We must first define the phenomenon in question. What do we mean when we say that some product is creative, or when we say of someone that he or she is a creative person? The two case studies in Chapter 1 were without doubt creative achievements, which allowed us to put aside the question of how one decides whether a product is creative. In order to go further in our discussion, however, we have to consider how to explicitly define the phenomena of interest. Once we have arrived at a definition, we will examine the kinds of methods used by researchers to study creativity. Those methods range widely, from the case studies with which we are already familiar, to self-reports of individuals of renown concerning how they achieved their creative breakthroughs, to laboratory studies of undergraduates solving problems like those presented in Figure 1.1C. I will then briefly examine several examples of the types of theories developed to explain creativity. Here too we will see a wide range, this time of theories, as psychologists

have attempted to understand the varied phenomena encompassed by the study of creativity.

Creative Product, Creative Process, and Creative Person: Questions of Definition

The critical element in calling some product *creative* is that it be *new*; if someone produces something that he or she has produced before, then that product is not creative. There are two aspects of novelty that must be separated: novelty for the person versus novelty for the world (Weisberg, 1986, 1993). It happens relatively frequently that a student will report to me that she (or he) was reading an assignment and got a great idea for an experimental study, only to turn the page and find, much to her disappointment, that the study had already been carried out. Was the student creative in thinking of her study, even though it had been thought of earlier by someone else? Yes, because the idea was novel *for her*. So long as she was not aware of what had been done before, then she was creative. It follows from this that the *creative process* or *creative thinking* comprises the thought processes that bring about products that are novel for an individual. A *creative product*—or an *innovation*—is one that is novel for an individual, and a *creative person* is one who produces such products. *Creativity* is made up of the factors that enable a person to produce creative products, as in “He has a lot of creativity”; it is also the activity involved in such production, as in “Creativity is hard work.” Creativity encompasses at least the creative process, but it may also depend on personality characteristics and on motivation (Amabile, 1996; Simonton, 1999; Sternberg & Lubart, 1995).

Creative Accidents?

An important point to be considered in defining creativity concerns the possibility of accidental creativity. Let us say that I am a painter, and one day I accidentally spill paint on a canvas, which leaves a stain on my partially finished work, making it unusable. Let us further assume that I am visited by the director of a museum, who sees my stained canvas, loves it, and purchases it for display in the museum. The painting is then discussed in art books, and other artists use my spilled work as the basis for innovations of their own. My piece of junk has thus become part of the world of art. Was I creative in producing that painting? No; since the novel element, the stain produced by the spilled paint, was an accident, then I get no credit. I am creative only when my novel product is produced *intentionally*. Similarly, if you ask a person who suffers from schizophrenia to try to solve a problem during a schizophrenic episode, he or she may produce a novel response,

such as a stream of free associations that you will not be able to understand and that are not relevant to the problem. Is that a creative product? Again, the answer is no; someone in the grip of a schizophrenic episode would not be able to direct his or her thought processes toward the problem at hand, so no creativity would be possible.

There is an interesting twist concerning schizophrenia as it relates to creativity. Sass (2000–2001) discusses cases in which individuals suffering from schizophrenia design complicated “machines” in order to carry out some task in their delusional worlds—say, to protect themselves from having their thoughts read by the CIA—although those machines obviously cannot succeed in carrying out the task. Is a schizophrenic individual exhibiting creativity in designing and building such a machine? In my view, the answer is yes. If the machine is a novel product, and if, *once one accepts the premises that the schizophrenic individual is working under*, the construction of the machine follows intentionally from those premises, the person is creative. There is, in my view, no contradiction in saying that a person is psychotic and creative. So long as he or she can carry out some thought process in pursuit of a goal, and if that thought process results in a novel product, then the person is creative.

The Question of Value in the Definition of Creativity

Almost all researchers who study creativity use a definition a bit different from the one I have just given: In addition to a product’s being novel, it is also proposed that the *value* of a product is important in determining whether it is creative (for examples, see chapters in Shavinina, 2003, and Sternberg, 1999a). In this view, to which I used to subscribe (e.g., Weisberg, 1986), in order for an invention to be called creative, it must carry out the task for which it was designed; a creative scientific theory must help us understand the domain in question; a creative work of art must be appreciated by some audience beyond the artist; and a creative solution to a problem must actually solve the problem. Csikszentmihalyi (e.g., 1988, 1996, 1999) has presented a detailed analysis of how novelty and value are both relevant to creativity. Since that view is now the dominant one in the field, and since my present view is different, it is worth discussing in some detail the issue of value in creativity.

Csikszentmihalyi (1988) proposed that three components, shown in Figure 2.1, play a role in making any product creative. First, we have an *individual*, who is working in some *domain*, say a researcher in molecular biology in a university, a fashion designer working in a design house, or a painter in a studio. The domain of molecular biology is all the accumulated knowledge concerning that subject matter, everything available in books

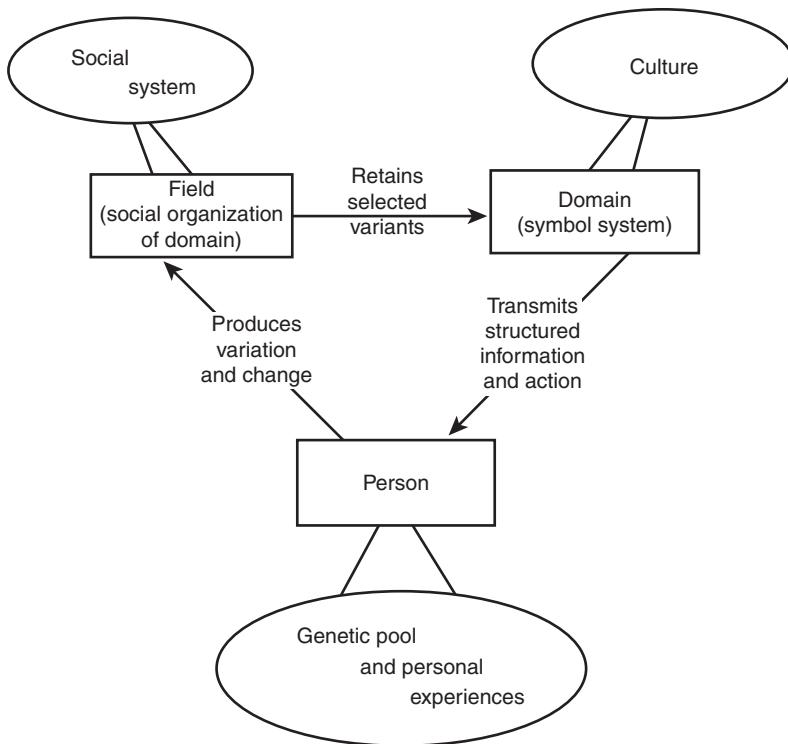


Figure 2.1 Csikszentmihalyi's systems view of creativity

Note: This map shows the interrelations of the three systems that jointly determine the occurrence of a creative idea, object, or action. The individual takes some information provided by the culture and transforms it, and if the change is deemed valuable by society, it will be included in the domain, thus providing a new starting point for the next generation of persons. The actions of all three systems are necessary for creativity to occur.

Source: Adapted from Csikszentmihalyi (1988).

and journals, that fills our libraries. Similarly, the domain of fashion design is all the accumulated knowledge about fashion, and here too we have libraries of accumulated information. The domain of painting consists of those works of past artists that are displayed in museums and galleries and are discussed in books on art and among artists.

At some point, that individual makes a novel contribution to the domain: The molecular biologist makes some novel research discovery or develops a new theoretical perspective; the designer comes up with new ideas for next season's collection; the painter creates a new painting or a new style of painting. When an individual produces something new, he or she has to make it public. In other words, the individual must present the discovery to the *field*, that is, those individuals who work in the area. The field in

molecular biology is made up of the scientists who carry out research in that discipline; in fashion, it is the individuals in the fashion industry; in art, it is art critics, museum directors, gallery owners, artists, and the members of the public who attend museum and gallery shows and who purchase art. In science, new ideas are usually presented through publication in a professional journal in the field. The best-known members of the field serve as journal editors and reviewers, and they decide whether the new finding is important enough—valuable enough—to merit being published. Those individuals thus serve as gatekeepers to the domain. Similarly, in fashion, the new ideas are presented to the field in a fashion show; fashion critics, clothes buyers for stores, and individuals who buy high-fashion clothing decide whether the new clothes are worthy of wearing. The world of art also has gatekeepers. Paintings are displayed in museums and art galleries; museum curators and gallery owners decide whether to put on display new works from artists.

In each of those areas, if the members of the field decide that an innovation is not of interest, then it may never see the light of day, and it will have no effect on the domain. The molecular biologist's discovery will not be published, and consequently most people in the field will never learn of it; the designer's clothes will never be worn; the artist's paintings will never be seen. On the other hand, if a new scientific finding is deemed worthy of publication, it then becomes part of the domain, where it is studied by other scientists, and the cycle continues. If the designer's new clothes are deemed worthy, they will be seen in fashion magazines, in stores, and eventually on the streets, and other designers may be stimulated by them. Similarly for the artist, the painting will be seen in a museum or a gallery; it may be discussed in a book or journal article; and it may influence the thinking and work of other painters.

In Csikszentmihalyi's (1988) view, the term *creative* should only be used to describe a product that goes through the whole cycle presented in Figure 2.1: A novel product becomes creative only after it has become part of the domain—that is, only after it has been positively valued by the field. If a product is rejected by the field, in this view, that product is not creative, whether or not it is novel. Thus, other scientists play a role in making a scientific discovery creative; fashion critics and clothing buyers for exclusive stores play a role in making a designer creative; and art critics and other artists play a role in making a painter creative.

Creativity Is Novelty, Irrespective of Value

As I said earlier, most researchers agree with Csikszentmihalyi that the value of a product plays a role in whether it should be called creative; I,

however, do not (Weisberg, 1993, Chap. 8). Csikszentmihalyi has produced a valuable analysis of the way in which multiple factors come together in determining whether an idea will be accepted by the intellectual community. However, I would make one small change in the terminology used to label the cycle in Figure 2.1 and its components: I would say that the cycle determines whether an innovation comes to be *valued*, and I would restrict the use of the term *creativity* to the individual's production of the innovation in the first place (see Figure 2.2). I make this distinction because I believe that one should separate the creativity of a product from its value, and therefore I will not use value as a criterion for calling something creative. The reasons I am reluctant to include value in the definition of creativity are twofold.

One difficulty that I see in using the value of a product as part of a definition of creativity is that value can change over time. Sometimes a product is not valued when it is produced but comes to be valued by later generations. Examples of this are easy to find; the Impressionist painters, whose work is

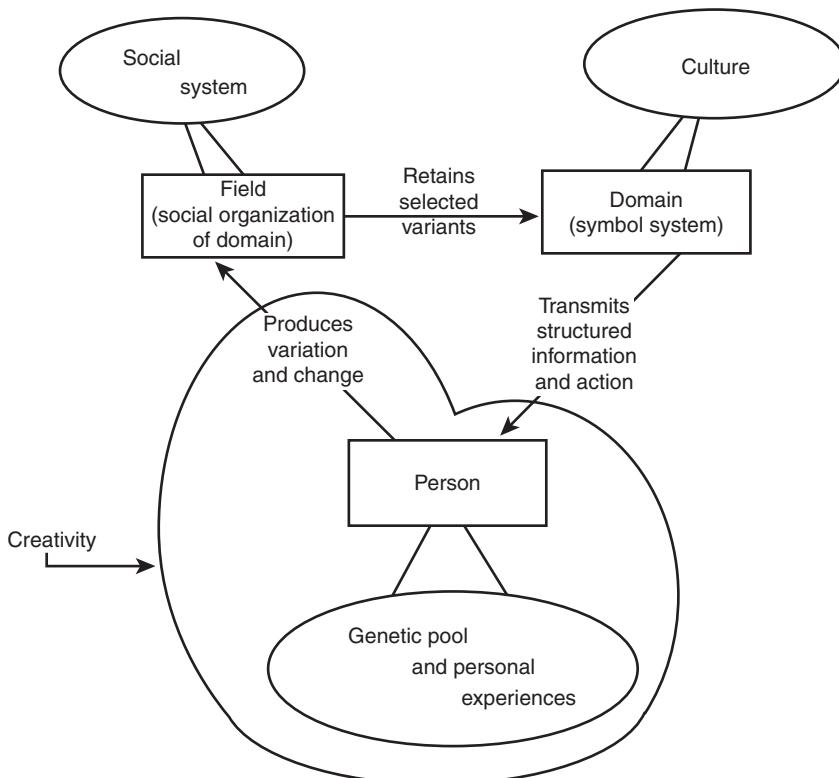


Figure 2.2 Modified Csikszentmihalyi cycle

now among the most beloved and historically important in all of painting, were ridiculed by art critics when their works were first put on exhibit in Paris more than 100 years ago. On the other hand, sometimes a product is valued greatly when it is produced but is then put aside by future generations as being of no lasting value. Many of the artists whose works were valued most highly by the art community when the Impressionists first came on the scene are no longer remembered in any way; art history, curators of museums, and the art-viewing public have forgotten them. If we use value as part of the definition of creativity, we would have to say that a person could be creative at one time and then become not creative later, and vice versa (Csikszentmihalyi, 1988, 1999). A person could become creative after death, for example, if that person's field comes to appreciate his or her works then. Even during one's lifetime, one's creativity could change, because of changes in how one's work is viewed by the field.

Csikszentmihalyi does not view as problematic the possibility of a change in a person's creativity, but I think that allowing the creativity of a product (and of the person who produced it) to vary when its value changes creates difficulties for understanding creative thinking. One critical problem is that we would never be able to say for certain who or what is creative. Since it is possible that the value of *any* product can change over time, it means that anything can become creative or become not creative, and can keep switching back and forth. There is no guarantee that any products that we value today—the music of Mozart, the paintings of Rembrandt, the scientific theories of Einstein and Darwin—will be valued by future generations. Indeed, I know people who think that Mozart's music has no value. This means that it is possible—perhaps not likely but still possible—that future generations may universally consider those works to be bereft of creativity.

In Csikszentmihalyi's view, Mozart is not creative to those people I know who are bored to tears by his music. This seems to me to miss the essence of what I think of as creative: the production of works that were novel for their creator at the time they were produced. I think it is more useful to keep the creativity of a product separate from its value, and to say that a product is creative so long as it is novel. If and when the field's opinion of a work changes, then we can say that the work (or the person who produced it) has become more or less *valued* or *appreciated*, but I do not think that we should say that the work (or person) has become more or less creative. Accordingly, I will assume that you can be creative even if you produce a new scientific theory that is totally wrong (such as the triple helix of Watson and Crick and that of Pauling; see Chapter 1), or new music that no one ever likes, or a new airplane that never gets off the ground, or new clothes

that no one ever wears. All that matters is that the product be novel for you and produced intentionally.

A related problem that I see with the notion that value should play an important part in defining creativity is that acknowledging that people can become creative after they die, or can become noncreative, means that we can never carry out the psychological study of creativity. As an example, let us say that we want to study the thought processes or personality factors involved in creativity in painting. Whom are we to study? As a start, we could study living painters whose work has been deemed important by the field. Let us say we do that, and we draw some conclusions as to what factors are important in making someone a creative painter. However, let us assume that in 10 years those painters are no longer in favor; that is, their work is no longer valued, which means that, if we use value in our definition, they are no longer creative. Therefore, our conclusions from 10 years ago are no longer relevant to creativity. We have to study the characteristics of the painters who are now designated as creative, which means that we may always be going back to the beginning as far as the scientific understanding of artistic creativity is concerned. One might try to get around this problem by studying people long dead who have been designated as creative, assuming, for the sake of discussion, that we had information about those people's lives, working methods, and personalities. However, even if a person has been dead for 100 years, say, or 200, or 500, and his or her work has been positively valued for all that time, there is no guarantee that the next generation will value those works. Even the long-dead could lose their status. I know that the opposite is true: I constantly see articles praising long-dead painters and composers who have been "discovered" by critics and orchestras, respectively. Thus, if we allow value to be part of our definition, there seems to be no way to achieve a solid foundation for our studies of creativity.

In contrast, if we use my definition of intentionally produced novelty to designate a creative product, then the only issues we have to worry about are whether a person has produced a novel outcome and whether it was intentional. Both of those criteria are relatively easy to ascertain. It should also be noted that the question of assessing the novelty of a product and the intention of the individual must also be addressed if one defines creativity as the production of novel products that are of value. Thus, my definition is simpler to apply to a product, since there is no need to worry about value. Furthermore, by my definition, if you are designated as creative—and if the novelty and intentionality of your product have been measured accurately—your status as creative stays with you forever. Similarly, if you die noncreative, then that cannot change, unless, of course, some previously

unknown novel work comes to light after your death. Therefore, we are free to study the characteristics of creative versus noncreative individuals, secure in the knowledge that those people we designate as creative will remain creative, barring unusual situations in which they are found to have copied someone else's work and passed it off as their own or to have produced some novel product by accident and passed it off as something produced intentionally.

It is interesting to examine the relationship between the two definitions of creativity being discussed: intentional novelty plus value versus intentional novelty. Consideration of the two sets of criteria indicates that they are related; one is contained within the other. In other words, anything that is designated as creative according to the novelty-plus-value definition currently used by most researchers will also be designated as creative using my definition, assuming that the novelty is brought about intentionally. If something is novel and valued, then it is, *ipso facto*, novel, and therefore we all would call it creative. Similarly, if something is *not* novel, then whether or not it is valued we would all agree that it is not creative. Thus, the only situation in which the two definitions would disagree is where some intentionally produced novel product cannot be said to have value (e.g., those triple helices); I would call that product creative, while most other researchers would not.

Consider again briefly what sorts of products those valueless things might be. One might produce an invention that fails miserably, a piece of music that all people find unlistenable, a painting that no one cares to look at, or a scientific theory that turns out to make no correct predictions and does not serve to make sense out of the area in which it was developed. As a concrete example, one reviewer of this book said that my definition would not work, and as evidence he raised the idea of using nails for money. A 1 cm nail would be worth \$1, and longer nails would be worth more. He said that there was no way that such an invention could be called creative, because it would be obvious to all that the idea was stupid, and he then dismissed the whole rationale of defining creativity based only on novelty.

However, I think the issue is more complicated than the reviewer did. First of all, it is not clear to me that anyone in his or her right mind would seriously propose such an invention, so the example raised by the reviewer might only be a red herring. If someone in seriousness did propose using nails as money, surely that person, if asked, would have interesting reasons for such a proposal, which means that dismissing it as completely stupid is premature. I believe that when people spend time and effort on some product, then the outcome, if it is novel, should be considered creative. If we do not like the product, or if we find that it is useless, then we can say so

in response to it, but those judgments are different from a judgment about whether the product is creative.

One other reason for leaving value out of our definition, related to the point just made, is that I see no reason to believe that the psychological processes involved in producing a positively evaluated innovation are different in any way from those underlying a negatively evaluated one.

We have already seen a number of examples of this in the case study of DNA in Chapter 1. First of all, compare Watson and Crick's development of the double helix with that of their earlier triple-helix model. The latter was of no value and was rejected almost immediately, while the former has changed the world. However, one sees processes at work in development of those two models that are the same; the information that the processes were working on had changed, so that the outcomes were different. The issue of value seems to be irrelevant to the processes involved. Similarly, we compared Watson and Crick's creative process with that of Franklin, who did not produce the ultimate outcome of value. The crucial element affecting her lack of success seems to have been that she was dealing with different assumptions and, most importantly, with a critical piece of information (her DNA X-ray photo that appeared asymmetrical; see Chapter 1) that led her in an unsuccessful direction. There does not seem to be any basic difference in the processes involved in production of more- versus less-valued products.

As another example, a painter might produce two paintings, one of which becomes a seminal work—that is, part of the domain—and the other of which does not. This is the case with Picasso's *Guernica* and *Minotauromacy*, the former of which is much more important (i.e., valued) in the history of art than is the latter. Similarly, an inventor might produce one machine that carries out some task well, and another that fails miserably at the same task (we will see examples of this in later chapters). Why should we assume a priori that different cognitive processes are involved in the production of the valued versus nonvalued innovations? It seems more reasonable in the case of valued versus nonvalued works of art, for example, to assume that the evaluations, both positive and negative, are the result of what others get out of the paintings rather than what the artist put into them. It is also of interest to note again that Picasso may have based *Guernica* on *Minotauromacy*, which again indicates that it is difficult to separate more- from less-valued innovations. Similarly, the inventor who produced a machine that failed miserably obviously missed some thing or things, but that does not mean that there was a basic difference in the processes involved in producing the successful versus unsuccessful one.

In addition, in many cases of creative innovation at the highest level, one

finds that an early product was unacceptable in some way, and the person modified it until it was acceptable. We already saw this in the case of DNA in Chapter 1: Watson and Crick first produced the triple helix, and only after much work was the double helix produced. In such circumstances, the negatively valued and positively valued products are part of the same process, and it seems difficult if not impossible to make a distinction between them. Thus, it seems that for a number of reasons things are much simpler for the student of creativity if we leave value out of our definition, so that is what I will do here.

External Verification of Creativity

Even if we agree to use goal-directed novelty as the definition of a creative product, that does not mean that social factors are irrelevant in determining whether some work is creative. A student once told me about an artist friend who at the end of each day destroyed that day's work. She raised the question of whether he was creative. The answer is not a simple yes or no—the way the artist has structured the situation, we cannot say whether he is creative. Let us say that the artist tells his friend that he has had a great day and produced work that went far beyond anything he had done before. Since he has destroyed that work, however, we cannot tell whether that statement is true. In order to conclude that the work is indeed creative, we have to have that work available, so that we can tell that it is in fact new. Perhaps the artist is repeating himself but does not realize it—surely his memory is fallible, as all our memories are, and he may have forgotten that some time ago he produced a work just like the work he produced today, the one that he thought was so new. Thus, we need to have a product that other people can look at before we can call something creative.

However, to reiterate, this need to have others look at a product is not, as Csikszentmihalyi believes (1988, 1999), because others' judgment of the *value* of the work is important in determining whether it is creative. Rather, we need external observers because at this time only external observers can verify that the work is *novel*. If the artist in question had some database available—say, a computerized pictorial record of all his work—in a form that was easily searchable, so that he or his friend could determine accurately whether some just-produced work was novel, then he would not need the rest of us to determine if he had been creative that day. However, until such a database is available, any individual who destroys his or her work before anyone else sees it simply makes it impossible for us to determine whether anything creative has been produced. Similarly, if we had a complete videotape of the artist working, including any spontaneous comments he or she might make in the course of producing some work, then

we could determine reasonably well whether some product came about by accident or intentionally. Again, until such records are available, we will have to ask the artist.

A Working Definition

We now have a working definition of creative thinking that we can use as the basis for the discussion in the rest of the book: *Creative thinking* occurs when a person *intentionally* produces a *novel* product while working on some task. Sometimes those intentional novel products are valued highly by society, and sometimes they are not, but all of them are creative products. A novel product intentionally produced by a person is a *creative product*, and the person who produces such a product is a *creative person*.

Different Kinds of Creative Contributions

If we agree for the moment that creative products are novel works intentionally produced, that does not mean that all creative works are equivalent. First, there are differences in the degree of novelty exemplified by different works. As one example, some of Picasso's early works, such as the Cubist works he produced in collaboration with Georges Braque in 1912–1914, were much more innovative than was *Guernica*, with which we are already familiar. The Cubist works went much farther beyond anything Picasso (or anyone else) had done before, whereas, as we saw in the last chapter, *Guernica* did not represent a radical break with Picasso's work of that time. We will at a number of points consider whether radically new works are produced by methods different from those involved in producing works that are more closely related to earlier works. The development of Cubism by Picasso and Braque is discussed in Chapter 5.

A second distinction that can be made among creative products centers on the influence of the product on the field. Sternberg and his colleagues (e.g., Sternberg, 1999b; Sternberg, Kaufman, & Pretz, 2002) have proposed that an important aspect of a creative product is the effect that product has on the other members of the field. A creative product can change the direction of a field, or *propel the field* in any of a number of directions. Sternberg and colleagues have developed a classification system that they call a *propulsion model of creative contributions*. In their view, a creative work can be seen as having the effect of propelling the field in some direction, which may be the same as or different from the direction in which the field is currently moving. This propulsive effect can occur whether or not the creator has intentionally set out to bring it about. There are at least eight different effects a creative contribution can have on a field. Let us examine

several of them, to get a feeling for the classification scheme proposed by Sternberg and colleagues.

A creative product might simply build on what has already been done, without changing the basic direction in which the field has been moving, in what can be called *forward incrementation*. *Guernica* is an example of such a work, since it did not represent a break with Picasso's then-current style. Similarly, the numerous researchers who built on the development of the double helix used that idea as the basis for forward movement, without introducing any radically new advances. A more radical change is seen in the development of the Cubist style of painting in 1912–1914 by Picasso and Georges Braque. This can be called a *redirection* of painting, since it took the then-current styles and proposed a radical shift away from them. Numerous painters adopted the Cubist style after it had been introduced, carrying on the innovations of Picasso and Braque and spreading them beyond the ways in which the originators had used them. Thus, in another example of forward incrementation, those artists used the Cubist style in ways not thought of by Picasso and Braque, but those painters and their works did not radically change the direction of painting, as the introduction of Cubism had.

Sometimes an individual may make a contribution that is an incrementation beyond what had been done but the degree of advance is too much for the field to absorb, so the contribution is rejected; one might say that it was “ahead of its time.” In this case, the development is an *advance forward incrementation*. In 1913, Igor Stravinsky’s music to accompany the ballet *The Rite of Spring*, choreographed by Vaslav Nijinsky, premiered to an almost riotous audience response. Stravinsky’s music (and the choreography) had gone so far beyond the accepted taste that it could not be accepted, and it took years before the music became part of the modern repertoire.

An important type of contribution is one of *redefinition*, in which the individual proposes a new perspective on the current state of the field. An example can be seen in medicine, when in the 1980s Drs. J. R. Warren and Barry Marshall developed the theory that peptic ulcers were caused by bacteria in the stomach (Thagard, 1998). Ulcers, in this view, were the result of bacterial infection. At that time, it was believed that ulcers were caused by excess stomach acidity, often triggered by stress. The typical treatment had been to try to reduce the person’s level of stress and to provide a bland diet that would reduce the irritation of the stomach lining. The bacterial-infection hypothesis was viewed by the medical establishment as absurd, but it is now generally accepted that bacterial infection plays an important role in the development of peptic ulcers. Redefinition can also be seen in

art (Sternberg, Kaufman, & Pretz, 2002). One example is the development of Pop Art in the 1960s, when such artists as Roy Lichtenstein and Andy Warhol took objects from “low culture”—comic books and labels from soup cans, respectively—and used them as subject matter for paintings meant to be looked at as “art.” Thus, Pop Art redefined the subject matter of painting.

This brief survey has demonstrated some of the ways in which creative products can shape the milieu in which they are introduced. Not only are creative products goal-directed and novel, they also have influences of various sorts on those working in the field and those who will do so in the future. As we consider additional examples of creative production in the chapters that follow, we will have occasion to consider the influence of a product. One important question from the present perspective is whether products that have different effects on their fields are brought about in different ways as far as psychological processes are concerned. For example, are different thought processes involved in redefinition versus redirection? Similarly, are there differences in the people that make contributions of different sorts? These questions will be considered in later chapters.

Now that we have defined the important concepts that we will be dealing with, we can begin to look at the still-broader picture. Let us first examine the kinds of methods that researchers have used to study creativity; we will then review the types of theories that have been proposed to explain it.

Method versus Theory in the Study of Creativity

It is important to make a distinction between method and theory in the study of creativity. On the one hand we have the data that an investigator collects and the method used to collect those data, and on the other we have the theoretical interpretation that he or she applies to the data. One might agree with a researcher’s theoretical perspective but raise questions about the data he or she adduces in support of it—for example, if the researcher’s methods were flawed in some way. As one example, some investigators study the creative personality—the personality characteristics that might be unique to creative people—by studying the characteristics of undergraduates who have been designated as creative based on their scores on tests designed to measure creativity. There are theoretical predictions made about the creative personality that can be tested in this way. In this case, one might agree with the desire to measure the creative personality, and with the specific predictions being made, but disagree with the choice of the specific individuals being studied—that is, with the method being used to collect the data to support the ideas. One might believe that in

order to study the creative personality one should study individuals who are acknowledged as creative in the “real world,” such as successful artists, scientists, or inventors, rather than undergraduates chosen as the result of test scores.

It is also possible, on the other hand, for one to be interested in the data an investigator produces but disagree with the interpretation that the researcher puts on them. Some researchers study creative thinking by examining the performance of undergraduates on problem-solving exercises carried out in the laboratory. One might find the data interesting as they relate to undergraduates’ capacities to solve problems of various sorts but question the ability of those studies to tell us anything about “real” creativity. One might feel that true creativity was not being displayed in such small-scale exercises. In this case, the data might have been collected using valid methods, but the interpretation of those data is the problem. A similar phenomenon might come about when case studies, such as those presented in Chapter 1, are used to study creative thinking. Such case studies would overcome any possible objection concerning whether “true” creativity is being studied. However, you might disagree with my interpretation of the data from the case studies. I might say that the results indicate that ordinary thinking processes are involved in creative advances, and you might disagree, saying that the results demonstrate otherwise. For these reasons, it is necessary to keep distinct the method used to collect data and the interpretation put on those data.

Methods of Studying Creativity

Consider again the broad range of creative thinking of which humans are capable, ranging from the creation of poems to skyscrapers. One might expect that such a wide range of phenomena would be brought about in many different ways. In order to study the psychological processes underlying such a broad range of phenomena, one might expect that researchers would have to use a wide range of methods, and that is correct. And, as we shall see, each of those methods has strengths and weaknesses.

Subjective Reports of the Creative Process

The oldest method of studying creativity uses personal reports by individuals of extraordinary accomplishment concerning how they carried out their work (Ghiselin, 1952). Those reports come from creators from across the spectrum of creative fields, including poetry, literature, music, visual arts, and the sciences, and are in the form of letters, addresses before scientific societies or other groups, responses to questionnaires, and

in-depth interviews. In the following passage, Ghiselin makes clear the motivation for use of such reports as the basis for theorizing concerning creativity.

[A] large amount of comment and description of individual processes and insights has accumulated, most of it fragmentary, some of it not perfectly reliable. Among these materials the most illuminating and entertaining are the more full and systematic descriptions of invention and the reflections upon it made by the men and women most in position to observe and understand, the thinkers and artists themselves. (1952, p. 11)

Let us examine several of those reports, because they seem to provide a fascinating glimpse into the world of the creative genius. The Romantic poet Samuel Taylor Coleridge (1772–1834) provided a description of how he came to write “Kubla Khan,” his famous poem that begins with a description of Khan’s elegant palace (“In Xanadu did Kubla Khan a stately pleasure dome decree”). Coleridge reports that he took an anodyne (a painkiller) because he was feeling indisposed. (This may not be true; it has been reported that he actually took opium, to which he was addicted at the time.) He then sat before the fire, reading a section about Khan’s palace in a well-known travel book describing exotic sights, and he dozed while reading. The following events then occurred (Coleridge refers to himself here as “the author”; qtd. in Ghiselin, 1952, pp. 84–85).

The Author continued for about three hours in a profound sleep, at least of the external senses, during which time he had the most vivid confidence that he could not have composed less than from two to three hundred lines; if that indeed can be called composition in which all the images rose up before him as *things*, with a parallel production of the concurrent expressions, without any sensation or consciousness of effort. On awakening he appeared to himself to have a distinct recollection of the whole, and taking his pen, ink, and paper, instantly and eagerly wrote down the lines that are here preserved. At this moment he was unfortunately called out by a person on business from [the neighboring village of] Porlock, and detained by him above an hour, and on his return to his room, found, to his not small surprise and mortification, that though he still retained some vague and dim recollection of the general purport of the vision, yet, with the exception of some eight or ten lines and images, all the rest had passed away like the images on the surface of a stream into which a stone had been cast, but alas! without the after restoration of the latter.

This report is interesting for at least two reasons. First, we are told directly by the poet how he carried out his work. Second, more specifically, we learn that a long poem—200 to 300 lines—came to him “without any

sensation or consciousness of effort." He just had to write it down, until the interruption by the businessman seems to have robbed him and us of the last section. Presumably, those 300 lines and the related images arose out of Coleridge's unconscious, stimulated by his reading and perhaps by the opium. How else could a complete poem suddenly appear? This report, since it comes directly from the poet, would seem, at least on an initial scrutiny, to carry much weight.

Another report concerning creative thinking is found in a letter by Wolfgang Amadeus Mozart (1756–1791) describing his working methods. Mozart began to compose music at the age of six, and he died at an early age, in somewhat mysterious circumstances, after composing more than 600 pieces of music. Reports of Mozart's legendary abilities abound; he is said to have produced music effortlessly, without mistakes, simply writing down whole compositions as they came to him, without having to revise them. Mozart described his creative process as follows (Ghiselin, 1952, pp. 44–45).

When I feel well and in a good humor, or when I am taking a drive or walking after a good meal, or in the night when I cannot sleep, thoughts crowd into my mind as easily as you could wish. Whence and how do they come? I do not know and I have nothing to do with it. Those which please me, I keep in my head and hum them; at least others have told me that I do so. Once I have my theme, another melody comes, linking itself to the first one, in accordance to the needs of the composition as a whole.

There are two important aspects of this report. Like Coleridge's, it comes directly from a creator of the highest level. Second, it too seems to point to the importance of unconscious processing in creative thinking. How else can one explain complete musical compositions being written down without error? Surely, they were worked out in Mozart's unconscious before they were "presented," in complete form, to consciousness.

The two examples of unconscious processing presented so far have dealt with artistic creation, but evidence for unconscious processing has also been reported by scientists. A critical event in the development of modern chemistry was A. F. Kekulé's (1829–1896) discovery of the structure of benzene, which forms the basis of many organic compounds. This molecule has a circular structure—it is a closed chain or ring of six carbon atoms—which serves as the foundation for many chemical structures that are crucial for the maintenance of life. Based on Kekulé's reports of his work, one can separate this critical discovery into two stages. In the first stage, Kekulé had been trying to conceive of a molecular structure for certain compounds made up of carbon atoms at their core, and he did so by imaging how the atoms making up those molecules might interact.

During my stay in London I resided in Clapham Road. . . . I frequently, however, spent my evenings with my friend Hugo Mueller. . . . We talked of many things but most often of our beloved chemistry. One fine summer evening I was returning by the last bus, riding outside as usual, through the deserted streets of the city. . . . I fell into a reverie, and lo, the atoms were gamboling before my eyes. Whenever, hitherto, these diminutive beings had appeared to me, they had always been in motion. Now, however, I saw how, frequently, two smaller atoms united to form a pair: how a larger one embraced the two smaller ones; how still larger ones kept hold of three or even four of the smaller: whilst the whole kept whirling in a giddy dance. I saw how the larger ones formed a chain, dragging the smaller ones after them but only at the ends of the chains. . . . The cry of the conductor: "Clapham Road," awakened me from my dreaming; but I spent a part of the night in putting on paper at least sketches of these dream forms. This was the origin of the "Structural Theory." (qtd. in Roberts, 1989, pp. 75–81)

Kekulé now had the idea of a string of carbon atoms as the basis underlying the structures of many carbon-based compounds. The structure of benzene seems to have been problematic for Kekulé's early structure theory, because the properties of benzene were very different from those of other molecules that were made up of strings of carbon atoms with hydrogen atoms attached to them. That raised the possibility that a different kind of structure was involved. In setting the stage for the discovery of benzene, Kekulé reports that he was sitting by a fire.

During my stay in Ghent, I lived in elegant bachelor quarters in the main thoroughfare. My study, however, faced a narrow side-alley and no daylight penetrated it. . . . I was sitting writing on my textbook, but the work did not progress; my thoughts were elsewhere. I turned my chair to the fire and dozed. Again the atoms were gamboling before my eyes. This time the smaller groups kept modestly in the background. My mental eye, rendered more acute by the repeated visions of this kind, could now distinguish larger structures of manifold conformation; long rows sometimes more closely fitted together all twining and twisting in snake-like motion. But look! What was that? One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lightning I awoke; and this time also I spent the rest of the night in working out the consequences of the hypothesis. (qtd. in Roberts, 1989, pp. 75–81)

Kekulé's discovery was that the carbon atoms in benzene formed a closed ring. Kekulé reported that when he made the discovery he was dreaming, or in a dreamlike state, which would support the claim that unconscious processes were involved. In addition, Kekulé was dreaming of a *snake*, which may be evidence of a symbolic component in his thinking, and this

again points away from ordinary conscious thought. Thinking of atoms as atoms presumably would not have produced a new structure—the closed ring—that opened up a new scientific domain (Csikszentmihalyi, 1996).

We have now considered three firsthand reports, from creative individuals of the first rank, concerning their creative process. When individuals of the highest repute provide the information, it seems that we have learned much. On closer examination, however, those reports turn out to be of little value as evidence for unconscious processes in creative thinking. Consider again Coleridge's "Kubla Khan," the marvelous poem that reportedly came to him whole out of his unconscious during a drug-induced dream. The most troubling obstacle to our believing Coleridge is the existence of another version of the poem, written in Coleridge's hand, which is different from the final version (Schneider, 1953). This other version seems to be an earlier one, because it contains some changes or corrections that appear in the published poem. Thus, contrary to what Coleridge reported, the poem was subject to the usual corrections and changes to which all works of art are subject (Weisberg, 1986). So this report, firsthand or not, should be put aside. Next we have Mozart's letter, describing a process much like that of Coleridge, in which complete works appear to the creator unannounced and unbeckoned; again the creator simply transcribes them for us. However, Mozart's letter is also not to be believed, because there is strong evidence that it was not written by Mozart (Weisberg, 1986). It is in a dialect of German that Mozart did not speak, and it refers to his sister by a nickname that he and his family did not use. So this letter too must be relegated to the trash.

Finally, there is Kekulé's report of his dream of a swirling snake biting its tail. There are four points to be made about this account. First, Kekulé's report was part of an address he gave at a celebratory dinner commemorating his discovery of the structure of benzene, which had occurred some 35 years earlier. Surely we cannot put too much faith in a 35-year-old memory. Second, even if we accept the report, one can raise the question of whether Kekulé's report says what it has usually been interpreted as saying (Weisberg, 1986). Kekulé is usually described as *dreaming* in front of the fire, but in his speech he used the German word *Halbschlaf* or "half-sleep" to describe his state, which seems to refer to *daydreaming* rather than fully sleeping. This would indicate that he imagined the snakes when he was *conscious*, rather than unconscious. Let us put this objection aside as well and look still further at Kekulé's report, which is usually presented as his dreaming of snakes. Kekulé described the strings of atoms as being in "snake-like" motion. This is a curious adjective, because if one calls something "snakelike" it means that the object being described is not a snake. If I tell you that your new car has race-car-like handling, then you must have not bought a race car. If we

can extend this analysis to Kekulé's description of the content of his dream, then Kekulé was not describing snakes. He was comparing the movement of the strings of atoms to that of snakes, but he knew there was a difference. The final point concerning Kekulé's report concerns whether the story is even true. It has been proposed that Kekulé made it up for presentation at that celebration (Wotiz, 1993). This last point has been the subject of some controversy (Rocke, 1985), but the fact that scholars can publish articles in respectable scientific journals debating whether Kekulé ever had the dream indicates that such reports are not the sorts of data that we can use as the basis for a theory of creative thinking.

In the course of this book, we will come across several first-person reports on the creative process. I am reluctant to put much emphasis on such reports, however, because they suffer from several shortcomings, some of which were just pointed out. They are usually made long after the fact, which raises questions about their accuracy; like everyone else, great creative thinkers have fallible memories (Perkins, 1981; Weisberg, 1986, 1993). Even if the subjective report were obtained very soon after the events in question, which might reduce potential memory problems, in most cases we have no way of verifying the accuracy of the report, because there is usually no objective evidence to support it. Furthermore, the individuals providing those reports, although of undeniable eminence in their fields, usually have no training as behavioral scientists, which may limit their ability to provide valuable data, even if they are available (Ericsson & Simon, 1996). And then there is the problem of poetic license, which may be relevant in Coleridge's case and that of Kekulé. Finally, even if there were no other issues, self-reports provide us with only qualitative descriptions of the creative process. They do not give us data that can serve in a rigorous scientific analysis.

For these reasons, contrary to Ghiselin's (1952) belief quoted above—that is, that the individuals who make creative advances are in the best position to tell us something about the processes involved—the position taken in this book is that the cognitive scientist, who is equipped with tools to analyze objective data, is the individual most likely to make valid observations about the creative process. In no other science—indeed, in no other area, even in experimental psychology—do we rely on such reports; we should also move beyond them in the study of creativity. (For a summary, see Table 2.1.)

Biographical Studies

In a large step away from reliance on subjective reports of the creative process, Gardner (1993) carried out biographical studies of seven of the most eminent creative individuals of the twentieth century: Sigmund Freud,

Table 2.1 Methods used in the study of creativity: Strengths and weaknesses

Method	Strength(s)	Weakness(es)
Autobiographical self-reports	Highest-level creators	Lack of control over accuracy; evidence that several are untrue; limited to qualitative analysis
Biography—creative thinking	Highest-level creators; historical data accurate	Only as good as data are complete; qualitative analysis
Biography—personality or psychopathology	Highest-level creators	Qualitative analysis; retrospective assessment or diagnosis is difficult; only as good as data; data not in form amenable to analysis
Case studies of innovations	Highest-level advances; historical data accurate	Qualitative analysis; only as good as data are complete; method and data may limit generality of conclusions
Historiometric analyses	Real creativity; hard data; quantitative methods	Only as good as data; may be limitations on kinds of questions that can be asked (fine-grain analysis?)
Quantitative case study	Real creativity; hard data; quantitative analysis	Lack of control; only as good as data; possibility of bias in selection of cases
In vivo (e.g., Dunbar)—thinking	Real situations	Lack of control; quality of data; highest level?
In vivo—personality	Real creators	Correlational study; highest level?
In vitro (e.g., Dunbar)—discovery	Control; approaches real situation	Artificiality; is situation too structured by experimenter?
In vitro—personality (undergraduates tested)	Control	Assessment of creativity depends on validity of test; correlational study
Laboratory experiment—problem solving	Control and analysis of phenomena	Artificial situation; is it real creativity?

Albert Einstein, Pablo Picasso, Igor Stravinsky, Martha Graham, T. S. Eliot, and Mahatma Gandhi. Each exemplifies one of Gardner's proposed multiple intelligences: interpersonal (able to achieve a high level of self-understanding; Freud); logical-mathematical (Einstein); spatial (Picasso); musical (Stravinsky); bodily-kinesthetic (Graham); linguistic (Eliot); and intrapersonal (able to achieve a high level of understanding or of relating to others; Ghandi). More recently, an eighth intelligence has been added (Gardner, 2003)—naturalist (able to discern patterns or regularities in the natural environment; Darwin would be an example)—and possibly a ninth.

Use of biographical data avoids some of the problems arising from subjective reports; most critically, biographies usually are based on verifiable historical records. Gardner used those biographies to derive a number of conclusions concerning how each individual brought about his or her groundbreaking work. For example, Gardner emphasizes the role of a support group in providing a sympathetic arena in which the individual can introduce radical ideas. The major strength of a biographical study is obvious: It provides direct study of individuals of the highest levels of creative accomplishment.

One possible limitation to the biographical method, however, is the quality of the data that are available; any incompleteness or inaccuracy can severely restrict the studies that one can carry out. A quantitatively oriented investigator is also left unsatisfied with biographies as the basis for an analysis of creative thinking. Biographies, while undoubtedly informative, provide little in the way of quantitative data to serve as the basis for scientific theorizing; for example, there are no data tables or graphs in the 400-plus pages of Gardner's book.

Investigators have also used biographical information to make retrospective assessments of psychological characteristics of creative individuals of the highest order. As an example, Jamison (1993; see also Weisberg, 1994) has used biographical information as the basis for diagnoses of bipolarity (manic-depressive illness) in many individuals of great creative renown, such as Vincent Van Gogh and George Gordon, Lord Byron. We will discuss such retrospective diagnoses, which can serve as a kind of personality assessment, in several places later in this book. The obvious strength of such methods is that once again one is dealing directly with creative individuals of the first rank. Using such methods raises problems, however, of several sorts. As with other biographical studies, one is dependent upon the quality of the available information. In addition, attempts to assess psychological characteristics from biographical information must be indirect, since we cannot test an individual who is no longer alive, and such indirect assess-

ments are subject to problems in interpretation of the historical record. For example, if a doctor's report on a nineteenth-century poet describes him as being "in a frenzy," does that phrase mean the same thing as it would if it were used today?

So biographical studies have several problems that may limit their usefulness. However, if we wish to examine the personality or other psychological characteristics of eminent individuals who are long dead, we may have no choice but to use such information. We can learn something from such studies, but it is important to keep in mind the limits to the conclusions that we can draw from them.

Historical Case Studies: Archival Data and Reconstruction of Process

A number of studies have examined individual cases of creative achievement, such as Gruber's (1981) analysis of Darwin's development of the theory of evolution through natural selection (see also Holmes, 1980, 1996, and Tweney, 1989). Gruber's groundbreaking and important study was based on *archival data* (i.e., Darwin's notebooks), and his work stimulated much interest among psychologists in case studies of creative thinking (e.g., Perkins, 1981; Weisberg, 1986). One difference between Gruber's historical case study of Darwin and Gardner's (1993) biographical studies is Gruber's concentration on Darwin's *theory*. That is, one could contrast Gruber's and Gardner's perspectives by saying that Gruber presented a biography not of Darwin but of the theory of natural selection. In the historical-case-study approach, the emphasis is less on the creator than on the work. In addition, since Gruber's study was based on Darwin's own notebooks, there is no question as to the accuracy of the data.

Gruber (1981) drew a number of important specific conclusions about Darwin's creative process from his case study, which will be discussed later. He also made a general proposal on the basis of his analysis of Darwin: that the creative process is unique in each individual and no generalizations may be made about the creative process or the creative person. In Gruber's view, each creative accomplishment is carried out by a unique individual working in a unique set of circumstances. This is obviously a conclusion of great potential importance. However, analysis of historical case studies may make it difficult to discover generalizations about the creative process, because one limitation of that method is that it provides little in the way of data to be analyzed in the search for generalizations. That is, historical case studies are usually limited to qualitative analyses. As in Gardner's (1993) biographical studies, there are no data tables in Gruber's study of Darwin. Gruber may be correct in his claim that no strong generalizations will come out of historical case studies of creative thinking, but the only way

to know is to carry out more of them and to try to use a method that allows any possible generalizations to become clear. So historical case studies may tell us much about a specific person, but they may make it difficult to draw conclusions about creative people in general. In addition, carrying out a case study means that the researcher depends on the availability of information over which he or she has no control. What one gains in authenticity, one may lose in control.

Historiometric Methods

A number of researchers have applied quantitative methods to historical data in order to formulate and test causal hypotheses concerning creativity, using what has been called *historiometric* analysis (Simonton; e.g., 1999; Martindale, e.g., 1990; Hayes, 1989). The term *historiometric* means “measuring history.” As an example, Simonton investigated the influence of war and other social upheaval on creativity, by breaking the last two millennia into 20-year “epochs” and determining for each the frequency of social unrest and of creative accomplishment, based on such measures as the number of years in each epoch in which active war was carried out, and the number of creative individuals who flourished during each epoch. Using statistical methods, Simonton has attempted to distill causal relations from historical data and has concluded, for example, that occurrence of war involving a nation results in a decrease in creative accomplishment in that nation in the following epoch. Also, the occurrence of a significant number of individuals of high levels of accomplishment during one epoch is positively related to the level of accomplishment in the next generation, which Simonton takes as supporting the idea that one generation serves as role models for the next. Similarly, Martindale (1990) has measured changes in the content of French poetry over many generations of poets, in order to test hypotheses about the creative process.

In a further variation on this perspective, Hayes (1981, 1989) examined the role of experience—what he called “preparation”—in the production of creative masterpieces. Based on available biographic information, Hayes measured the amount of time that elapsed between an individual’s beginning a career in the fields of musical composition, painting, or poetry, and the production of that individual’s first “masterpiece.” Hayes defined a masterpiece in objective terms as, for example, a musical composition that has been recorded relatively frequently, a painting that is cited in reference works, or a poem that is included in compendia. There was a consistent relationship between time in a career and production of the first masterpiece: All of the individuals in all of the domains that were studied required significant periods of time—approximately 10 years—before production of

their first masterpiece. This finding has been codified as the “10-Year Rule.” Thus, Hayes provided quantitative evidence for the claim that immersion in a discipline is necessary before an individual can produce world-class work (see Weisberg, 1999, 2003, and Chapters 4 and 5 in this volume for further discussion).

The strength of the historiometric method is obvious: One is dealing directly with creative accomplishment at the highest level. One weakness is one that we have already seen in examining other case studies: the availability of data. If no data are available concerning some individual or individuals, say, then one cannot set up a situation that will produce the relevant information. However, if data are available—as was the case for Simonton, who was able to obtain necessary data on the amount of war and the amount of creative innovation of many epochs of Western civilization—then historiometric case studies can provide a level of analysis beyond that of biographical or historical case studies. Obviously, Simonton (1999) was not able to manipulate the occurrence of war, and Martindale (1990) was not able to control the variables that might have affected the poets he studied, but through different types of statistical analysis those researchers were able to draw some relatively strong conclusions about causal relations in their studies. For example, if it is true that war results in a decrease in creative accomplishment, then one can predict a negative correlation between the intensity of war in one epoch and the amount of creative achievement in the next one. So in carrying out a historiometric case study one is not simply at the mercy of the already available data with no way to determine possible causal relations.

Quantitative Case Studies

Historiometric methods have usually been applied to the analysis of groups of individuals, over relatively long periods of time. This general approach can, however, be applied to the study of the creative process in individuals; my students and I have analyzed several individual case studies using methods similar to those of Hayes (1989), Martindale (1990), and Simonton (1999; Buonanno & Weisberg, 2005; Ramey & Weisberg, 2004; Rich & Weisberg, 2004; Weisberg, 1994, 1999, 2004). Two examples of this approach were seen in the case studies discussed in Chapter 1, the double helix and *Guernica*. Bringing a quantitative orientation to case studies (even when it is difficult, as in the case of DNA, to actually quantify things) sometimes results in discoveries that would not have been apparent from only qualitative presentations of historical information. A number of other quantitative case studies will be presented at various points in this book. Quantitative case studies have the obvious strength of the other

types of case studies already mentioned: One is studying creativity at the pinnacle. However, one is also at the mercy of the data that are available; sometimes all the ingenuity in the world will not bring forth data on a case of interest. For example, if one were interested in determining whether Picasso was thinking about *Minotauromacy* when he was painting *Guernica* (see Chapter 1), one could not find an answer based on the sketches and photos available. One would need more, and, since that information is not available, it seems (at least at the present time) that one will never be able to answer that question.

A second potential difficulty with quantitative case studies, which actually is relevant for any type of case study, including biographical and historical case studies, is that there are concerns about selectivity in choosing the cases to examine. For example, in responding to the results from the examination of the development of *Guernica*, students and other researchers have me asked if those results are (1) representative of Picasso's creative process (that is, did his other works develop similarly?); (2) representative of the creative process in painting (that is, did the works of other artists develop similarly?); (3) representative of the creative process in general (that is, did works in other domains—*invention*, say, or *science*—develop in similar ways?). People are concerned that the specific case study chosen might lead to a conclusion that is not really general. This is an important concern, and the only ways to counter it are, first, to investigate as wide a range of case studies, in as wide a range of domains, as possible. Other case studies will be presented later in this book. Second, those case studies should be carried out by as many different investigators as possible, so that the possible biases of any one investigator will not shape any conclusions that are drawn. Carrying out many case studies also has the additional benefit of making it more likely that any conclusions will have wide generality.

Studying High-Level Creativity in Real Time: “In Vivo” Investigations

Another way to try to study the creative process at the highest level is to observe it directly. Over several years, Dunbar (e.g., 1995, 2001) observed the ongoing activities in four high-level research laboratories in molecular biology. The directors of those labs, all scientists of high repute, gave Dunbar complete access to the laboratories' activities. He regularly attended and recorded laboratory meetings, discussed ongoing work with the scientists involved, and was given copies of research papers in various stages of completion. On the basis of those observations, Dunbar made several discoveries concerning the processes underlying creative work in those laboratories (2001). As one example, he found that a scientist's conception of his or her own work sometimes changes radically as the result of input

from colleagues during laboratory meetings in which data and analyses are discussed. The scientist alone is less likely to try to deal with recalcitrant data. Dunbar was also able to quantify various aspects of the activities in the laboratories and so was able to test some rigorous hypotheses concerning factors influencing creative activity. Thus, one could say that Dunbar has shown how scientific research can be studied *in vivo*, and his investigations have produced a number of important results.

One obvious strength of Dunbar's research and other studies like it is that there is no question that the object of the study is real creativity. However, although the laboratories studied by Dunbar are directed by scientists of strong reputation, those individuals and their research groups are as yet nowhere near attaining the significance of Einstein, Darwin, and the like, and so there is still a question of whether the conclusions from Dunbar's research would illuminate those more illustrious individuals. Therefore, we still need some method or methods that allow us to directly study the creative process in historically significant individuals. Dunbar's method also does not allow the researcher control over possible extraneous variables, and it also does not enable the researcher to manipulate any variables of interest.

Psychologists interested in the creative personality have carried out investigations similar to that of Dunbar, asking creative individuals in many domains—scientists, artists, architects, novelists, poets—to complete personality inventories of various sorts in order to determine personality characteristics associated with creative accomplishment (e.g., Feist, 1993, 1999). Research in this area will be discussed in Chapter 10. The individuals studied in those investigations are usually chosen on the basis of their career accomplishments. They may be nominated by members of the field of interest (e.g., chairs of departments of psychology might be asked to nominate psychologists who have made creative contributions to the profession). These studies have provided a wealth of information concerning the characteristics of individuals at the top of their respective fields. This information is no doubt potentially valuable in understanding creativity, although here too one can also raise the question of whether the results are relevant to individuals such as Picasso and Edison and the like, who cannot be studied in that way.

There are also limitations to the kinds of conclusions one can draw from *in vivo* studies of the creative personality. For example, Feist (1993) concluded that an “arrogant thinking style”—the tendency of an individual to work alone and to be less than completely receptive to the opinions of others—was characteristic of the scientific researchers of high creativity whom he studied. The question arises as to whether having that style of thinking *caused* those individuals to be creative, and that question cannot

be answered by Feist's study. We do not know if the individuals had that style from the beginning—or at least early in their lives, before they began their scientific careers—in which case it might have played a role in causing their creative accomplishments. It is possible that the arrogant thinking style developed in response to or as part of their success as scientists, which means that the personality style was the result, not the cause, of their creativity. In these ways, *in vivo* studies of the characteristics of creative individuals are limited in the kinds of inferences they support.

Laboratory Investigations of the Creative Process and Creative Individuals

Modern psychology has a strong tradition as a laboratory experimental science, and researchers who study creative thinking have carried out experimental studies of various aspects of creativity. Typically, but not always, these center on the study of undergraduates carrying out some task requiring creative thinking, such as the problems in Figure 1.1C. A significant strength of experimental studies is that one can exert control over extraneous variables that might contaminate the interpretation of the results, and one also has control over the variables of interest, so one can draw conclusions concerning cause-and-effect relationships. In one example of an experimental study of creativity, Amabile, Hennessy, and Grossman (1986) asked children to tell a story in response to a series of pictures in a book. The stories were rated for creativity by teachers. Some of the children agreed to create the stories in order to earn an extrinsic reward: They were allowed to play with a Polaroid camera if they agreed that they would tell the story afterward. They “contracted” to create the story in order to be given access to the camera. A second group simply played with the camera and then created the story, with no connection made between the two activities. The children who created the stories because they had contracted to do so—the children who created because of an extrinsic reward—produced stories judged less creative than those produced by the children whose creative activities were motivated only by their interest in the task.

Laboratory studies of creativity are potentially valuable because they allow researchers to make strong claims about cause-and-effect relationships among variables. Amabile and colleagues (1986), for example, were able to conclude that working for extrinsic reward had a negative effect—a causal effect—on creativity. Such conclusions are not possible in many of the other sorts of investigations already discussed (see Table 2.1). However, this strength does not mean that researchers studying creativity should rely only on experimental methods and abandon all others, because there are limitations on how much information one can get from laboratory studies. Such

renowned creative individuals as Picasso, Mozart, Edison, and Einstein are also part of the population of creative thinkers one wishes to understand, but one may not be able to draw conclusions about such individuals on the basis of controlled investigations of undergraduates or schoolchildren. As I have mentioned several times, it is my belief that the same cognitive processes are involved in all acts of creativity. If correct, that view would mean that one could learn about Picasso or Edison by studying undergraduates in the laboratory. However, at this point that is only an unsupported belief. In order to provide support for it, it is necessary to also study creative thinking at the highest level, if at all possible, to show that the cognitive processes involved in highest-level creativity are indeed the same as those used by undergraduates in the laboratory or by schoolchildren working for intrinsic versus extrinsic rewards. So experimental methods are only one of several that creativity researchers use.

“In Vitro” Investigations of the Creative Process

An interesting method has been developed that attempts to bridge the gap between *in vivo* studies of creative individuals at work and controlled laboratory investigations. Dunbar (1995) calls the method the *in vitro* method, as an analogy to the situation in biological research where a phenomenon of interest is brought out of the organism in which it usually occurs and is studied in a glass (*vitro*) dish in the laboratory. If the biological researcher has isolated the basic mechanism of interest, the *in vitro* method allows him or her to exert some control while examining a situation of potential importance. In using the *in vitro* method to study creativity, one takes important pieces of information from a historically significant discovery and presents them to undergraduates under controlled conditions. The questions of interest are whether the students produce the same discovery and what manipulations are necessary in order to make it possible for them to do so.

In one use of an *in vitro* design, Dunbar (1995) examined undergraduates' responses to a situation in which they had to “discover” the regulatory function of certain genes in a microorganism. Monod and Jacob were awarded the Nobel Prize in 1965 for their discovery of the existence of regulator genes, which control the activity of other genes through inhibition. Regulator genes turn off other genes until the products of those genes are needed. Monod and Jacob believed originally that some genes served to stimulate other genes, and the discovery of inhibition was surprising to them. In Dunbar's studies, undergraduates were first taught about genetic influences based on genes' stimulating or activating other genes. That put them in a state of knowledge similar to that of Monod and Jacob when

they had begun their research. The undergraduates were then given a new situation to work through, in which they had to determine the functions of three new genes. The entire experiment was done as a computer simulation, without live organisms. The students were able to conduct virtual experiments of various sorts, based on availability of information, in order to test hypotheses about how the genes worked. Unbeknownst to the students, not all the new genes worked through activation. In the first study, two of three genes in the organism worked through inhibition of other genes; in the second, one of three genes worked through inhibition.

The results indicated that the students were able to develop hypotheses concerning the functioning of the new genes, but the ease with which this occurred depended on the relation between their knowledge and the new information. When two of the new genes were inhibitory, there was a much greater likelihood that the students would discover the inhibitory effect, compared to when only one was inhibitory and the other two were excitatory. Dunbar (1995) concluded that the students' experience with excitatory genes got in the way of their exploring the possibility of inhibitory relationships between genes. When there was only one excitatory gene in the group of three new genes, there was a greater chance that the student investigators would explore other possibilities. Thus, Dunbar tested several hypotheses concerning how creative thinking might work by taking information from a case study and bringing it into the lab, allowing him to exert control over the potentially relevant variables, which he could not do in a historical case study of Monod and Jacob.

The *in vitro* design may serve as an intermediate method between the tightly controlled lab experiment and the less-controlled historical case study. One caution concerning the *in vitro* design is that the situation simulated in the laboratory may not always be a good match for that in which the original researchers found themselves. That is, how close is the situation of the undergraduates in the laboratory to that of Monod and Jacob in the laboratory in 1965? If the situations are not comparable, then the *in vitro* lab situation may have little or no connection to the historically important situation that one hopes to understand.

One recent interesting method somewhat analogous to the *in vitro* method involves developing computer models that make scientific discoveries (e.g., Langley, Simon, Bradshaw, & Zytkow, 1987). In those studies, computer programs are developed that can analyze data in various ways that are designed to be close to the methods available to a historically significant creative figure. The program is then given data that correspond to those that the original researcher had, and the question is whether the computer program will discover in those data what the original researcher did. We will

discuss several programs of this sort later, but it is worth noting here that one of the objections raised to such studies is that the computer program is fed relevant data, whereas the original researcher had to determine in the first place exactly which data were relevant to the problem he or she was facing. This objection can also be raised concerning *in vitro* simulations with undergraduates, and it points to a possible problem: In order to gain control over the situation, the researcher may have to control things too tightly.

Methods of Studying Creativity: Conclusions

Research on creativity uses a wide range of methods (see Table 2.1); studies of the creative process have ranged from randomly chosen undergraduates solving problems or puzzles in the psychological laboratory, to real-time studies of scientists working in their laboratories, to case studies of significant advances, to *in vitro* laboratory simulations of seminal creative advances. Studies of the creative person have also ranged over a wide variety of methods and participants, ranging from examination of the personality characteristics of undergraduates selected as creative because of their responses on a creativity test, to studies of the personalities of scientists and artists who have been nominated by their peers as being highly creative, to attempts to study retroactively the personality of individuals of acknowledged greatness whom we cannot test or interview directly. In all those methods, the data are *objective*—that is, they are available for all to see—and thus can support theorizing concerning the creative process. We have also seen that each of those methods has strong points and weaknesses, so we cannot say that only one or two methods are useful in the study of creativity. Depending on the question one wishes to investigate, one chooses the method or methods best suited to answering that question, and one tries to keep in mind the possible weaknesses brought about by the methods one is using and to draw conclusions that are sensitive to the strengths and weaknesses of those methods.

Researchers sometimes also rely on reports by creative individuals concerning how they achieved their seminal innovations. I am skeptical about the value of subjective reports concerning the creative process, even those reports given by individuals who have reached the highest levels of creative achievement. As we have seen, many questions can be raised about several subjective reports that have been cited many times in the literature as evidence for various aspects of the creative process. We will in a number of places have occasion to review other such reports, because they have been brought forth as support for theoretical proposals. In each case, the reports will be examined carefully in order to determine whether they can support

the conclusions being drawn from them. Such scrutiny is necessary if our attempts to understand creative thinking are to be on a firm foundation.

So far in these two chapters we have examined in some detail the development of two creative advances of the first rank, defined the relevant concepts, and discussed the strengths and weaknesses of the broad range of methods used to study creativity. We now turn to a brief review of the broad range of theories that investigators have proposed to explain creativity.

An Introduction to Theories of Creativity

For as long as humans have thought about where new ideas came from, it has been believed that truly novel ideas that produce creative leaps forward must come from extraordinary sources. Often, the very people who produce those ideas have no awareness of where the ideas came from (“How on earth did I think of that?”). Therefore, in order to understand how that idea came about, many of the creators as well as many theorists have postulated processes outside ordinary conscious thinking that produce the ideas and present them to the conscious thinker. I have found it useful to divide the history of theorizing on creativity into several more or less separate streams, each of which focuses on one general idea or issue, as shown in Table 2.2. Reality, of course, is not as clear-cut as the outline in Table 2.2: The streams are not separate; there is cross-talk between them, as will become evident from later discussions. However, for now the outline in Table 2.2 will serve to orient us to the issues to be dealt with.

The Gods and Madness

The question of the origin of new ideas has been of interest for several thousand years; early scholars, among them Plato and Aristotle, speculated on how creative ideas came about (Murray, 1989). It was proposed originally by the Greeks that creative ideas were gifts from the gods. Specifically, the Muses—nine daughters of Zeus, each of whom was in charge of a separate domain—played a central role in producing novel ideas. This meant that not only did the ideas originate outside the normal thinking process, they actually originated outside the person. The person served as the *messenger* or *conduit* through which the ideas were presented from the gods to the rest of us. The residue of this school of thought is seen whenever someone says that he or she “got an inspiration” or was “inspired” in describing the appearance of a creative idea. *Inspiration* means “breathing in”; one received inspiration from the Muses, because they breathed creative ideas into people.

It was believed that an individual in the throes of creative activity was out of his or her mind, in the sense that an outside source was providing the

The Study of Creativity

Table 2.2 Theories of creativity

Theoretical stream	Issue(s)
The gods and madness	Muses: Plato, Aristotle \Rightarrow genius and madness: modern interest in creativity and psychopathology
Unconscious thinking: associative unconscious; unconscious processing	Freud: unconscious conflicts in creativity, associative unconscious Genius and madness: creativity and psychopathology Poincaré: unconscious processing ; incubation and illumination Wallas: stages of creative thinking; Modern interest in associative unconscious and unconscious processing
Leaps of insight in creativity: the Gestalt view	Insight in problem solving and creative thinking Productive versus reproductive thinking
Psychometric theories	Guilford: testing creativity; divergent thinking; creative personality Other creativity tests Confluence models of creativity: Cognition (general creative thinking and domain-specific thinking); personality; environmental (social) factors Amabile; Sternberg & Lubart
Evolutionary theories	Campbell: blind variation and selective retention Simonton
Cognitive theories	Newell, Shaw, & Simon: creative thinking and problem solving Expertise in creative thinking Perkins: Ordinary thinking in creativity

ideas (Murray, 1989). Plato, for example, described the poet in this way. His description did not mean that the poet was crazy; rather, the creation was occurring as the result of processes outside of the poet's mind—the inspiration from the gods. However, by the generation after Plato, his student Aristotle had come to the conclusion that states of mental illness could play a role in creativity. In more recent times, beliefs about the sources for creative ideas moved away from the supernatural to internal processes, but the underlying notion—that processes beyond ordinary day-to-day thinking

are involved—still remains. Examples of such processes are (1) unconscious thinking, (2) psychopathological thinking, (3) intuitive leaps of insight, and (4) divergent thinking. In addition, some theorists have gone beyond a concentration only on creative thinking processes and also emphasize the roles of personality and environmental factors in creativity.

Unconscious Thinking

We are all familiar with the Freudian conception of the unconscious. Freud applied his ideas to creativity. In addition, a different conception of unconscious processing has also been discussed in the context of creativity (Poincaré, 1913).

The Freudian View: Associative Unconscious

The notion that unconscious thinking is important in creativity has been with us for a long time, at least since Freud applied his theoretical ideas to the understanding of creativity, and others have carried forward various aspects of the Freudian view to the present (e.g., Csikszentmihalyi, 1996; Gedo, 1980; Koestler, 1964; Rothenberg, 1979; Simonton, 1988; 1999). From the Freudian perspective, unconscious needs and conflicts played an important role in determining both the subject matter that creative individuals dealt with and the way they portrayed it. As an example, consider Leonardo's portrait of the *Mona Lisa*, with that enigmatic not-quite-smile that is more distant than welcoming. Freud proposed that the emotional tone of that smile was the result of unfulfilled needs stemming from Leonardo's early childhood. He was orphaned at an early age, so Freud concluded that the reason that the *Mona Lisa* looks distant is because Leonardo was expressing through the painting his feelings about his lost mother, who would forever be out of reach. Thus, in Freud's interpretation, deep feelings from Leonardo's childhood affected his choice of subject matter and how he portrayed it.

A modern example of the influence of the Freudian view on theorizing about creativity is seen in Gedo's (1980) analysis of Picasso's creativity. Gedo proposed that the origins of many of Picasso's works could be traced to childhood trauma. As one example, Gedo proposed that *Guernica* was an expression of several conflicts from early in Picasso's life, concerning Picasso's relationship with his mother and his younger sister. Gedo believes that the women in *Guernica* represent Picasso's mother and the dead baby represents Picasso's younger sister, whose arrival on the scene served to take the spotlight from Picasso in a female-dominated household. Therefore, the portrayal of the baby as dead represents Picasso's unconscious wish that his sister be removed. He could not actually get rid of her in real life when she arrived, but, years later, in an attempt to satisfy the still-simmering need

from childhood, he did so in his art. In theories of creativity based on the Freudian concept of the unconscious, the creator cannot tell us how and why certain ideas surfaced in his or her work, because unconscious connections among ideas lead from one to the next. Since we are not aware of those unconscious connections, the creator on a conscious level knows nothing about where his or her ideas came from. Thus, I will refer to this class of theories as postulating an *associative unconscious*.

The Freudian view, with its emphasis on unresolved conflicts and early trauma, is related to the theory that psychopathology plays a role in creativity. It is not a very large leap to assume that, since the creative individual's conflicts are close enough to the surface that they show themselves in his or her works, those conflicts may manifest themselves elsewhere in the person's life as well—specifically, in psychopathology. Among the sorts of mental illness that have been postulated as being related to creativity are schizophrenia and bipolarity (manic depression). In addition, Eysenck (e.g., 1993) has proposed that people who are high in the personality trait of *psychoticism* have a greater tendency to be creative. Psychoticism is an underlying inherited tendency to become mentally ill when placed in a stressful environment. Psychoticism is not *psychosis*: People high in psychoticism are normal, although a bit eccentric and hard to get along with. Eysenck found that normal people high in psychoticism exhibit certain characteristics—among them a looseness of thinking—that he believed are potentially important for creativity. We will examine the Freudian theory of creativity and the related views on genius and madness in Chapter 7.

Unconscious Processing

A different conception of the role of unconscious thinking in creativity was proposed at the end of the nineteenth century by Henri Poincaré (1854–1912), a world-renowned mathematician and scientist (Miller, 1996). In studying his own creative achievements, Poincaré concluded that thought processes that occurred outside his consciousness had played a critical role in his own creative thinking. Poincaré's view centers on the phenomena of *illumination* and *incubation*. Illumination is the sudden appearance in consciousness of a creative idea or solution to a problem when one has not been thinking about the matter consciously—an Aha! experience. Poincaré (1913) reported several illuminations when describing his creative achievements. The occurrence of illuminations was taken as evidence for unconscious processing by Poincaré and many who have followed his lead. If Aha! experiences do not come from conscious thinking, then, so the argument goes, where else can they come from? It has been proposed that *unconscious incubation*—thinking about the problem unconsciously while

consciously thinking about something else—is the explanation for sudden illumination.

Poincaré's view is not the same as the Freudian view, because Poincaré did not assume that the connections among ideas were any different in unconscious thinking. That is, Poincaré's view was not based on the premise of the associative unconscious. The only difference between conscious and unconscious processing, according to Poincaré, was that multiple thought processes could go on at once; in modern terms, the creator was assumed to be capable of carrying out parallel processing, with consciousness comprising only one stream of that processing. Thus, it is important to differentiate between *unconscious associations* (postulated by Freud and theories evolving from his work) and *unconscious processing* (postulated by Poincaré and his followers). Furthermore, those two views are not mutually exclusive; both the associative unconscious and unconscious processing may be true. We will discuss those issues further in Chapter 8.

Wallas (1926) elaborated Poincaré's ideas in a four-stage model of creative thinking, which can still be found in modern theorizing (e.g., Csikszentmihalyi, 1996). Modern psychologists have become increasingly interested in the role of unconscious processing in cognition, so the ideas on unconscious processing in creativity introduced by Poincaré have become more mainstream than ever before. The idea of unconscious processing has also had an impact on analyses of creativity beyond psychology. As one example, Kantorovich (1993), writing in the philosophy of science, has invoked unconscious processing (e.g., Simonton, 1995) as support for a theory of scientific discovery. Also, Miller (1996) has used unconscious processing as the basis for an analysis of developments in the history of science. Chapter 8 will examine evidence for unconscious processing in creativity.

Leaps of Insight in Creativity: The Gestalt View

An idea related to the role of unconscious processing in creative thinking is the notion that problems are sometimes solved, and creative ideas in general sometimes come about, as the result of leaps of insight, a notion introduced broadly into psychology by the Gestalt psychologists early in the twentieth century. Who among us has not had such an experience, if only when suddenly remembering a name that has slipped our mind? Leaps of insight, or *Aha!* experiences, come about when a new idea seems to flash into consciousness from nowhere, bringing with it a way of looking at a problem that is totally different from what one had just been thinking about. According to the Gestalt psychologists (e.g., Wertheimer, 1982), true creative advances require that the person use *productive* thinking to go beyond what had been done before. Staying with what had been done

before was dismissed as mere *reproductive* thinking, in the sense that it *reproduced* what had been done before. Furthermore, if one relied on the past and “mechanically” reproduced habitual responses, one would not be able to deal with the particular demands of any novel situation that one might face, and would therefore be doomed to failure.

The notion of leaps of insight is related to other views of extraordinary thinking, because sometimes those leaps are explained by positing an unconscious processes. Poincaré, for example, who as we know was one of the first to postulate unconscious processing in creative thinking, brought that theory forth in order to provide an explanation for several leaps of insight that he experienced. In more modern versions of this view, Csikszentmihalyi (e.g., 1996) and Simonton (e.g., 1988, 1999) both postulate unconscious processes as the basis for creation of new ideas. However, the notion of leaps of insight can be examined independently of questions concerning conscious versus unconscious processes in creative thinking, because the occurrence of leaps of insight does not necessarily mean that unconscious thought processes are involved. We will examine the question of leaps of insight in creativity in Chapter 6, separately from the question of unconscious processes.

Confluence Theories of Creativity: Divergent Thinking and the Creative Personality

There was a significant change in the direction of research on creativity around 1950, as the result of Guilford’s (1950) presidential address to the American Psychological Association. Guilford, an expert on intelligence testing, surprised many people by proposing in his address that psychology had not spent enough time examining thinking that went beyond the kind of thinking measured by IQ tests—that is, creative thinking. He outlined a theory of how creative thinking worked, and, using intelligence testing as a guide, he proposed a set of tests that could be used to measure creative-thinking ability and to identify individuals with creative potential. One important component of creativity is the ability to see that a problem exists in some area. For example, if two individuals use the same appliance and one is dissatisfied with its performance, he or she might attempt to create an improved version of that product. That person has demonstrated *sensitivity to problems*, which may be necessary to set the creative process in motion. A person who sees no problem with the appliance will have no chance to create something.

Concerning the role of knowledge in creative thinking, Guilford reasoned, similarly to the Gestalt psychologists, that an important step in the creative process must be a breaking away from the past, which is the func-

tion of what he called *divergent thinking*. As the name implies, this type of thinking *diverges* from the old and produces novel ideas, which can serve as the basis for a creative product. Once divergent thinking has served to produce multiple new ideas, then *convergent thinking* can narrow down the alternatives to determine the best one. The highly creative individual is assumed to be high in divergent-thinking ability (e.g., Csikszentmihalyi, 1996); that is, the highly creative individual is creative, at least in part, because he or she is capable of producing many novel ideas.

It must be emphasized that there are two uses of the term *divergent* in the context of discussions of creative thinking. On the one hand is the ordinary usage, as when we say that a great creative advance, like Watson and Crick's discovery of the double helix, *diverged* from what others at the time had been thinking about. In the sense of the new product being different from the old (*diverging* from the old), that use of the term is based on ordinary language and is completely straightforward. However, there is a second use of *divergent*, as exemplified in the phrase *divergent thinking*, proposed by Guilford (e.g., 1950) as part of his theory of creative thinking. In this case, one is referring to a *special kind of thinking*. In Guilford's view, creative thinking works in two stages: Divergent thinking is the first stage, which produces numerous ideas that then serve as the input to convergent thinking, the second component of the process. Convergent thinking takes the ideas produced by divergent thinking and narrows them down into a workable product.

It is this second meaning of *divergent*—*divergent thinking as a theoretical term*—that I will be referring to numerous times in this book. Creative products obviously diverge from the past, and therefore they are by definition the result of thinking that can diverge from the past (the first use of *diverge*). However, that conclusion does not mean that creative products are *ipso facto* the result of divergent thinking as presented in Guilford's theory, where it means a special type of thinking skill. That is, one might be able to produce new things without using a special kind of thought process that breaks away from the past.

Guilford's (1950) work was the stimulus to the *psychometric* stream of creativity research, which has focused on measuring the psychological characteristics of creative people (*psychometric* means “measuring the mind”; Feist, 1999; Plucker & Renzulli, 1999). Many people took Guilford's proposal to heart, and his ideas were carried forth in a number of ways. First, Guilford and others used his tests in attempts to measure the thought processes underlying creative thinking. Second, other investigators developed their own tests (e.g., Torrance, 1974; Wallach & Kogan, 1965), which differed from Guilford's in various ways. In addition, current theoretical analyses of

creative thinking sometimes assume that it is based on divergent thinking, even if that term is not explicitly used. For example, Simonton (1999, p. 26) proposes that the creative process must begin with “the production of many diverse ideational variants.” Those “ideational variants”—that is, numerous and varied ideas, produced presumably as a result of divergent thinking in Guilford’s terms—provide the basis for the thinker’s ability to deal with the new situation that he or she is facing. Guilford’s ideas on testing for the potential to think creatively, and research that followed from those ideas, will be critically reviewed in Chapter 8.

In addition to his discussion of types of thinking processes that might underlie creativity, Guilford proposed in his presidential address that a person’s personality was involved in making that person creative. That proposal stimulated work that tried to uncover the *creative personality*, that is, those aspects of personality that were prevalent in people of great creative accomplishment and that were not present to the same degree in “ordinary” people (e.g., Feist, 1999). It was proposed that those personality characteristics were important in the person’s innovations. For example, it was suggested that a flexible personality structure allowed a person to think flexibly, which was assumed to be necessary for the person to think creatively. Research on the creative personality will be reviewed in Chapter 9.

The psychometric perspective has led to the development of *confluence models of creativity*, which assume that creative products arise when there is a *confluence*—a coming together—of several factors, all of which are needed for creative production to occur: Creativity requires a person with a particular thinking style, knowledge base, and personality, who is in a particular environment (e.g., Amabile, 1983, 1996; Simonton, 1999; Sternberg & Lubart, 1995). It is assumed that thinking skills of various sorts are involved in creative thinking, both general creative-thinking skills and skills specific to the domain in which the person is working, such as painting versus science versus poetry. In addition, personal characteristics are assumed to be critically important in determining whether the person will put those thinking skills to use in the task of producing innovation. Finally, the environment can play a role in fostering or interfering with creative production. I will briefly sketch several influential confluence models here; they will be discussed in detail in Chapter 11. Two examples of confluence models of creativity are outlined in Table 2.3.

Amabile’s Componential Theory of Creativity

Amabile (e.g., 1983, 1996) developed an early theory that proposed that creativity was the result of the coming together of several components, some related to the person and others related to the environment,

Table 2.3 Two confluence models of creativity

Amabile's componential model				
Domain-relevant skills	Creativity-relevant skills		Task motivation	
Knowledge about the domain Required technical skills “Talent”	Appropriate cognitive style: Breaking set Keeping response options open Breaking out of performance “scripts” Knowledge of heuristics for generating new ideas: Try something counterintuitive Play with ideas Conducive work style: Concentrate effort Persistence Personality traits		Attitudes toward task Perception of one's own motivation for undertaking the task	
Sternberg and Lubart's investment theory				
Intellectual abilities	Knowledge	Thinking styles	Personality	Motivation
See problems in new ways	Domain knowledge; possibly negative	Legislative and global	Perseverance Risk-taking	Intrinsic Environment Supports innovation

including the social environment. She was one of the first theorists to incorporate social-psychological factors in thinking about creativity. The original theory developed by Amabile is presented in Table 2.3; in Chapter 9, I will discuss newer developments in this viewpoint. The first component in Amabile's (1983) theory consists of domain-relevant skills, which are skills relevant to the domain in which the individual is working. They include knowledge and technical skills, such as the ability to play a musical instrument or paint, as well as any talent that the domain demands. Some of those skills are based in innate abilities, while others are acquired through formal and informal education. The second component of the theory is creativity-relevant skills, which are skills that go beyond any specific domain and that can be applied to any domain in which one might be attempting to produce innovation. Creativity-relevant skills incorporate methods of *breaking set* during problem solving—that is, abandoning an unsuccessful approach to a problem—as well as knowledge of heuristics, or *rules of thumb*, for generating novel ideas. An example of such a heuristic is the guideline “When all else fails, try something counter-intuitive” (Newell, Shaw, & Simon, 1962).

The creativity-relevant skills are interesting because many if not all of them are based on the assumption that creativity depends on breaking away from the past. That is, one is not creative by staying within what one already knows. It seems that this notion is contradicted by the development of *Guernica* and the discovery of DNA, the two case studies presented in Chapter 1. In neither case did the creative thinkers reject the past: Rather, they built solidly on it. Obviously, two case studies cannot serve as the basis for a very general conclusion concerning the role of the past in production of the new, but those cases raise questions about the notion of creativity-relevant general skills that serve to enable the thinker to break from the past. This example also demonstrates the usefulness of having a database at the ready to apply to claims made by theories of creativity, as we will do in many places in this book.

According to Amabile (1983), the person's attitude toward the task is critical in determining whether he or she will respond creatively to it. If the person finds the task intrinsically motivating—that is, if he or she is interested in the task for its own sake and not because of some extrinsic reward that might come about as a result of successful performance—the chances of the person's producing an innovative response will be maximized. One hears individuals who work in creative fields—writers, artists, scientists—say again and again that they do what they do because they love it, and the fact that they make a living doing it is a bonus. There is also some evidence that being extrinsically motivated (carrying out a task in order to gain some reward, such as making money or winning a prize) may interfere

with creative work, although there have been conflicting findings in this area (Eisenberger & Cameron, 1998). In addition, if the person believes that he or she has independently chosen to work on the task, the outcome will be more creative than if the person believes that he or she is working on the task because of external pressures; the attitudinal/motivational components of the individual's status at any time are affected by the social environment. Amabile's discussion represented an early attempt to broaden the factors taken into account when attempting to understand creativity.

Sternberg and Lubart's Investment Theory of Creativity

Sternberg and Lubart (e.g., 1995; see also Rubenson & Runco, 1994) have proposed an analysis of creative thinking based on economic principles, which assumes that the creative thinker *buys low and sells high*. *Buying low* means that the creative thinker tends to propose ideas that are *unpopular but have potential for growth*. That is, the ideas could become popular with a little help. Due to the creative person's perseverance and ability to convince others of the value of the new ideas, they will become accepted. At this point, the creative thinker will *sell high*: He or she will *give up work on the now-popular idea, and move on to some now-unpopular idea*, to start the whole process again. Carrying the economic analogy further, Sternberg and Lubart propose that the person capable of creative production must possess several resources, some of which are as follows:

1. a set of intellectual abilities, with three of particular importance: the ability to see problems in new ways and go beyond ordinary ideas (which is similar to Guilford's (1950) divergent thinking); the ability to recognize which ideas are worth pursuing; and the ability to persuade others of the value of one's ideas
2. knowledge of the domain, although too much knowledge can interfere with generation of new ideas
3. a personality that allows you to think independently, which is necessary if you are to defy the crowd and advocate ideas that most others do not agree with
4. an environment that supports and rewards creative ideas

Evolutionary Theories of Creativity: Blind Variation and Selective Retention

Campbell (1960) proposed an analysis of the creative process based on Darwin's theory of evolution through natural selection. In Darwin's theory, species change randomly from one generation to the next due to such fac-

tors as mutation, which is a blind process. When a mutation occurs, there is no intelligence that directs it. Some of those changes, although produced blindly, have positive effects on the survival and reproductive abilities of the organisms that possess them. Those organisms will have a greater chance of passing on those characteristics to the next generation, since they have a greater-than-average chance of reproducing. Thus, those changes will be “selected” by nature, and the species will evolve.

In Campbell’s view, a similar process is at work in creativity. First comes the blind or random generation of ideas in response to some problem. In Campbell’s view, if true creativity is involved in dealing with some situation, then it must come about through the rejection of the past as the basis for constructing the new. Otherwise, the response will not be truly creative. Once an idea or ideas have been generated through a blind or chance process, each is then subjected to testing to determine if it meets the present needs. One or more ideas may then be retained, to be used in similar situations at a later time. Thus, Campbell proposed an evolution of ideas analogous to evolution of species, with similar underlying mechanisms.

Simonton (e.g., 1999) has taken Campbell’s basic ideas and elaborated them into a wide-ranging confluence theory of creativity, which incorporates the blind-variation-selective-retention mechanism with other components, such as cognitive factors, personality characteristics, and environmental influences on the creative process. Simonton’s theory has broad implications, as he has attempted to incorporate many phenomena within his theory. In the discussion of historiometric methods earlier in this chapter, we discussed his analysis of the influence of war on creativity. That is but one of the ingenious methods that he has developed in order to bring under scrutiny many phenomena that one would have thought were outside the range of methods of scientific psychology. We will examine the evolutionary perspective in detail in several later chapters, in conjunction with discussions of unconscious processing in creative thinking as well as discussions of confluence theories of creativity.

Cognitive Perspective: Creative Thinking and Ordinary Thinking

One idea that we have come across frequently in the theories of creativity that we have just reviewed is that a critical part of the creative process is to break with the past. In order to produce innovation, one cannot depend on what one knows, because true creativity demands something new. Because of this need to break with the past, many theories of creativity postulate extraordinary thought processes of one sort or another, because ordinary conscious thinking is closely tied to the past. The idea that creativity must

break with the past has become part of our culture, as evidenced in the often-heard comment about the need for “out-of-the-box” thinking in situations demanding creativity. The “box” that one must get out of is the constraints that the past, in the form of our experience and habits, imposes on us. Examples of such out-of-the-box processes are productive thinking and leaps of insight, divergent thinking, and set-breaking skills. The general perspective that underlies this view can be summarized as an assumption that a tension exists between creativity and experience.

The view of creativity that underlies this book assumes, in contrast, that creative products come about through the use of ordinary thinking processes; creative thinking is simply ordinary thinking that has produced an extraordinary outcome (Weisberg, 1986, 2003). From this perspective, when one says of someone that he or she is “thinking creatively,” one is commenting on the *outcome* of the process, not on the process itself. Although the impact of creative ideas and products can sometimes be profound, the mechanisms through which an innovation comes about can be very ordinary. This perspective is called the *cognitive* view because it was developed by Newell and Simon (e.g., 1972; Newell, Shaw, & Simon, 1962), leaders of the cognitive revolution in psychology that began in the 1950s. The cognitive revolution was so called because Newell and Simon advocated the study of cognitive processes—internal mental processes—as the avenue to the understanding of human functioning. One early expression of the cognitive view was a paper by Newell, Shaw, and Simon (1962) in which they proposed that creative thinking was basically the same as the thinking involved in solving ordinary problems.

My take on the cognitive perspective is a bit different from that of Newell and Simon; in my view, in order to understand creative thinking, we must consider ordinary thinking in a wider sense than just problem solving (Weisberg, 1986, 2003; see also Perkins, 1981). There may be times when we think creatively without specifically solving a problem, but we may still do so using ordinary thought processes. Furthermore, problem solving is a complex activity, made up of simpler cognitive components, and those components should also be considered if we are to understand the structure of creative thinking. Accordingly, I will begin the introduction to the cognitive perspective on creativity in Chapter 3 by examining the idea that ordinary thinking serves as the basis for creativity. This requires that we begin with a consideration of what “ordinary thinking” entails. We can then examine the DNA and Guernica case studies for evidence that ordinary thinking was involved in those seminal advances. This will lead to an examination in Chapters 3, 4, and 5 of details of the cognitive perspective on problem solving and creative thinking.

Theories of Creativity: Conclusions

We have now examined several theoretical perspectives that have played important roles in directing research on creativity. This relatively brief review has provided enough specifics to position each perspective in history relative to the others. As mentioned earlier, the theoretical positions are presented here as more or less separate entities, with no communication among them. However, there is often overlap among theories. For example, Simonton's evolutionary view is part of a larger confluence theory that he has developed, and the evolutionary perspective contains as one component the notion of unconscious processing (e.g., Simonton, 1999). Given this inevitable complexity, Table 2.2 will still serve as a useful outline to the views that will be discussed in more detail later.

CHAPTER

3

The Cognitive Perspective on Creativity, Part I

Ordinary Thinking, Creative Thinking, and Problem Solving

The view of creativity that underlies this book assumes that novel products come about through the use of ordinary thinking processes (Weisberg, 1986, 2003). From this “ordinary-thinking” perspective, when one says of someone that he or she is “thinking creatively,” one is commenting on the *outcome* of the process, not on the process itself. “Creative thinking” is simply ordinary thinking that has produced an extraordinary outcome (Simon, 1966). Although the impact of creative ideas and products can sometimes be profound, the mechanisms through which an innovation comes about can be very ordinary. We saw some evidence to support this conclusion from the case studies in Chapter 1. In discussing the discovery of the double helix and the creation of *Guernica*, it was not necessary to invoke extraordinary thinking in order to explain how those creative advances came about. As we have seen, this perspective on creativity is also called the *cognitive* view, because it developed as part of the cognitive revolution in psychology that began in the 1950s. I will use the terms *ordinary-thinking view* and *cognitive view* more or less interchangeably.

The cognitive revolution was so called because Newell and Simon (e.g., 1972; Newell, Shaw, & Simon, 1962), two of the leaders of the developments that came to be perceived as revolutionary, were advocates of the study of cognitive processes as the avenue to the understanding of human functioning. An early paper by Newell, Shaw, and Simon (1962) proposed that creative thinking was basically the same as the thinking involved in solving ordinary problems. My take on the cognitive perspective is broader

than that of Newell and Simon. I assume that, in order to understand creative thinking, we must consider ordinary thinking in a wider sense than just problem solving (Weisberg, 1986, 2003; see also Perkins, 1981). This wider perspective is necessary, I believe, because it is possible that there are times when we think creatively without specifically solving a problem, and I assume that we still do so using ordinary thought processes. In addition, problem solving itself is a complex activity made up of simpler cognitive components, and those components should be considered if we are to understand the structure of creative thinking.

Similarly, “ordinary” thinking is a complex activity, made up of components that we have not yet examined in detail. We have informally discussed the role of ordinary thinking in the case studies in Chapter 1, without specifying what is meant by ordinary thinking. If creative thinking is simply ordinary thinking writ large, then it is necessary to explore the structure of the latter in order to understand the former. Accordingly, I will in this chapter begin the introduction to the cognitive perspective on creativity with a consideration of what “ordinary thinking” entails. We can then reexamine the DNA and *Guernica* case studies for specific evidence that ordinary thinking was involved in those seminal advances. This will lead to an examination of details of the cognitive perspective on the relationship between ordinary thinking, problem solving, and creative thinking in the remainder of Chapter 3 and in Chapters 4 and 5.

Outline of the Chapter

I first examine the general and specific components of ordinary thinking and their implications for the understanding of creative thinking. I then reexamine the two case studies from Chapter 1 to show that the components of ordinary thinking can be found in each. I then turn more specifically to a consideration of the cognitive perspective on problem solving, as developed by Newell and Simon and their colleagues, in which solving a problem is seen as a process of *search* through a space of possible *moves*.

This perspective has developed in several ways over the 50 years since it was first proposed. First, there has been much research in the laboratory examining the methods used by humans working on problems of many different sorts. This chapter will concentrate on so-called weak heuristic methods of solving problems, which are methods that are very general and apply across a broad range of problems. I will examine those methods and the theory proposed to understand them, and will explore some of the implications for understanding creative thinking. Stemming from the interest in humans as information-processing systems, researchers have

also developed computer programs that they claim are able to carry out creative problem solving. Those programs are designed to reenact—to simulate—scientific discoveries, using weak methods of solving problems similar to those discovered in the laboratory by cognitive researchers. I will discuss examples of those programs and consider their theoretical and philosophical implications. Studies of problem solving from the cognitive perspective have also focused on the role of knowledge and expertise in high-level problem solving. This research will be considered in Chapter 4. In Chapter 5, I will use the cognitive perspective to direct an examination of the role of ordinary thinking in several additional case studies of creative thinking at the highest level.

Basic Cognitive Components of Ordinary Thinking

Although the term *thinking* is one that we all use all the time, when asked to define it precisely, one realizes that ordinary thinking is a complex activity. The phrase “I’m thinking” can refer to any of a large group or family of (not necessarily independent) activities, some of which are the following.

- *remembering* something
- *imagining* some event that you witnessed (which depends on memory)
- *planning* how to carry out some activity before doing it (which may depend on both imagination and memory)
- *anticipating* the outcome of some action (which may depend on imagination)
- *judging* whether the outcome of an anticipated action will be acceptable (which may depend on imagination and judgment)
- *deciding* between two alternative plans of action (which may depend on imagination and judgment)
- *determining* the consequences of some events that have occurred, through deductive reasoning (which may or may not depend on imagination)
- *perceiving* a general pattern in a set of specific experiences, through inductive reasoning
- *comprehending* a verbal message
- *recognizing* that two statements are contradictory
- *interpreting* a picture or diagram

As a concrete example of the use of those cognitive components in thinking, someone might tell you that he is thinking about the birthday party he went

to yesterday; in this case, thinking means remembering, and it might involve his imagining himself at the party. Similarly, you might say that you are thinking about how you are going to get to the meeting tomorrow, since your car is broken. In that case, thinking means solving a problem; it involves working out a plan and perhaps imagining specific events. As still another example, someone would be thinking if she were working out the deductions on her income tax return, which might involve reading, comprehending, and following instructions, as well as using logical reasoning and drawing conclusions. Thus, we as “thinking” organisms possess mastery of all those skills, as well as others that we could add to the list with some further thought.

Basic Cognitive Components of Creative Thinking

If creative thinking is ordinary thinking, it should be constructed from those basic cognitive activities (Perkins, 1981). We should, for example, find *remembering* to be important in creativity, as well as *logical reasoning*, both induction and deduction; we should see *planning*, including anticipation and correction of potential errors; we should see examples of *comprehension* of verbal and nonverbal information; and so forth. Several examples of those components of thinking in the case studies discussed in Chapter 1 are presented in Table 3.1. We see the importance of memory in both case studies: The double helix and *Guernica* were both built on earlier work, which in turn obviously depended on the creators’ memory. An example of the use of imagination as well as judgment in the discovery of the double helix was seen when Watson and Crick decided that the bases would be on the outside in their initial models because they saw that the different-sized

Table 3.1 Basic cognitive components of ordinary thinking exemplified in two case studies

Cognitive component	Double helix	Guernica
Memory	Antecedents, etc.	Use of antecedents
Planning		Variations over composition sketches
Judging	Bases outside because they could not fit inside	Change in position of bull; removal of up-raised arms
Reasoning	Crick—Franklin’s unit cell to antiparallel chains; Watson—Franklin’s A↔B change in length to two chains	

bases could not easily be made to fit between the backbones. That is, they anticipated the consequences of putting the bases between the backbones, and they concluded that the result was unacceptable. They made this decision before they built models, so it was done mentally—in thought. When Crick used Franklin's information concerning the structure of the unit-cell of DNA to conclude that the backbones were antiparallel, he was using deductive reasoning to determine the consequences arising from that information. Watson used a similar reasoning process when he used Franklin's information concerning the length change in the $A \leftrightarrow B$ transformation to deduce that two backbones were probably involved.

Picasso's use of composition sketches at the beginning of his work on *Guernica* can be interpreted as evidence of planning on his part. That is, he was planning the overall structure of the composition. It is interesting to note that it is not easy to specify the thought processes, if any, underlying Picasso's work. All we have are the sketches, without letters or other components of the historical record, which would have been more informative than the sketches alone. Any conclusions concerning thinking that are based only on the sketches should therefore be taken as very tentative. Given that caveat, however, it is significant that we can at least tentatively discuss the components of ordinary thinking that might underlie two cases of creative thinking at the highest level.

General Characteristics of Ordinary Thinking

In addition to being made up of the family of activities just listed, ordinary thinking also possesses a number of general characteristics, among which are the following.

- Our thoughts follow one from another, or are related to one another: That is, our thinking has *structure*.
- Ordinary thinking depends on the past: That is, our thought exhibits *continuity* with the past.
- Knowledge and concepts direct ordinary thinking: Psychologists call the direction of our thinking by knowledge and concepts *top-down processing* (which we discuss in more detail).
- Ordinary thinking can be influenced by environmental events: Our thought is *sensitive to environmental events*.

Let us examine each of those components in more detail, and we can also look for evidence of the presence of each in the discovery of the double helix and the creation of *Guernica*.

Structure in Ordinary Thinking and in Creative Thinking

It has been acknowledged for millennia, at least since the time of Aristotle, that our ordinary thinking is *structured*: One thought follows another in a comprehensible manner as we carry out our ordinary activities (Humphrey, 1963). When asked “Why did you think of that?” we can usually trace the path, or the stream of thought, that led to some specific thought. Sometimes we may not be able to specify all the thoughts in that stream, because of the quick and sometimes fragmented nature of the process, but usually we can trace the general path of our thought. Tracing the stream of thought is possible because ordinary thinking is structured in several ways. On the one hand, sometimes our thoughts are linked through associative bonds, which reflect the links between events in our past. The “glue” linking the thoughts is the original occurrence of the events in *contiguity*, that is, close together in time. The role of contiguity in linking thoughts is expressed in Hobbes’s often-quoted statement concerning the stream of associations in ordinary thinking (qtd. in Humphrey, 1963, p. 2):

The cause of the *coherence* or consequence of one conception to another is their first *coherence* or consequence at that *time* when they are produced by sense: as for example, from St. Andrew the mind runneth to St. Peter, because their names are read together; from St. Peter to a *stone* for the same cause [the name “Peter,” given to the saint by Jesus, means “stone”]; from *stone* to *foundation*, because we see them together; and for the same cause from *foundation* to *church*, from *church* to *people*, and from *people* to *tumult*: and according to this example the mind may run from almost anything to anything. (Emphases in original)

Thus, Hobbes proposed that thoughts lead one to another because the events that correspond to those thoughts were experienced together.

A second basis for the tendency of one thought to follow another is *similarity*; as Aristotle noted, common content will tend to make one thought call forth another (Humphrey, 1963, pp. 3–4), even though the events corresponding to the thoughts might never have occurred in contiguity. So, for example, thinking about your team’s loss in its most recent game may bring to mind earlier losing games you attended. Similarly, an environmental event can remind you of a similar event from your past, as when attending a concert can result in your thinking of earlier concerts. In the case of similarity, you have made connections between events that cut across time and space. Sometimes one event can remind you of another even though they are not similar in terms of the objects involved. For example, last week a fellow professor told me that seeing two students trying to outdo one another during a class discussion reminded her of the competition in an athletic event. The two situations are not physically similar, except that

people are involved. However, they are similar in *structure*: Both involve competition, and winning and losing. When events or objects are similar on the level of structure, they are *analogous*. So ordinary thinking sometimes exhibits structure as a result of the use of analogies to link one thought to the next.

Ordinary thinking also possesses structure because sometimes we use reasoning processes of various sorts in our ordinary activities, and this provides a basis for moving from one thought to the next. For example, a friend says to you: "If it rains tomorrow morning, I am not going." The next morning, you look out the window, see that it is raining, and think, "She is not going." That conclusion—that thought—arises from the logic of what your friend said. In this case you used deductive logic to draw a new conclusion from what your friend told you.

If creative thinking depends on ordinary thinking, then creative thinking too should possess structure of those sorts: We should be able to understand the succession of thoughts as a creator brings a new idea or product into existence. Examples of structure in the thinking underlying the double helix and *Guernica* are presented in Table 3.2A. Watson and Crick's adoption of Pauling's helical perspective for DNA may have occurred in part because of the analogical relation between alpha-keratin and DNA: Both are large organic molecules made up of repeating units. That is, alpha-keratin and DNA are *analogous* objects: They are similar in their underlying structures—that is, the relations among their parts are similar. Throughout this book we shall see numerous additional examples of analogies providing structure in creative thinking.

There were also many instances in which reasoning was used in determining the structure of DNA, as when Crick used Franklin's unit-cell information to deduce that the chains were antiparallel. We also saw examples of structure in Picasso's thinking, both in the overall pattern of the sketch process—that is, he began with composition studies and then moved on to the individual characters—and in the way he worked systematically through each of the characters. Also, Picasso's adoption of characters from Goya's *Disasters of War* may have been due to similarities in subject matter and emotional content.

The hypothesis that creative thinking possesses structure leaves us facing the question of why creative individuals can be surprised by the ideas that they produce ("How did I think of that?"). If creative thinking is like ordinary thinking, and if we can track the origins of thoughts in ordinary thinking, then the creative thinker also should always be able to understand where his or her ideas came from. Some examples of that structure were presented in Table 3.2A, but there are situations in which

Table 3.2 General characteristics of ordinary thinking seen in the two case studies

Characteristic	DNA	Guernica
A. <i>Structure in thinking</i> Similarity Logic	Helix from alpha-keratin to DNA; analogy Logical analysis; bases outside; deductions concerning antiparallel backbones	Picasso's <i>Guernica</i> and Goya's <i>Disasters of War</i> Structure in sketches; composition sketches and character sketches
B. <i>Continuity with the past</i> Antecedents	Watson and Crick's use of Pauling's ideas Pauling's reuse of his own helical ideas Wilkins's analysis of DNA based on other Macromolecules; analogy Triple helix first; had to be rejected Backbones of double helix first, then base configuration Base pairings: like-with-like to complementary	Adoption of skeleton of structure from <i>Minotauromacy</i> Characters adopted from other artists' works Final structure slowly worked out in detail Presentation of characters worked out
C. <i>Top-down processing</i>	Decision on helix directed their work Interpretation of data based on knowledge: Watson and Franklin's $A \leftrightarrow B$ length change Crick and Franklin's unit cell	Decision on overall structure (from <i>Minotauromacy</i>) first, followed by working out of specifics
D. <i>Sensitivity to environmental events</i>	Watson's exposure to Franklin's photo 51 Watson's response to Franklin's $A \leftrightarrow B$ change Crick's response to Franklin's unit cell Watson's response to Donohue's information re: tautomeric forms	Bombing of Guernica as the basis for the painting

people cannot tell you where a thought came from. Most important, when we solve a problem in a leap of insight, or an Aha! experience, we may not be able to tell where a thought—in this case, the solution to the problem—came from. What are the differences between situations in which you can follow the sequence of thoughts and those in which you cannot? This question is obviously of great importance in the current context. The phenomenon of insight in problem solving, which is central to the question of the structure of thinking as well as to the related question of whether creativity depends on ordinary thinking, will be discussed in detail in Chapter 6.

Continuity with the Past in Ordinary Thinking and Creative Thinking

Ordinary thinking is firmly rooted in experience: In our ordinary thinking activities, we are constantly referring to and using the past. Consider the processes involved in an activity that typically would not be labeled creative, such as a mechanic's repairing a defective fuel pump on a car's engine. This activity obviously involves thinking: The mechanic must understand what he or she is trying to do, and why, and must plan how the components of the repair will have to be carried out. For example, if some other piece of the engine is blocking access to the fuel pump, that piece will have to be removed before the fuel pump will be accessible. In addition, the mechanic must insure that any parts that are needed are available before work begins, which is another sort of planning. An obvious but by no means trivial aspect of this repair job is that the more times the mechanic carries it out, the better he or she will become; we take it for granted that one will show learning in such a situation. Thus, a crucial component of thinking as expressed in our day-to-day activities is that it builds on what has come before. When the mechanic thinks today about making that repair, he or she uses experience as the foundation for what to do now. (It is interesting to note that if the mechanic has never repaired that kind of a fuel pump before, then the activity is creative: It results in a novel product—a repaired fuel pump—that was produced intentionally.)

Several different sorts of evidence would demonstrate continuity with the past in creative thinking. First, it should be possible to discover connections between innovations and what came before. That is, there should be *antecedents* for creative works (Weisberg, 1986, 1993), because the past serves as the foundation for innovation. Numerous examples of antecedents for creative works were present in the case study on the discovery of the double helix (see Table 3.2B). We saw, for example, Watson and Crick's adoption of several of Pauling's ideas; Pauling's transfer of his own ideas from alpha-keratin to DNA; and Wilkins's transfer of techniques used by other

researchers in the earlier analysis of other organic molecules to his analysis of DNA. In the development of *Guernica*, likewise, many antecedents were noted, including Picasso's own *Minotauromacy* as well as characters from Goya's *Disasters of War*.

Second, in ordinary thinking we also see no great leaps far beyond what we know; our ordinary thinking moves incrementally away from the past as we go on to something new. We do not reject the past; we build on it. Similar reliance on the past should be seen in creative thinking: Creative works—even works that seem to us to be radically new—should develop as the result of incremental movement beyond what has been done before. Examples are presented in Table 3.2B. The double helix began life as a triple helix, and was only gradually changed in the correct direction. In what can be conceived of as one incremental step, for example, the backbone was constructed independently of placement of the bases. The bases then went from like-with-like to complementary pairing. Each of those can be looked upon as an increment away from the old. In *Guernica*, the overall structure in general terms was available from the beginning (building on the past, i.e., *Minotauromacy*), but the specifics were worked out over several composition sketches, and the initial structure of the painting gradually changed into the final version.

Also, just as the hypothetical mechanic we just discussed got better at making a repair, so too should there be a learning curve in creative disciplines: People who work in creative disciplines should over time get better at what they do. This learning curve might be seen in several ways. Creative people may be expected to show increasing productivity over time; the work should come more easily, so they should produce more of it. Another way in which creative work might be expected to get better with experience on the part of the creator is based on the fact that creativity by definition involves producing novel works. Surely, the most important aspect of deciding to work in any creative field is that one desires to make a unique contribution to the field. Thus, we may expect to see an individual “learning to be creative”: The originality of a person’s work should develop over time, as he or she develops original ideas. Thus, in addition to producing more work over time, the person should produce work of increasing originality over time. Evidence to support this general perspective comes from a study by Hayes (1989) on the career development of individuals of renown in several different creative fields. Hayes found that 10 years were needed before a person made a significant contribution to the field; additional evidence will be adduced in Chapter 5, where the role of expertise—the development of detailed domain-specific knowledge—in creativity is examined through consideration of a broad range of case studies.

Top-Down Processes: The Use of Knowledge in Problem Solving and Creative Thinking

Continuity with the past plays another important role in ordinary thinking: Our knowledge serves to direct all our activities, including our thinking activities. As one example, if we have misplaced a book, our knowledge about where we have recently been, as well as where we might have taken the book, serves to direct our search in the environment. We do not simply look everywhere, as might a young child who has misplaced a toy; we sophisticated adults search systematically. One can say that one's knowledge is directing the search in the environment. Another example of this directive function of knowledge in ordinary thinking can be seen when we solve a problem, in algebra, say. Our knowledge of algebra directs us at each step, as we use that knowledge to take what we have available at a given time to decide what operation to apply next. Processes in which knowledge plays a directive role can be contrasted with processes where knowledge does not play such a role. For example, if we had absolutely no idea what we might have done with our book and searched hither and yon, much as a child might, we would be searching without direction based on knowledge.

In analyses of many cognitive phenomena, psychologists have again and again found evidence for an important directive role played by knowledge (or concepts or expectations; psychologists use all those terms, more or less interchangeably) in such processes as storage and recall of information from memory, selectively attending to stimuli in the environment, forming images, problem solving, and language comprehension and production. As noted earlier, psychologists use the terms *concept-driven processing* or *top-down processing* to describe the use of knowledge and expectations in cognitive functioning, a terminology that derives from a particular analysis of cognition.

Figure 3.1A presents one way of thinking about how cognition works. Let us say we are describing how a person might recognize a stimulus in the environment, say, a familiar face. The process begins with presentation of the stimulus from the environment, and the person's attending to it. The stimulus works its way through the visual system until it reaches that portion of the person's memory where previous encounters with people are stored. At this point, the input information matches some record in memory, which results in its being recognized, with the result that one says something like "I see John." The process outlined in Figure 3.1A can be called *bottom-up processing*, because the information flow starts at the bottom of the diagram and works its way "up" into the system until relevant information is found and the stimulus is recognized. The act of seeing John today also adds new information in memory.

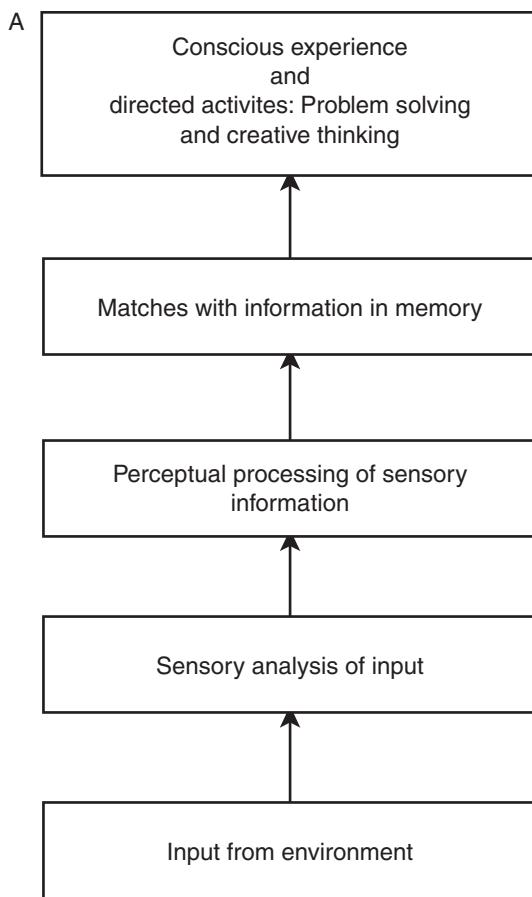


Figure 3.1 Bottom-up versus top-down processing:
A, Bottom-up processing

Much evidence indicates that the bottom-up flow of information in Figure 3.1A is incomplete, however, because, at any time, information already in memory (which, as noted, we can call concepts, knowledge, or expectations) plays an active role in the recognition of information in the environment, and in many other sorts of processes, such as the storage of information in memory and in the generation of responses to that information. That is, recognition does not simply involve information working its way up through the system, being recognized, and then being stored in memory; even the primary act of recognizing an event is affected by the information about that event that is already available in memory. This situation, described in Figure 3.1B, can be called top-down processing, because information at the

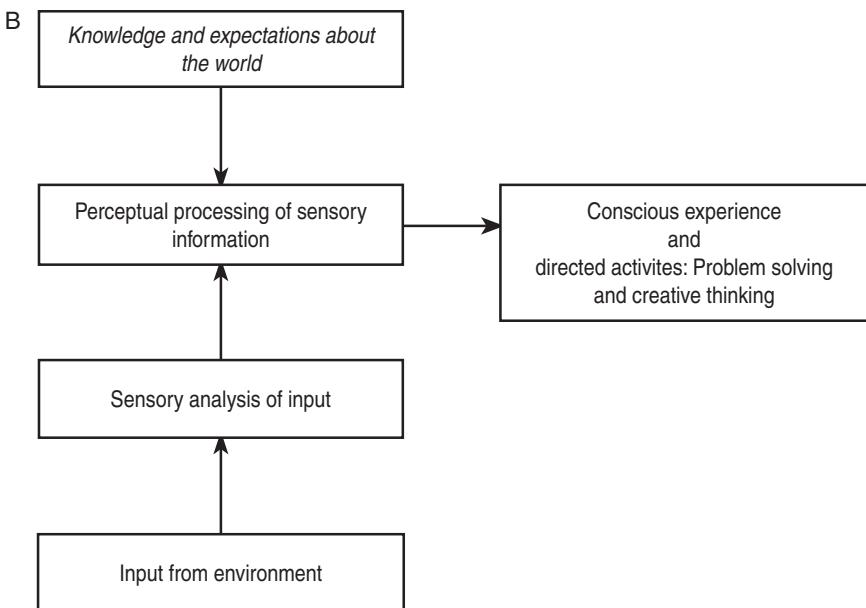


Figure 3.1 (continued) Bottom-up versus top-down processing:
B, Top-down processing

top of the system works *down* into the earlier flow of information to affect those processes.

So if you and I are moving through an environment (when riding in a car, for example), or listening to a conversation, or watching a movie, or attending a concert, or mowing the lawn—that is, in almost all circumstances—*familiar* events will be processed more easily than *unfamiliar* ones. If two people are watching a football game and one person knows more about football than does the other, the knowledgeable person will literally *see* more of the events in the game than the naive person will. This happens in every situation in which we might find ourselves: The more you know about that situation, the better you will be able to get information out of the situation. In addition to extracting more information from the situation in the first place, you will also be better able to attend to events in the situation and to keep track of what has happened. The knowledgeable person will also be better able to recall the events from the situation at a later time. So top-down processes play a role in attending to information, extracting information from a situation, and recalling that information.

It would seem reasonable to expect the same importance of top-down processing in problem solving and creative thinking: One might expect that

knowledge and experience would be of crucial importance in how we solve problems and, more generally, in our production of new things. It might be expected that our success in solving a problem at the present time would depend on how successful we have been in similar situations in the past. It stands to reason that the more we know about the type of problem we are facing, the better we should be at devising a solution. In creative thinking also we should see examples of top-down processes; that is, creative thinking should be directed by knowledge. We should not find much evidence of creative thinkers simply responding in a random and unconstrained manner when they find themselves in a situation that demands that they think of something new. Each step in the process should in principle be predictable from the previous one, based on what we know about the creative thinker's ideas. This does not mean that we will be able to predict with complete accuracy every idea that occurs; the human thought processes are too complicated for us to expect to do that. However, if we understand where the thinker is coming from, we should be able to understand at least in a general way where he or she goes.

In support of the importance of top-down processing in creative thinking, there is evidence that effective problem solving and creative thinking in general are deeply dependent on knowledge and past experience. The case studies presented in Chapter 1 provide evidence that we think creatively by building on the past, not by rejecting it (Weisberg, 1999, 2003; see Table 3.2C). In the development of the double helix, the initial decision that DNA was helical directed all the work that followed, and we saw several places where, because of that assumption, Watson and Crick were able to make advances that others did not. In addition, Watson deduced that two chains were involved as a result of his interpretation of Franklin's finding of the change in length in the A↔B transition. That interpretation was based on his developed knowledge about molecular structure. Similarly, Crick's unique state of knowledge enabled him to deduce the antiparallel nature of the backbone chains from Franklin's information about the structure of the unit cell of DNA. Picasso too seems to have used top-down thinking in his creation of *Guernica*, as we have seen that he first chose the overall structure and then worked out the details. We will in later chapters see many additional examples of top-down processing in creative achievements.

One specific component of this top-down use of knowledge in problem solving and creative thinking is *planning*. As we have just seen, the knowledge of the individual serves to direct the steps that are taken as a situation is dealt with. The role of planning in problem solving has been reviewed by Mumford and colleagues (Mumford, Baughman, & Sager, 2001).

Creative Thinking and Environmental Events

A final important aspect of ordinary thinking is that it is sensitive to environmental events, which often change the direction of thought and action. For example, you might need to figure out how to get to a meeting because your car needs repair. As you are thinking about taking the bus, calling a taxi, and other options, someone rides by on a bicycle, and you realize that you can borrow a bike. External events can also provide you with information that can change how you think and act. You might change your beliefs about someone by witnessing their behavior in some situation. Perhaps you observe someone you thought was kind behaving cruelly toward someone else without any reason that you can see. That might change your opinion of the person's character.

If creative production is based on ordinary thinking, it too should be sensitive to external events; we should be able to find evidence that the creative process changes in direction and outcome as the result of events in the world. Examples of the influence of environmental events on creative thinking are presented in Table 3.2D. In the development of DNA, Watson's exposure to Franklin's photo 51 and her data on the $A \leftrightarrow B$ length change played important roles in shaping his thinking, and so did Crick's learning about the structure of the unit cell. In Picasso's case, the painting of *Guernica* was stimulated by the bombing of the town, which set Picasso on a new path.

Creative Thinking and Ordinary Thinking: Conclusions

We have now put a bit of flesh on the bones of the idea that creative production is based on ordinary thinking. As Tables 3.1 and 3.2 demonstrate, the case studies presented in Chapter 1 provide some support for the assumptions just outlined concerning structure in creative thinking. In both cases, there was no need to postulate extraordinary modes of thinking to understand how the innovation came about. Watson and Crick made no great leaps far beyond what was already known; rather, they took what was known, extended it in several ways, and added critical new pieces of information in order to arrive at the specifics of the structure of DNA. Similarly, Picasso stayed close to things he had done before, and the innovation evolved relatively directly from the past. In addition, we saw in several places that the expertise of Watson and Crick was crucial in their discovery, and we also saw how Picasso's deep familiarity with the works of other artists played an important role in the development of *Guernica*. This perspective will be filled out in the remainder of this chapter and in Chapters 4 and 5.

In many places in those chapters and later in the book I will point out the role played by components of ordinary thinking in creative thinking. In some places, however, the connection will be so obvious that for the sake of the flow of the text I will not make it explicit.

It is important to keep in mind that the identity of creative thinking and ordinary thinking is not uncritically accepted by most researchers who study creativity. The brief review in Chapter 2 of theories of creativity indicated that many theorists assume that the creative process is different from ordinary thinking in any of several ways. Examples of those differences include the creativity-specific processes discussed by Amabile (1983, 1996) and Sternberg and Lubart (1995), as well as the notion of blind variation that forms the initial stage in Darwinian theories of creativity (Campbell, 1960; Simonton, 1999). That view conflicts with the notions of structure in creative thinking and top-down processing directing creative thinking. Thus, it is important that one approach each example that is presented as evidence for ordinary thinking in creativity with a question: What would someone who does not believe in this theory say about that example?

It should also be noted once again that the study of creative thinking is for many researchers only part of the task of understanding creativity. As pointed out in Chapter 2, confluence theories of creativity are built on the assumption that creative production is the result of the coming together of several factors, of which the creative-thinking component is but one. Other components that must be considered are, broadly speaking, the psychological characteristics of the person (i.e., the personality of the person) and also the environment in which he or she is working. From the perspective of confluence models of creativity, a discussion of the thought processes involved in creativity serves to illuminate but one facet of creativity, and therefore it must be incomplete. As noted, in several later chapters we will examine the psychometric perspective and several confluence models of creativity, at which time the discussion will be broadened to examine factors beyond the thought processes that may play important roles in creativity.

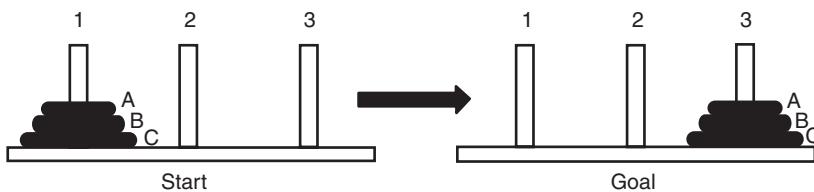
The Cognitive Analysis of Problem Solving

We now turn to a consideration of the cognitive perspective on problem solving and creative thinking, which can be traced to the seminal research of Newell and Simon (e.g., 1972). As noted earlier, the cognitive perspective derives from Newell and Simon's belief that, in order to understand any behavior, one must study the cognitive processes that underlie it. Newell and Simon also proposed that human beings should be looked upon as

information-processing systems, analogous to computers, and that the concepts underlying our understanding of the functioning of computers could be applied to understanding human cognition. Newell and Simon began their study of human cognition with the analysis of problem solving, and the basic viewpoint that they adopted toward creative thinking was that it too was problem solving, requiring nothing more in the way of unique cognitive processes (Newell, Shaw, & Simon, 1962). Newell and Simon's (e.g., 1972) theoretical perspective for analyzing problem solving will be the main focus of the rest of this chapter and of the next. Please go to Table 3.3 before reading further.

Table 3.3 Some demonstrations of problem solving.
The reader should try to solve each before continuing.

A. The Towers of Hanoi problem

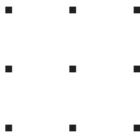


The goal of the problem is to move all three disks from peg 1 to peg 3 so that C is on the bottom, B is in the middle, and A is on top. You may move only one disk at a time, and it must have no disc on top of it; you may not place a larger disk on top of a smaller one.

B. The Missionaries and Cannibals problem

Three missionaries and three cannibals are traveling together and come to the bank of a river. The only method of transportation across the river is a boat that will hold at most two people. The missionaries and cannibals hope to use the boat to cross the river, but there is one difficulty: If at any time the cannibals outnumber the missionaries on either bank of the river (including people in the boat at the bank), the outnumbered missionaries will be eaten. How can you get everyone across the river without losing anyone? It will be easier to try to solve the problem on paper by making a diagram.

C. The Nine-Dot problem



Connect nine dots in a 3×3 matrix with four connected straight lines. For solution, see Fig. 6.2A, p. 285.

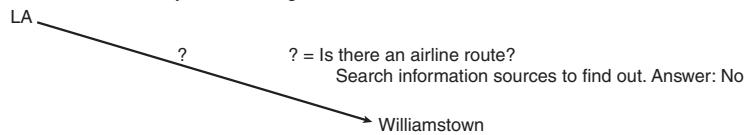
An Example of Problem Solving

I know a person who lives in Los Angeles who has a problem (adapted from Hunt, 1994): She has just been invited to attend a friend's wedding in Williamstown, Massachusetts. How will she get there? She would like to fly on a commercial airline. She knows very little about Williamstown, so she checks a map and finds out that it is in the northwest corner of Massachusetts, almost at the border of New York and Vermont. She checks on the Web to see if any airlines fly there, and she finds that none does, which means that she will have to drive at least the last leg of the journey. However, what about the rest of the trip? She does not want to drive all the way from Los Angeles to Williamstown. She knows that New York City and Boston have airports, and both those possibilities come to mind, but she sees from the map that each of those cities is several hours' drive from Williamstown, and she would like a shorter drive. So those two possibilities are unacceptable. Going back to her map to find cities closer to Williamstown, she notes Albany, New York, and Hartford, Connecticut, and she knows that both those cities have airports. She sees from her map that Albany is close enough to Williamstown for her purposes, so she decides to check whether there are flights from Los Angeles to Albany. On checking the airline's online route map, she finds such a flight. She books a flight to Albany, rents a car for the last leg of the trip, and thereby solves her problem.

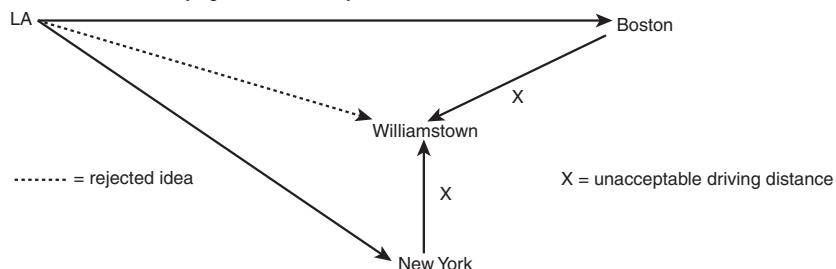
The problem our traveler just faced, and the way she worked through it to solution, is outlined as a series of stages in Figure 3.2. This not atypical example of problem solving can be looked upon as the traveler's exploration of, or *search* through, an imaginary space (*a problem space*), which in this case contains possible transportation links from Los Angeles to Williamstown. The problem solver can search this space in various ways, such as by checking a map to determine the locations of places relative to each other and checking the airline route map to determine existing routes. Figure 3.2 contains the record of the traveler's search through her problem space. At first (Stage 1 in Figure 3.2), there is only the basic question with which she began: the question of whether there is a flight—direct or indirect—from Los Angeles to Williamstown. This initial situation is relatively simple, as she considers the possibility of a connection between her present location and her desired destination. However, since there is not a connection between those two locations, she has to fill in more information. That is, she has to do some further searching, which means that she explores more of the space, as she examines her map. Stage 2 represents what she knows next: There are connections between Los Angeles and New York and Boston, but both are too far from Williamstown for an easy drive. Her search

CREATIVITY: UNDERSTANDING INNOVATION

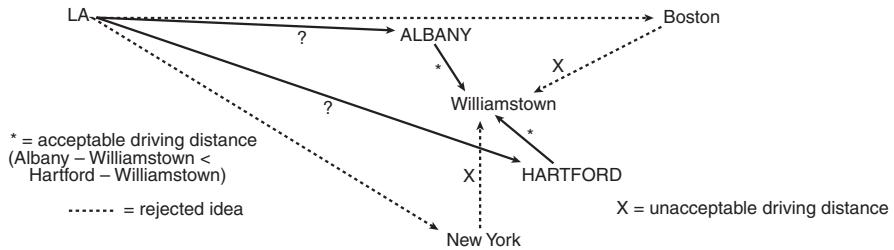
Stage 1: Traveler's knowledge on receiving the wedding invitation. (Diagram not to scale.)
 She wants to fly from Los Angeles to Williamstown, MA, on a commercial airline.



Stage 2: Traveler's knowledge of possible routes after learning that there is no airport at her desired destination.
 She considers flying to New York City or Boston.



Stage 3: Traveler's knowledge after further examining a map; Albany and Hartford are possibilities.



Stage 4: Traveler's knowledge after consulting airline web site. Her problem is solved.

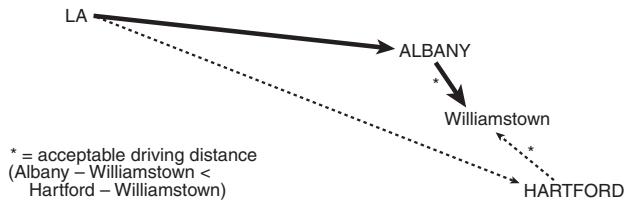


Figure 3.2 Solving the travel from Los Angeles to Williamstown problem

of the problem space grows in size and complexity as our traveler works her way through the possibilities—flying to Albany or Hartford—that present themselves as she considers her map of the United States and her map of airline routes (Stages 2 to 3). She then prunes the possibilities to one path (Stage 4) based on considerations of distance between her destination and an airport.

One could summarize this example by saying that our traveler was faced with a problem because she had to get from one location to another and she did not have an already-used method of transportation that she could call forth and use again. She therefore had to create a new method, and she did so by examining various sources of information which allowed her to consider and work through various possibilities. She chose the alternative that best matched the criteria she had set: get as close as possible by plane to Williamstown and do not drive too far. We can now take this informal presentation and use it as the basis for a more formal examination of the processes involved in solving problems.

Solving a Problem: Questions of Definition

You have a *problem* when your present situation is not the situation you want to be in and you do not immediately know how to change it into something more satisfactory. (See Figure 3.3.) The unsatisfactory situation is called the *problem state*. The situation that you want to be in—that is, the situation that you want to change the problem state into—is called the *goal* or *goal state*. If you are able to devise a way to change the undesired situation so that it becomes one that you are satisfied with—that is, if you devise a way to transform the problem state into the goal state—then you have solved the problem. The activities that you carry out in your attempts to solve the problem are called *operators* or *moves*. A move or operator changes the present situation or state into a different one. If you are in the initial state of a problem and you carry out some operator that by itself does not solve the problem, then you arrive at an *intermediate* state. So most problems contain a problem state, a goal state, and intermediate states. For example, let us say that you want to send an e-mail message, and your computer is not on. Applying the operator of *turning on your computer* changes the present state (computer is off) into a new one (computer is on). The state of your computer being on is an intermediate state, because you have not yet solved your problem: You have not yet sent your message. Finally, any problem is presented in a context, which is called the *task environment*; it consists of all the stimuli to which the individual could respond, includ-

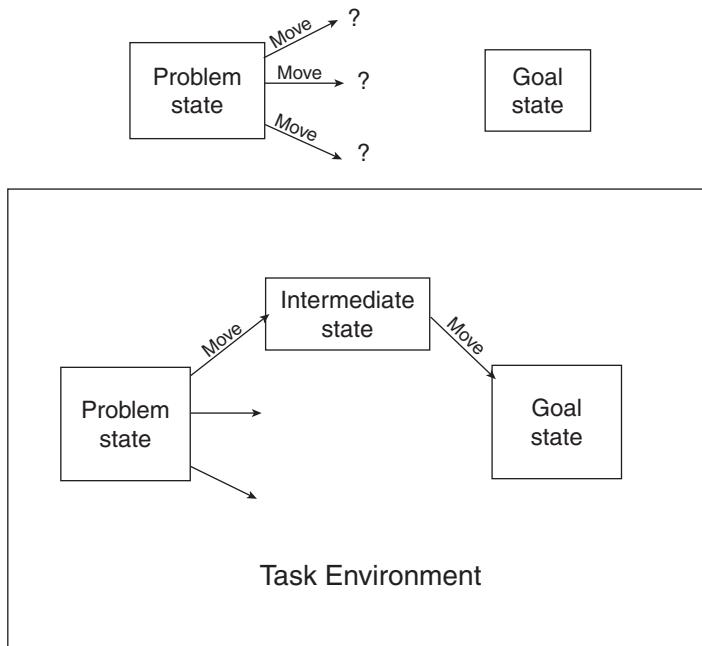


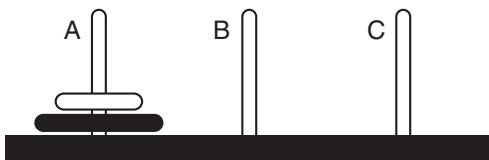
Figure 3.3 Diagram of components of a problem:
Initial state, goal state, moves, and task environment

ing the instructions for the problem, as well as any objects provided to the individual (Newell & Simon, 1972).

As an example of how these concepts can be applied to problem solving, let us say that you are faced with the two-disk Towers of Hanoi problem as shown in Figure 3.4A. Assume that as you try to solve it, you say something like the following to yourself. “I will first move the small disk to peg B. Then I will move the large disk to peg C and put the small disk on top of it. That solves the problem.” Let us assume that all of that internal monologue was carried out at first without your doing anything in the world; that is, you first solved the problem mentally, through use of your imagination. The hypothetical sequence of moves and outcomes that you imagined in solving the problem is presented in Figure 3.4B. This sequence of imagined situations and the imagined moves that led from one situation to the next make up the string of thoughts that you went through in solving the problem (Robertson, 2001).

Your first thought involved imagining what would happen if you made a certain move, and that led to a new thought, which led to a further move and still another thought, and so on. Each time you made an imaginary mental move, you changed the problem as you imagined it. Ultimately, you

A. A trivial version of the Towers of Hanoi puzzle



Using only your imagination, determine how you would get the two rings from peg A to peg C in three moves bearing in mind the following:

- you can move only the top ring from a pile,
- you can move only one ring at a time from one peg to another, and
- you cannot put the large ring on top of the small one.

B. The sequence of imagined moves in solving the two-ring Towers of Hanoi puzzle

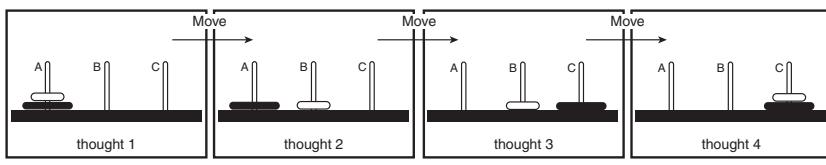


Figure 3.4 Towers of Hanoi

changed your imagined problem so that it matched the goal as stated, so you knew you had mentally solved the problem. In order to actually solve the problem, you would then carry out the corresponding actions in the world. Each of the thoughts that you experienced when you imagined solving the problem is a state of knowledge, and carrying out each move changed one state of knowledge into another one.

Thus, in order to solve a problem, you have to be able to apply a sequence of operators that changes the problem state into the goal state. That sequence of operators is the solution of the problem. If you cannot find a way to transform the problem state into the goal state, you cannot solve the problem. Before an operator can be applied to a given situation, moreover, there may be *constraints* that must be satisfied. As an example, in the Towers of Hanoi problem in Figure 3.4A, before you can move the large disk to Peg C, the large disk must have nothing on it, and Peg C must be empty. In some problem situations there may be *obstacles* that prevent the direct application of operations to the problem state. For example, you might be trying to fix a flat tire on your bike, when you realize that you cannot find the tool needed to remove the tire from the wheel.

Those concepts can be applied to the traveler's problem. The initial state or problem state is her holding the invitation and having no transporta-

tion to Williamstown, and the goal is that she has secured a method of transportation that does not involve what she considers to be an excessive amount of driving. The operators that she has available are examining maps, examining airline web sites and schedules, and making purchases online. By carrying out a sequence of operators, she solves her problem. There are also constraints operating in the traveler's problem: Before she will purchase an airline ticket to a city in the northeastern United States, she must ascertain that the destination is reasonably close to Williamstown. There is also an obstacle in that situation: Our traveler cannot apply the *purchase-airline-ticket-from-Los-Angeles-to-Williamstown* operator to solve her problem, because there is no route available to purchase a ticket for.

Many of the activities of ordinary people, like determining how to travel from one location to another, can be described as solving problems. A student might be faced with the problem of writing a paper for a course. A shopper might be faced with the problem of computing the sales tax on a purchase. A corporate lawyer might be faced with the problem of negotiating a successful merger between two companies. An orthopedic surgeon might be faced with the problem of reducing the discomfort felt by a patient after he plays basketball. That patient might be faced with the problem of reducing his own discomfort while he plays.

Problem Solving and Creative Thinking

The critical characteristics of problem solving are that the situation be novel and that the person devise a sequence of operators that changes the problem into the goal. Since the person has never been in the situation before, if he or she solves the problem then the solution must be novel. Thus, problem solving requires *creative thinking* as we have defined it. The novelty of a problem means that you must go beyond what you know and devise a method that is new for you and that fits the situation you are facing.

There are varying degrees of innovation in problem solutions. For example, if you are asked to multiply two 2-digit numbers, your knowledge of arithmetic makes that problem easy to solve. It should be noted that, if the numbers are new to you, the solution is creative, if minimally so. A bit more innovation is involved if, say, you are given a new problem in algebra to solve. In this case, you have to set up a new equation, which requires more on your part than does the multiplication example. Still more innovation might be seen if a mathematician devised a new method for solving certain sorts of problems. So, for example, inventing algebra is more innovative than solving a new problem using the algebra that you have been taught. However, I will assume that, as far as cognitive processes are concerned, there may be little difference among those situations. That

is, I will assume that degrees of innovation of solutions are not matched by differences in the underlying cognitive processes. This assumption will allow us to attempt to deal with the whole range of phenomena involved in solving problems—and more generally in creative thinking—with one set of concepts. Lovett (2002, p. 317) proposes that problem solving should be defined as the analysis and transformation of information toward a specific goal. In ordinary terms, she considers problem solving as one example of “deciding what to do next.” Lovett considers all such decision situations equivalent, whether the decision is easy or difficult (see also Anderson, 1980, p. 257). Lovett’s definition also does not distinguish among situations that result in the person’s producing sequences of responses of varying degrees of novelty. That premise is similar to the idea just expressed that we might be able to explain all problem-solving situations, regardless of the novelty involved, using the same explanation.

Since problem solving is an example of creative thinking, examination of problem solving in this chapter and the next will contribute to the foundation for an analysis of creative thinking on a broader scale in later chapters, including specific questions concerning the cognitive processes underlying the production of scientific theories, works of art, and inventions. In addition, the assumption that problem solving is an example of creative thinking raises the question of whether all creative thinking—production of scientific theories, works of art, and inventions—can be looked upon as problem solving of one sort or another. Considering the possible broader implications of problem solving as the basis for understanding creative thinking, one might say, for example, that Watson and Crick were faced with the problem of devising a molecular structure for DNA that would be compatible with what was then known about the molecule from X-ray studies and other investigations. One might also say that Darwin was faced with the problem of developing an explanation of how species evolved. The Wright brothers were faced with the problem of developing a powered heavier-than-air machine that could fly. Edison was faced with the problem of developing a light bulb that could be used to illuminate ordinary human activities. In each of those cases, “problem solving” seems to be a reasonable description of the situation.

Extending this analysis further, one might even say that a poet could be faced with a problem; for example, she might be trying to describe her relationship with a dying parent in a manner that results in an effective poem. A novelist too might be faced with problems, such as formulating an effective plot or creating dialogue that will serve the plot and also convey realism. A painter might be faced with the problem of deciding how to render the appearance of a person on canvas so as to produce an effective portrait. One

could also say that, after learning about the bombing of Guernica, Picasso was faced with the problem of creating a painting that could adequately express his feelings about what happened.

Thus, not only can one say that problem solving is central to many of our ordinary activities, but, perhaps more important for the present discussion, at least some of the not-so-ordinary situations that we think of as requiring creative thinking can also be looked upon as problem solving. As noted earlier, one of the foundations of the cognitive perspective on creativity, as formulated by Newell, Shaw, and Simon (1962), was that creative thinking is just ordinary problem solving. This does not necessarily mean that *all* creative-thinking situations automatically involve problem solving; that is a question that remains to be addressed. But it does indicate that what we know about problem solving may shed light on at least some instances of creative thinking. Given the potential importance of understanding problem solving, let us now examine in more detail the cognitive view of problem solving. I will begin by placing the modern research on problem solving in its historical context.

A Brief History of the Cognitive Perspective on Problem Solving

The development over the last 50 years of the cognitive orientation to the study of thinking was stimulated in part by the development of computers in the aftermath of World War II. (See Newell and Simon [1972, epilogue] for further discussion.) Those machines had broad influences on all aspects of our society, ranging from the practical (e.g., changes in the workplace) to the theoretical (i.e., opening a new perspective on the study of thinking). On the practical level, computer scientists and engineers focused on the possibility that the wondrous new “thinking machines” could relieve humans of many burdens by carrying out repetitive tasks. We all have seen how computers have taken over such tasks as keeping track of inventories in stores and carrying out routine financial transactions such as balancing checking accounts. Of course, over the years computers have come to take over tasks of a much larger scale and complexity, such as constructing automobiles, controlling trains on railroads, and directing spacecraft on exploratory journeys in space. However, they began on a much more limited scale, by doing things like keeping track of the number of students enrolled in a college course. Those simple repetitive tasks require some intelligence when a person carries them out, so programs designed to carry out those tasks are examples of what was designated *artificial intelligence* (AI). AI programs are designed from a practical perspective: Their purpose is to carry out the target task in an error-free and efficient manner.

There was also a second stream of interest in computers as thinking machines, and this stream has had a deep impact on the direction of modern psychology: It was believed by some researchers that thinking machines might tell us something about human thinking. Simon, Newell, and their colleagues (e.g., Newell, Shaw, & Simon, 1957; Newell & Simon, 1972) were among the pioneers in developing programs designed to carry out intellectual tasks in the same way that humans did. If one could construct a program that could make a computer play chess like humans did, for example, making the same sorts of good *and* bad moves that people made, then one could look upon the program as a theory of how humans carried out the task. In this case, one has moved away from AI into what is called *computer simulation* of human behavior. The computer program is designed to provide a simulation, or a *model*, of the way a human carries out the task. (The term *sim* in modern video gaming comes from *simulation*.) Computer simulation programs are designed as theories of human performance, and their performance should include both positive and negative aspects of human functioning.

The attempt to simulate human behavior with computers raises the question of how one decides that a simulation is successful. The answer is familiar to anyone who has dealt with simulations in computer video games: The simulation is successful if it can make you believe that real people are involved. The physical appearance of a computer is obviously nothing like that of a human, but that is irrelevant to the researchers, who are interested in the *output* of the program. The question of interest is whether, for example, a string of moves proposed by a chess-playing program during a game played against a human looks like a string of moves that might be produced by a human. When one ignores the source, does the description of the *behavior* look similar to human behavior? Similarly, let us say you were engaged in a typewritten conversation with a respondent, perhaps instant-messaging with someone. Could a computer carry on one of those conversations in such a way that you could not tell, solely from the messages appearing on your screen, whether a person or a computer was on the other end? If so, then the computer program could be said to be simulating human behavior.

Computers and Humans as Information-Processing Systems

When a computer is examined as a functioning system—that is, as a “thinking” and “behaving” system—rather than as a silicon-plastic-and-metal machine, one can describe its functional components as shown in Figure 3.5. The perspective adopted by Newell and Simon (1972) was that humans could also be described in similar terms. First, there are input and output units, which allow the system to interact with the world. Computers

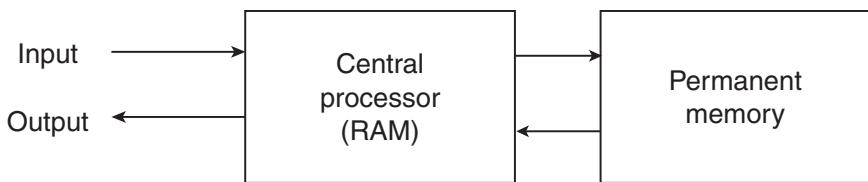


Figure 3.5 Diagram of an information-processing system

have a keyboard and mouse (input) and screens or printers (output); humans have five senses (input) and effectors—including a mouth, arms, and legs—that allow them to operate on the world (output). Those components are not central to the discussion here; more important is the *processing unit*, which carries out tasks, using a program or set of instructions to do so. The processing unit uses a *working memory* (RAM), a limited-capacity storage system, to hold information needed to carry out the task, as well as any new information that arises from the operations of carrying out the task itself. The parallel here between humans and computers is easy to draw. For example, if I were to ask you to add 17 and 57, and I say the numbers to you aloud rather than writing them down for you, then you must store them using working memory in order to carry out the calculation. Similarly, as you are working through the calculation, you might arrive at an intermediate step, such as “57 plus 10 = 67,” and that results in a new piece of information, which is put into working memory so that the next operation can be carried out (“67 plus 7 = 74”). In order to carry out that operation, you have to remember (again, using working memory) that you have 7 left to add.

One important potential constraint on the ability of any system to carry out processing operations is the amount of working-memory storage available. The activities that a computer can carry out are limited by the size of its RAM, as is well known by anyone who has talked to a computer consultant about crashes that occur when you are trying to work with large files, such as files with many pictures in them. The first thing the consultant asks is “How much RAM do you have?” Humans are also limited in this regard, as can be easily seen if you try to carry out the following activity in your head without constantly referring back to the written numbers: What is 729×964 ? You cannot keep track of the original numbers and all the intermediate products, and you quickly lose track of where you are. Thus, information can be lost from working memory if it is not attended to, especially if there is other information being put into working memory as the result of processing being carried out.

In addition to the working-memory system, with its temporary storage of information, there must also be a long-term memory storage system, which

allows for the more permanent retention of information. In a computer, this system (the hard drive) is able to retain the results of programs that were carried out previously, so that the information is available at a later time as needed. In a human, the long-term storage system retains, among other things, the results of previous problem-solving experiences, as well as all of our learning experiences. In a computer, the hard drive has capacity limitations, although that capacity can be very large. In studying the human being as an information-processing system, one can assume that there is essentially no limit on the amount of information that can be stored in human long-term memory; at least, no one has any idea about what the capacity of human long-term memory might be. There are no reported examples of a person's memory being completely full, so that he or she can no longer put new information into memory.

However, information can be forgotten from long-term memory. Cognitive psychologists have examined two mechanisms that may be involved in forgetting (see, e.g., Medin, Ross, & Markman, 2005, for review). First, information can be forgotten because of interference from other information. That is, if one learns something similar to something one already knows, the new information may interfere with the remembering of the old. This would be the case, for example, if you have an old friend named Mary Jo and meet someone called Mary Jane, and for a time you call your old friend "Mary Jane." The new information has interfered with the old. The opposite type of interference also occurs, with old information interfering with the new. In that case, you would call your new friend by the name of the old one. When information cannot be recalled because it is being interfered with by other information, in either of the two ways just discussed, the old information may still be "in memory"; it simply cannot be remembered when it is needed. That is, after you call your new friend "Mary Jo" (i.e., your old friend's name interfered with the new name), you may quickly apologize and correct yourself, which indicates that you did have the new name in memory. This situation is analogous to not being able to find a specific book on your bookshelf because you have many books: The book is there. A second mechanism whereby information in long-term memory may be forgotten is through *decay*, where the information fades away and is actually lost from the system, so that it is not there any more.

Artificial Intelligence versus Computer Simulation

In order to program a computer to carry out some AI task—for example, to control a spacecraft on a journey to a distant planet—one must have extensive knowledge about the factors that might affect the craft's journey, such as whether the propulsion system is in good working order, whether the

research equipment on the craft is working, whether the communication systems are working, whether the solar cells are working, and so forth. The program has been designed to carry out the task as well as can be done, and one's main concern is whether it is up to the challenge. In order to program a computer to simulate human behavior, another factor comes into play: One has to possess deep knowledge about the human. For example, if you are developing an AI program to play chess, you simply want it to play the best chess possible. As noted earlier, if you are programming a computer to simulate human chess playing, the situation becomes more complicated, because you want the computer to do what the human does, good *and* bad.

So, if a human makes an error playing chess at a particular point, the simulation program, if it is a faithful simulation, should make an error there also. But before the researcher can program a computer to simulate that behavior, the researcher must understand *why* the error occurred. Let us say that a researcher believed that the person made an error at a particular point (i.e., chose a poor move) because at that moment he or she did not have enough working-memory capacity available to plan the most effective move. One might provide support for that hypothesis by developing a chess-playing computer program that had a small amount of RAM and showing that that program made errors of the same sort at that point in the game. If the program were given a larger RAM, then the error would not be made. In this way, one could attempt to model the behavior of the person by using the program with the limited memory, and that program would provide support for the analysis of the way the human carried out the task.

Thus, the availability of computers provided researchers with new ways to test hypotheses about mental processes, by using the computer to model the hypothesized processes. In order to develop a simulation program, one had to be very explicit about the processes one was hypothesizing inside the person, because otherwise one could not incorporate them into a program: Computer programs do not tolerate vagueness. This demand for precision in order to program computers to simulate humans resulted in a new rigor in theorizing about "hidden" mental or cognitive processes, which in turn opened the door to new ways of thinking about thinking itself. In the 1950s, Newell and Simon began to develop simulation programs that were able to carry out several different types of intellectual tasks with some success. It was claimed, for example, that one program, the Logic Theorist (see Newell & Simon, 1972, Chap. 4), was able to prove theorems in logic. Examples of more recent programs that are designed to simulate human creativity in science (Langley et al., 1987) will be discussed later in the chapter.

This perspective toward the analysis of human cognition was adopted by numerous researchers, many of whom did not actually develop computer

programs to simulate human behavior in specific tasks. In fact, much research discussed in this book can be traced in various ways to the cognitive perspective, but I will discuss almost no computer simulation programs. More important than the specific efforts to simulate human behavior was the philosophy that one could carry out analyses of the cognitive processes underlying any behavior, which was a radical break from the behaviorist perspective dominant in mid-twentieth-century American psychology. In another break with behaviorism, researchers following the information-processing perspective began to study complex tasks (e.g., chess playing, proving theorems in logic, solving other sorts of complex problems) that could not be studied in animals. Furthermore, some of this research involved the participants' thinking out loud as they carried out the task, which provided information concerning thought processes underlying behavior. The stream of verbalized thought, called a *verbal protocol*, could be used as a source of information concerning the internal steps that the human thinker might be going through. In the discussion of the hypothetical solution of the solution of the two-disk Towers of Hanoi (see Figure 3.4), it was assumed that you produced a verbal protocol as you solved the problem. Collection of verbal protocols had been carried out earlier in the twentieth century by the Gestalt psychologists (e.g., Duncker, 1945) but had been ignored in American psychology until the development of the cognitive perspective.

Other measures, such as recording of eye movements while the individual was carrying out a task, also provided subtle measures to support claims about internal mental processes. If, say, a researcher hypothesized that the person shifted attention from one component of a problem to another, then examining the person's eye movements or verbal protocols might provide concrete evidence for that internal process. The person's point of visual fixation might move to the hypothesized object at just that point in time, or the object might be mentioned in the protocol at that point.

Verbal Protocols and the Thought Process

The collection and interpretation of verbal protocols has been a particularly important source of information for researchers in the cognitive perspective. However, a basic question can be raised concerning the collection and analysis of protocols: Might the act of producing a protocol change the thought process? That is, is the thought process that one uncovers using protocols different from the actual process—the thought process that the person carries out when he or she does not think aloud? Before we proceed further, it is important that we deal with this question.

Ericsson and Simon (1993) developed a theory to guide the collection

and interpretation of protocols, and to evaluate support for the theory they reviewed studies that have collected protocols in different sorts of situations. Ericsson and Simon concluded that verbal protocols, if collected using specific controlled methods, were a useful source of data concerning cognitive processes. Ericsson and Simon distinguished several different types of verbalizations that might be produced during an episode of thinking, for example, during problem solving. First, the individual might already be carrying out an internal verbalization as he or she is working through a problem. A person might be adding two numbers using verbalization or working verbally through a problem in reasoning. In those situations, the information in working memory would be verbal in format, so the person would simply have to speak it aloud, or “turn off the mute.” Verbalizing aloud in such circumstances would be expected to have minimal effects on thinking. Ericsson and Simon used the term *Type I verbalization* to refer to the overt verbalizing of information that is already in a verbal format in working memory.

A second type of verbalization (*Type II verbalization*) occurs when the individual is using a nonverbal format to solve a problem, as when, for example, a person is asked to determine the fastest route from point A to point B and does so by imagining herself actually following a route, or reading off the route from a mental map. Another example would be solving the two-disk Towers of Hanoi as outlined in Figure 3.4B using visual imagery. In such a case, the information in working memory is visual, and so it is not in a form that is directly verbalizable; it must be translated into verbal form. In Ericsson and Simon’s view, Type II verbalization should slow down problem solving—because translation from visual to verbal format, for example, takes time—but it should not affect the direction of the thought process.

Type III verbalization, the final type, goes beyond simply producing a verbal record of thinking—either direct or translated—and includes reporting specific pieces of information, or explaining *why* some action was carried out. So, for example, the researcher might ask the participant to report why certain pieces of information were attended to as he or she carried out a simulated driving task in the laboratory. Another example might be if the person were asked to report during problem solving why he or she made a given move. In this latter case, the person might say something like “Let’s see if I can do X, because that would allow me to. . . .” There is evidence that carrying out Type III verbalization can affect the outcome of the thinking process. Most important, Type III verbalization can change the information that people deal with and the sequence of thoughts that occurs. Those changes occur because the Type III instructions require that additional thinking be carried out, and this by definition changes the sequence

of thoughts. Ericsson and Simon (1993) reviewed studies that examined possible influences of verbalization on thinking, and the results supported their analysis. Overall, then, there is evidence that under certain circumstances the collection of verbal protocols can provide useful information concerning the thought processes (i.e., when Type I and Type II verbalizations are involved).

We can now turn to a consideration of the specific components of the cognitive perspective on problem solving by reviewing some of the concepts that cognitive psychologists have developed to understand problem solving. We will then examine how those ideas can illuminate our understanding of creativity.

Problem Solving: Processes of Understanding and Search

As noted earlier, a person faced with a problem is in a task environment, either in the laboratory or in some real-world situation. When a person begins to tackle a problem, a process of *understanding* comes into play (Robertson, 2001). The person takes the instructions and interprets them so he or she can begin to deal with the problem. Thus, the task environment—the objective situation in the world—is transformed through the understanding process into an *internal representation of the problem*. This internal representation includes the person's initial analysis of the problem situation, including the objects available and the interpretation of the instructions, and the representation of the goal.

Understanding and the Problem Representation

There can be significant differences between the problem solver's representation of the problem and that of the researcher. Problems are usually presented verbally, and psychologists have provided many demonstrations of situations in which people's comprehension of a verbal message involves going beyond what is explicitly presented in the message. As an example, consider the meanings of the following statements (Bransford, Barclay, & Franks, 1972).

1. The customer talked to the store manager about the increased meat prices.
2. Three turtles rested on a log and a fish swam beneath it.

These statements were presented to people as part of an experiment on memory. The participants were asked to study them and were told that their memory of the sentences would be tested. After a study list of sentences had

been presented, test sentences were presented, including sentences 3 and 4 below. The participants' task was to indicate whether each test sentence had been presented exactly on the study list. Try to determine whether sentences 3 and 4 are the same as sentences 1 and 2 *without looking back at 1 and 2.*

3. The customer complained to the store manager about the increased meat prices.
4. Three turtles rested on a log and a fish swam beneath them.

In the original experiment, neither sentence 3 nor sentence 4 had been presented on the study list, but the participants tended to mistakenly say that they had seen them. The reason for those mistakes is that when the people studied sentences 1 and 2, they presumably carried out a process of comprehending them, which resulted in a representation of the meaning of those sentences that included more information than was explicitly presented in each. For example, in interpreting sentence 1, it seems to follow that the customer was complaining about the meat prices, because it seems absurd that a customer would tell the manager that it was great that meat prices were going up. Thus, the person reading the sentence adds information to what is explicitly presented in the sentence. That added information can result in the person mistakenly identifying test sentence 3 as the original study sentence 1, because sentence 3 explicitly includes that information. Similarly, on hearing study sentence 2, the person might construct an image of the scene described by the sentence, and we all know from our knowledge of spatial relations that if the turtles are on a log and a fish swims under that log, it also swims under the turtles—under *them*. So these errors are evidence for processes of interpretation or comprehension that occur when we are faced with verbal messages.

Problems are usually verbal messages, so the same sort of processes of interpretation can be at work during the first step in problem solving, when the individual is constructing a problem representation. As an example, consider the following simple problem.

Solve the following for x : $4x + 20 = 0$.

When you read that problem, assuming that you know algebra, you know that the solution to the problem will be an equation of the form $x = ?$, and you immediately begin to carry out operations that will produce such an equation; that is, you subtract 20 from both sides, and so forth. None of that information was explicitly presented in the problem; your knowledge of algebra allowed you to understand the problem and to begin the solution

process. Someone who does not know algebra would be at a loss as to how to proceed.

The upshot of this is that the process of understanding the problem as presented can result in significant differences between the problem representation as conceived by the researcher and that constructed by the participant in the experiment. The researcher may believe, for example, that a given object should be used by the individual in solving the problem, and he or she may be surprised when that object is not used. However, the individual facing the problem might not have included that object among those available to solve the problem, and so would not think of using it. Similarly, the experimenter may be surprised when the individual does not carry out some operation when solving a problem when the experimenter thinks the operation is obvious and potentially useful. That operation might not have been explicitly prohibited by the problem instructions, but the individual, on interpreting those instructions, may have assumed that that operation was not to be carried out. As an example, consider the following matchstick-arithmetic problem.

The following equation is constructed out of matchsticks; that is, assume that each line in the equation, including those comprising “+” and “=,” is made up of one matchstick.

$$||| + || = ||$$

As it reads now, the equation is incorrect. Move only one matchstick, from its present location to another location in the equation, so that the equation becomes one that is correct. Try to solve the problem before going on.

The solution is to move the vertical matchstick from the “+” to the group of three matchsticks on the left, so that the equation becomes $||| - || = ||$. That is a correct equation. One difficulty in solving a matchstick-arithmetic problem is that people may not realize that they can go beyond ordinary arithmetical/algebraic operations. For example, in algebra, when you carry out an operation, you must apply it to both sides of the equation. If you subtract some quantity from one side of an equation, you must also subtract the same quantity from the other. In matchstick arithmetic, in contrast, operations (e.g., taking away or adding a matchstick) may be carried out differently on each side of the “equation,” so one must go beyond what one knows about ordinary arithmetic and algebra. Also, in algebra, when you are solving a problem you do not change the operators (+, -, /, x), but one sometimes does so in matchstick arithmetic. It takes people a while to learn to do those things, as their early problem representations are gradually changed with increasing exposure to matchstick-arithmetic problems. Thus,

in order to understand the way a person approaches a problem, one must understand the problem representation he or she has constructed.

The Problem Space and Search

Based on the individual's internal representation of the problem, he or she can then construct the problem space, which is the set of possible moves that he or she might attempt in trying to solve the problem. When the thinker has constructed the problem space, based on the interpretation of the instructions and of the context in which the problem is presented, he or she can begin the solution process, which is analogous to searching that space in order to construct a path that leads to the solution. We have already informally examined the process of searching a problem space in the traveler's solving the Los Angeles-to-Williamstown problem. We must make a distinction here between the problem space, which contains all the possible links that the person *might* explore in trying to solve the problem, and those links that the person *actually does* explore. As we saw with our traveler, in many cases the person does not examine every possible link that he or she might have considered; the person selectively searches the problem space. The methods used to keep the search exercise under control are critical in understanding human problem solving.

Well- versus Ill-Defined Problems and the Problem Space

In some problems, all the components—see Figure 3.3—are specified in the statement of the problem. One example is the Towers of Hanoi (Table 3.3A). The initial state is presented in the problem, the goal state is described precisely, and the moves and the conditions for their application are also specified. In order to solve such a problem, you simply have to work out a sequence of legal moves that will transform the problem state into the goal. A problem situation with all the components specified is called a *well-defined* problem. Another example of a well-defined problem is tic-tac-toe. The initial state is a blank board, the moves and constraints are specified, and the goal state is three Xs or Os in a straight line, which can be specified precisely.

One difference between Towers of Hanoi and tic-tac-toe is that the goal states are described differently. In Towers of Hanoi, there is only one goal state, which can, for example, be pictured precisely. In tic-tac-toe, however, there is a set of states, any one of which serve as the goal; that is, one can win with three in a row in a horizontal line (actually in any of three horizontal lines), or a vertical line (again, any of three vertical lines), or a diagonal line (again, any of two diagonal lines). So there are really eight specific

solutions to tic-tac-toe. When we describe the game to someone who does not know it, we say that you have to get three in a row, horizontal, vertical, or diagonal. So the solution is described in *abstract* terms (Weisberg, 1995). However, all the components are still available from the description of the problem.

In other problems, so-called *ill-defined problems*, at least one of the problem components is not specified in the statement of the problem. For example, let us say that you are a psychotherapist, and a client comes to you complaining that he is unhappy and wants to change his life. He is not clear about exactly what is bothering him; he just knows that he is not happy. In other words, his problem state is not specified precisely. In addition, he does not know how he wants to change his life; he simply wants it to be better than it is now. So his goal state is not specified either. Finally, it is not clear what operations are available to change this person's life: Can he change jobs, end a relationship, move to another city? What constraints come into play? The traveler's problem discussed earlier is also an ill-defined problem. Although the initial state is specified, the goal is not precisely specified: We only know that she wants to get from Los Angeles to Williamstown without driving too much.

It should be noted that the terms *well-defined* and *ill-defined* are not *evaluative* when applied to problem situations; that is, a well-defined problem is not in any way a *better* problem than an ill-defined one, nor is it necessarily easier to solve. Rather, well- and ill-defined are *descriptive* terms, which simply tell you how much information you are given before you begin to solve the problem. Ill-defined problems require that the problem solver specify some missing elements before solution can occur. The therapist, for example, must learn some specifics about the client's life before beginning to work out how it might be changed for the better.

Problem Finding?

Examining the notions of well- and ill-defined problems in the context of creative thinking, one could say that Watson and Crick were faced with an ill-defined problem in trying to determine the structure of DNA. As we know, they assumed that it would be helical, which provided some specificity concerning the goal, but there were still many additional parameters of the structure that remained to be determined. Similarly, Picasso set for himself an ill-defined problem when he decided to paint a picture in response to the bombing of Guernica. Another example of an ill-defined problem that is of some theoretical interest would be if a hypothetical painter went to her easel without any specific idea of what she wanted to paint, knowing only

that she wanted to work. She would then be facing an ill-defined problem, since the initial state (the blank canvas) and the possible moves (applying paint to the canvas) are specified, but the goal state is not. This hypothetical situation is different from that faced by Picasso when he heard about the bombing of Guernica, since he at least had, presumably, a general idea of what he wanted to paint.

Some researchers (see, e.g., Reiter-Palmon, Mumford, Boes, & Runco, 1997; chapters in Runco, 1994) reserve a special name—*problem finding*—for the situation faced by the hypothetical artist, in which there seems to be nothing specified in the way of a goal. The term *problem finding* was introduced in an influential study by Getzels and Csikszentmihalyi (1976), who observed art students while they painted a still life. The painting was to be created by the student from a group of objects provided by the researchers; the student chose the specific objects, arranged them in any way he or she desired, and then painted them. The resulting paintings were rated for quality by other painters. The more-highly-rated paintings were produced by students who had taken longer to decide on the objects to be painted and how they were to be arranged. Getzels and Csikszentmihalyi proposed that that preparatory work be called *problem finding* and posited that the better student artists were more proficient in that skill.

Rather than introducing a new theoretical term, I would call that situation an ill-defined problem, because it seems not very different from other situations that are called problems, and it would be simpler to think about them in the same way. I would say that the students in the Getzels and Csikszentmihalyi (1976) study were actually faced with two problems: (1) deciding on the arrangement that they wanted to paint (i.e., solving the ill-defined problem of creating an acceptable arrangement of objects to paint), and (2) rendering it in paint in an acceptable manner (another ill-defined problem). Thus, the hypothetical painter who went to her easel with no idea of what she would do was also facing two problems: deciding what type of painting to create, and actually creating that painting. One could say that, since she is a painter, she does not have to *find* a problem. When she decided to be a painter, she set a lifelong problem for herself: create paintings. Similarly, if a writer goes to his desk to work with no idea if he will begin a novel, a short story, or an essay (this seems implausible, but let us assume that it is true), we could say that he is first attempting to solve the ill-defined problem of what to write today. Since he is a writer, he does not have to *find* a problem; he has one—he has to write *something*. This analysis provides further support for the close relationship between problem solving and creative thinking. For further discussion of the relevance of problem finding to the study of creativity, see Chapter 12.

Strategies for Searching Problem Spaces

When one is facing a well-defined problem, the task is to find a sequence of moves that will lead from the problem state to the goal state. One way to begin to understand how people solve such problems is to diagram the problem space—that is, all the possible sequences of moves that one could make in attempting to solve the problem. As an example, Figure 3.6A presents the problem space in the three-disk Towers of Hanoi problem (Table 3.3A). One begins at the top, in state₁, which is the initial state of the problem. One can make two moves from that state that follow the rules of the problem, which change state₁ into either state₂ or state₃. From either of those states, three moves are possible, as can be seen by counting the paths leading away from either state (one of those paths would be the return to state₁). Continuing from state₂ (and not returning to state₁), there are two moves possible, and so forth. One solves the problem by reaching state₂₇, which corresponds to the goal as exemplified in the directions. In this problem, it is possible to reach the goal through paths of varying degrees of directness, as one can see by tracing some of those paths. In addition, from any state in Figure 3.6A there is always a solution path possible (there is always a path that can be traced from that state to the goal), so if one simply keeps working long enough, one will ultimately solve the problem. Figure 3.6B presents the problem space for the Missionaries and Cannibals problem (see Table 3.3B). That problem's structure is a bit different from that of Towers of Hanoi, because in carrying out a sequence of moves you may come to a situation in which you have the wrong ratio of missionaries to cannibals, in which case the solution attempt is over. That is, it is possible to fail to solve the Missionaries and Cannibals problem.

When one is faced with a problem such as Missionaries and Cannibals or Towers of Hanoi, where there is a small problem space, one strategy to solve the problem is to search that space completely, or *exhaustively*, until you find a path that leads to the solution. That is, if you simply try every possible combination of moves, at some point you will solve the problem. (However, in Missionaries and Cannibals, you may have to start over more than once.) In such problems, it is possible that a person might search the entire problem space before solution, depending on how efficiently he or she searches.

Many problems that we face, however, have problem spaces that are too large for a person to search exhaustively. One problem with such a space is tic-tac-toe. It is a relatively simple game, and, as noted above, it is a well-defined problem. If you try to imagine the problem space, however, so that you could work through exhaustive search, you see quickly that that space

A

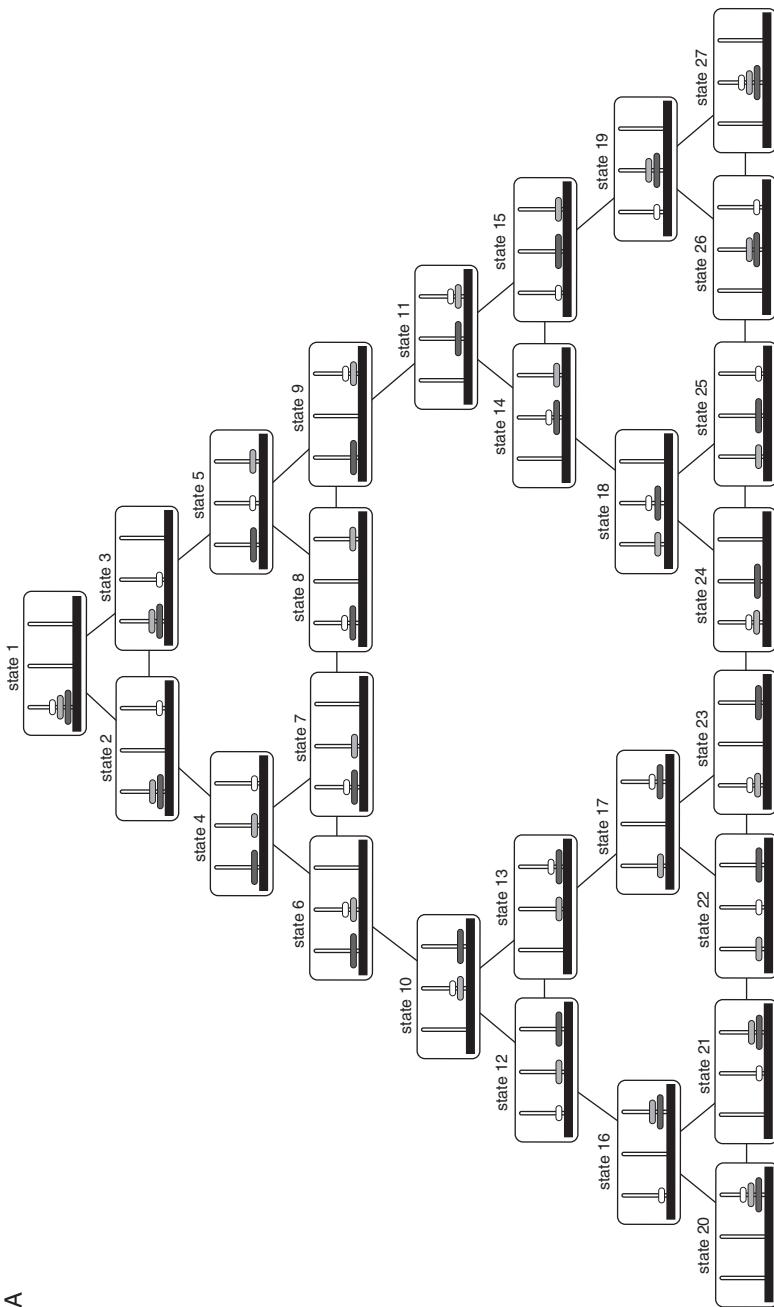


Figure 3.6 Problem spaces: A, State space of all legal moves for the three-ring Towers of Hanoi puzzle (adapted from Robertson, 2001); B, Problem space for the Missionaries and Cannibals problem

The Cognitive Perspective on Creativity, Part I

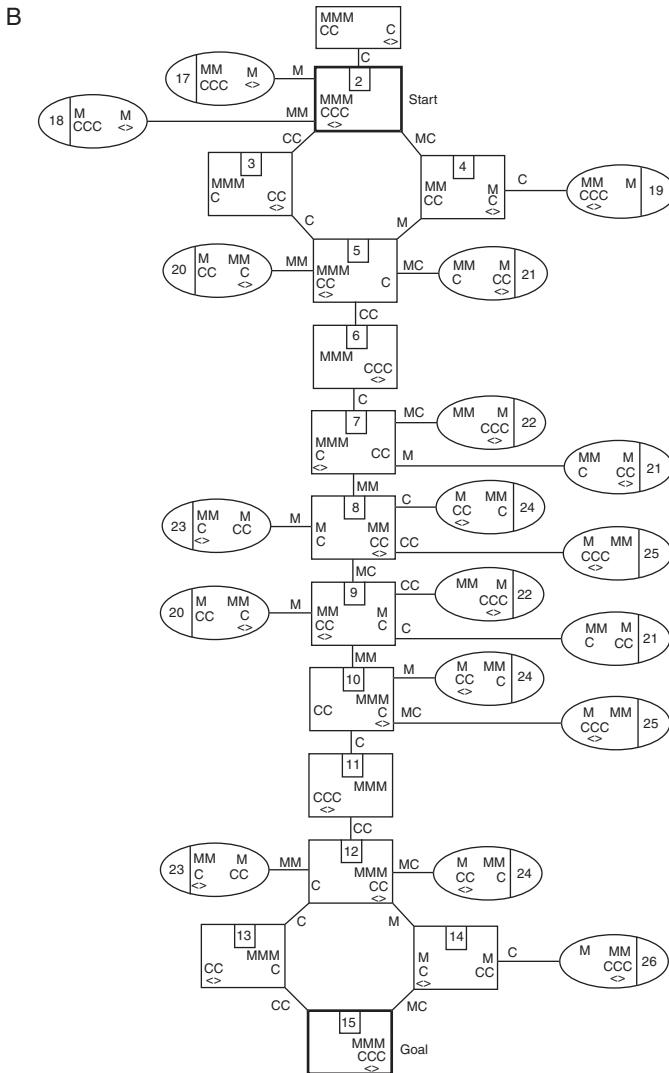


Figure 3.6. (continued)

Note: Diagram is read as follows: The Ms in each box represent the missionaries on the left-hand and right-hand banks of the river, and the Cs represent the cannibals. The symbol \leftrightarrow represents the boat. Thus, in state 2, there are three missionaries, three cannibals, and the boat is on the left bank; in state 21 there are two missionaries and one cannibal on the left bank, and the boat is on the other bank. The letters on the lines between states represent the move made in changing from one state to another. So, for example, from state 2 to state 3, two cannibals are moved.

Source: Weisberg (1980).

is so large that without external assistance you cannot keep track of all the possible solution paths. Let us say that you go first. From the initial state, there are three possible moves that you can make: a corner, the center space, or one of the middle spaces on the outside (I am assuming that all corner moves are equal, as are all moves to the middle of an outside line). If you move in a corner, your opponent can make one of five different moves. If you move into the center, then two different opposing moves are possible. If you move into the center of an outside row, then five different opposing moves are possible. You can respond to each of those possible moves with several moves, and so forth. The number of possible paths quickly becomes so large that it is difficult to analyze them (or even to discuss them) without some help from paper and pencil. Thus, this seemingly very simple well-defined problem cannot be solved by an ordinary person's exhaustively searching the problem space.

Heuristic Methods for Searching Problem Spaces

Another example of a problem with a large problem space is the traveler's Los Angeles-to-Williamstown problem. When the traveler checked the airline's route map to see if there was a connection from Los Angeles to Williamstown, she did not examine routes heading west or north or south from Los Angeles. If she had done so, she would probably still be searching for possible connections, because there are many possible routes leading out of Los Angeles to somewhere in the world (e.g., Los Angeles to Tokyo to Sydney to Cape Town to London to Williamstown). Our hypothetical traveler considered only routes leading northeast from Los Angeles, in the general direction in which she wanted to go. She thus cut down the problem space to one of manageable size.

The strategy used by the traveler is one example of a general mode of solving problems: When one is faced with a problem space that is too large to be searched exhaustively, one must use *heuristics*, which are *rules of thumb* that allow you to cut that space down. With heuristic methods, the portion of the problem space that the person actually searches may turn out to be much smaller than the total problem space. Heuristics do not guarantee a solution to your problem, but they may help in producing a solution (Newell & Simon, 1972). As an example, in tic-tac-toe, a good move is to start in the center if you go first. That move is no guarantee of success, but you raise your chances of winning. Our traveler was also using a heuristic, something like this: "If you are looking for a possible flight, explore possibilities in the general direction in which you wish to travel."

A number of different types of heuristics have been discovered by psychologists analyzing people's problem solving (Newell & Simon, 1972).

One heuristic method is to try to change the current state so that it looks more like the goal state. As an example, in attempting to solve the Towers of Hanoi, one would move the smallest disk to the goal peg, since that makes the situation look more like the goal. This strategy is called *hill climbing*. Imagine that you are climbing a mountain, but there is a dense fog, so you can see only a minimal distance in front of you. You cannot see the mountain peak that is your ultimate goal. Assuming that you want to continue your ascent, there is a simple strategy that you can use: Whenever there is a choice to make, using your sense of direction, test out the various possible paths, and go in the direction that leads higher. In this way, you know that you are moving at least generally in the correct direction. You have changed your current state to one that more closely resembles the goal (that is, you are closer to the peak than you were). When each possible path from your current location leads downward, then stop, because you cannot get any closer to the peak. In more general terms, the hill-climbing strategy says that at any point you should try the various possible moves leading away from your present state. Choose the move that most changes your present state in the direction toward the goal.

One problem with the hill-climbing strategy, however, is that you might be on a small hill adjacent to the peak that you are heading toward, so moving up only got you to the top of the hill, not to the top of the mountain. You reached what can be called a *local maximum*: a state that is closer to the goal than where you started from, and that is the highest place in the area you have climbed through, but that is not the ultimate goal. In order to get up the mountain, it turns out that you first must go *down* the hill. However, the fog makes it impossible for you to know that. So when your ability to see ahead—that is, when your ability to plan an overall strategy—is limited, then hill climbing may be a useful strategy. There is always the chance, however, that you will reach a local maximum rather than the ultimate goal. That means you will be better off than you were, but not at the ultimate solution.

An example of a limit to the usefulness of the hill-climbing strategy can be seen in both the Towers of Hanoi and Missionaries and Cannibals problems. In both of those problems, there comes a point at which you have to move away from the goal in order to solve the problem. That is, for a short period of time it looks like your situation is getting worse. At that point, hill climbing has to be abandoned, because if you persist in attempting to change your present state so that it looks more like the goal, you will not solve either problem. Those intermediate states are reversals only on the surface, however, as you are in actuality making progress toward the ultimate solution of the problem.

A different type of heuristic method involves *working backward* from the goal to the initial state. This method can be helpful because it can limit the number of possible moves that must be considered at any point. Towers of Hanoi, for example, can be solved relatively easily if one works backward. Let us say that you are trying to decide on the first move you should make: Should the small ring, which begins the problem on the top of the stack on peg A, go to the goal peg (C), or the middle one (B)? Working backward from the goal, you realize that in the solution the large ring must be at the bottom on the goal peg. Therefore, the goal peg must be empty before it goes there. In addition, in order to move the large ring from peg A to the empty goal peg, the large ring must have no other rings on it. In order to have no rings on the large ring on peg A, and also to have peg C empty, the other two rings must be on peg B. Putting those two rings on peg B means that the middle-sized ring must be on the bottom on that peg. In order for the middle-sized ring to be on the bottom on peg B, the smallest ring cannot be on that peg. Therefore, the smallest ring must be on the goal peg. So that is the first move in the problem: small ring to goal peg.

Still another heuristic method works by comparing the goal state and present state and examining the differences between them. One then attempts to find an operator that will serve to reduce the most important of those differences. This method may involve breaking a problem into smaller subproblems and solving each of those in turn, which might lead ultimately to solution of the overall problem. An example of the use of this heuristic was presented by Newell and Simon (1972, p. 416) in their important early discussion of heuristics in problem solving:

I want to take my son to nursery school. What's the difference between what I have and what I want? One of distance. What changes distance? My automobile. My automobile won't work. What is needed to make it work? A new battery. What has new batteries? An auto repair shop. I want the repair shop to put in a new battery; but the shop doesn't know I need one. What is the difficulty? One of communication. What allows communication? A telephone.

At each point, the person determines what has to be done (what *end* is to be accomplished) and what to do (the *means* to bring it about). This heuristic is thus called *means-end* analysis. Means-end analysis can also be applied to the Towers of Hanoi, in the following manner. When the problem begins, I want to move the large disk to the goal peg, but I cannot do that because that disk has others on top. How do I clear the large disk? I have to move the middle-sized one, but that disk has the smallest one on top of it, so I have to move the smallest disk. Moving the smallest disk allows

me to move the middle-sized one, which will then allow me to move the large one. However, this analysis does not enable me to determine where to move the smallest disk.

A different type of heuristic is *planning*, which entails using one's imagination to carry out a solution mentally, so that one can determine in advance the outcome of a given move or sequence of moves and thereby determine if it should be carried out. The discussion of the two-disk Towers of Hanoi (see Figure 3.4) involved planning, and in trying to solve the three-disk Towers of Hanoi in Table 3.3A, for example, one can mentally carry out at least some of the possible moves and see which move leaves one in the best position. However, consider what would happen if you were given a seven-disk Towers of Hanoi problem. If you tried to plan a strategy for that problem, you would very quickly be overwhelmed by the size of the problem space. The difficulty in planning in the seven-disk Towers of Hanoi arises because one uses working memory in order to think through one's plans before carrying them out. As we have discussed, human working memory is of limited capacity, so there is a limit to the complexity of the planning that one can carry out without some external aid, such as a pencil and paper. If one is working without such external assistance on a problem as complex as the seven-disk Towers of Hanoi, one must use other heuristic methods, which place fewer demands on working memory, such as means-ends analysis, hill climbing, or working backward.

Finally, it is important to note that for some problems there are specific rules, or *algorithms*, that will, if you follow them correctly, guarantee that the solution will be found. An example of a set of algorithms is the rules of arithmetic. Schoolchildren can solve addition problems, for example, because they have learned those algorithms. Thus, a particularly useful heuristic to use when solving a problem is to first determine if there are any algorithms that can be applied to it. Most problems that humans face are not solvable through application of algorithms, however, so we must resort to other heuristic methods, such as those discussed here.

Weak Heuristic Methods in Problem Solving: Broader Implications

The heuristic methods considered so far use information given in the problem, and little else, as the basis for setting up a method of solution. Those methods are called *weak methods* of problem solving (Newell & Simon, 1972); they are very general in their applicability, but precisely because of that generality they do not provide much specific information useful for solving any particular problem. The laboratory problems in which weak heuristic methods are typically studied (e.g., Towers of Hanoi, Missionaries and Cannibals, and tic-tac-toe) are *knowledge-lean problems*. That is, the

person can bring little or no knowledge to bear on those problems, because of the way they are designed. For example, what kind of knowledge would be relevant to solving Towers of Hanoi? Except for experience in solving that particular problem, it is not clear that one knows anything that would be helpful (Gunzelmann & Anderson, 2002).

One might be tempted to dismiss heuristic methods as being too weak to be of interest in any situation beyond academic laboratory exercises in problem solving. However, weak heuristic methods may have broader applicability. It could be argued, for example, that Watson and Crick may have used the heuristic of working backward from the goal when, as discussed earlier, they decided to adopt the assumption that DNA was a helix. Although they could not determine all the parameters of the helix, making that decision enabled them to concentrate on certain pieces of evidence and to ignore others, which made their problem space smaller than it might have been. One interesting aspect of Watson and Crick's method, if they did indeed work backward from the goal, is that they were facing an ill-defined problem in which the goal was not specified at all, so they had to make an assumption about the goal before they could work backward from it. Thus, the situation facing Watson and Crick was more unstructured than in the well-defined problems such as Towers of Hanoi and Missionaries and Cannibals. This conclusion leaves open the question of why Watson and Crick specifically assumed that DNA was helical; I briefly explained this in Chapter 1 (i.e., DNA and alpha-keratin are similar in various ways), and I will address it in more specific detail in the next chapter.

Carrying this discussion one step further, one might also propose that Picasso's using *Minotauromacy* as the structure on which he built *Guernica* is another example of working backward from the goal. That is, Picasso used an already available structure that provided specificity to his task and allowed him to get started. As with Watson and Crick, making that move did not completely solve Picasso's problem—there were still many details to be worked out—but it at least allowed him to begin to work. Thus, perhaps surprisingly, weak heuristic methods may have relevance to important examples of creative thinking.

Heuristic-Based Simulation of Scientific Discovery

Moving away from the case studies considered so far in this book, it has also been proposed that heuristic methods of the sort just outlined have played important roles in many other examples of creative thinking, at least in science. Langley and his colleagues (Langley, Simon, Bradshaw, & Zytkow, 1987) have developed several computer programs that are designed to apply heuristic methods to data made available by the researchers, in

order to simulate well-known scientific discoveries. The researchers claim, furthermore, that those heuristically based computer simulations are of interest because they are brought about in the manner in which the discoveries were made in the first place by the individuals who are now famous for those accomplishments. In order to see the possible range of usefulness of heuristic methods in creative thinking, let us examine the performance of one of those programs.

In the early seventeenth century, Johannes Kepler (1571–1630) made several discoveries concerning the motions of the planets, which are now known as Kepler's Laws of Planetary Motion. Kepler took data from observations of the planets that had been collected by Tycho Brahe (1546–1601), whom Kepler served as an assistant, and summarized them in a particularly elegant form. Kepler's laws were important in the history of astronomy because they paved the way for Newton's analysis of the orbits of the planets. We will examine here the development of third of those laws, which states that, for any planet orbiting the sun, there is a regular relationship between the *period* of orbit (the time it takes to go around the sun) and the distance between the planet and the sun. Kepler's Third Law says that the relation between period (P) and distance (D) can be expressed in the following formula:

$$D^3/P^2 = C \text{ (a constant; in the case of planetary motion, } C = 1)$$

That is, the cube of the distance divided by the square of the period equals one.

The data that Kepler had to work with are presented in columns 2–3 in Table 3.4. Brahe had measured several aspects of the travel of each of three planets (A, B, and C in Table 3.4). (In actuality, Kepler developed his law based on Brahe's observations for only a single planet, Mars, but that is not directly relevant to this discussion.)

Langley and colleagues (1987) developed a program called BACON that, when given Brahe's data, produced a summary equivalent to Kepler's law. The program analyzed the numbers using several heuristic methods that were built into the program by the researchers/programmers. Those heuristics, general methods for manipulating numbers that are within the grasp of a high school student, are the following.

1. If the values of a term are constant, then assume that the term always has that value.
2. If the values of two numerical terms increase together, then consider their ratio.

Table 3.4 BACON program's determination of Kepler's Third Law of Planetary Motion

Planet	D	P	Term 1 (D/P)	Term 2 (D ² /P)	Term 3 (D ³ /P ²)
A	1	1	1	1	1
B	4	8	0.5	2	1
C	9	27	.33	3	1

3. If the values of one numerical term increase as those of another decrease, consider their product.

Those heuristics are both very simple and very general, since they do not apply to specific terms or domains. Most important, they are not directly relevant to astronomy and planetary motion. They have no content, in the sense of being related to any specific terms in the world; they can be applied anywhere one finds series of numbers such as those in columns 2–3 of Table 3.4. That lack of problem-specific content makes them weak methods, of the sort that we have already discussed.

Let us now consider how BACON dealt with the numbers. Basically, it determines whether a given situation fits the description in any of the heuristics and, if so, applies that heuristic. Application of a heuristic results in a new set of numbers, and the process continues with the new set of numbers until nothing further can be done. In this case, BACON first examined the two columns of numbers and determined that heuristic 2 was relevant. It then produced the quantity D/P , which is shown in column 4 in Table 3.4, labeled *Term 1*. The values of Term 1 are not equal, so the program does not stop. Heuristic 3 can be applied to columns 3 and 4 (P increases while Term 1 decreases), but doing so just results in going back to the numbers in column 2 (the D values), so that heuristic is not applied. Heuristic 3 can also be applied to columns 2 and 4 (D and Term 1), so that is the next step. That results in Term 2 in Table 3.4. Heuristic 3 is now relevant to the data in the fourth and fifth columns (Term 1 decreases while the values of Term 2 are increasing), so it is applied. Dividing one by the other produces Term 3, which equals one for all the values, so the program stops, drawing the conclusion that the relationship between D and P for this set of measures is $D^3/P^2 = 1$, which is Kepler's Third Law.

Thus, with a few simple arithmetic-based heuristics—which, it should be noted, were available to Kepler—BACON carried out a series of calculations that resulted in production of a formula that is equivalent to Kepler's

Third Law of Planetary Motion, a discovery that played a singular role in the development of modern physics. Langley and colleagues (1987; see also Langley & Schrager, 1990) have developed a series of programs that, based on heuristics such as those presented earlier, are able to deal with sets of data of various sorts and produce summaries of those data. As we have just seen, sometimes the output of those programs resembles great discoveries made by pioneering human scientists who are honored by us for their great creative achievements.

Non-computer-based researchers who study creative thinking have usually responded negatively to those attempts at computer modeling of the creative process. It is usually noted, for example, that the BACON program had all the hard work done for it. That is, the data were laid in its lap by the programmers, which allowed the program to grind through its heuristics until it reached a point where it could stop. There seems to be little that is truly creative in such an activity; surely there was more to Kepler's accomplishment than that. Csikszentmihalyi (1988) has compared computer simulations of scientific discoveries to fine copies of artistic masterpieces. Although the masterpiece and the copy may be very similar in appearance, there is something basic missing from the latter. Similarly, although the computer's output may look like Kepler's Third Law, that does not mean that the processes involved in producing that output were the same as those that Kepler went through. For example, it is sometimes argued that the critical issue is not Kepler's developing the laws that bear his name; that is, the calculations he went through were not that crucial. The important step was his deciding to concentrate on certain questions in the first place, which made the data relevant and opened up the opportunity for his calculations.

However, some parallels can be drawn between Kepler's situation and that of the BACON program, which indicate that the two situations may not have been as different as sometimes supposed. First, Kepler did not have to raise the critical questions concerning the motions of the planets and what they might mean; those questions had already been put forth by others and were well known to educated people. Evidence that Kepler was aware of the critical questions and what was occurring in the way of answers can be seen in the fact that he served as Brahe's assistant. In addition, the data had not been collected by Kepler but by Brahe, so here again we see that the table was already set when he began his work. One could conclude that Kepler's status in the enterprise was not all that different from that of the BACON program when the researchers gave it the data and turned it on.

There is also a slightly different question that BACON and other programs address, which is whether weak heuristic methods play a role in important creative discoveries. Based on some of the evidence discussed

here, it seems that such methods might be useful, perhaps more useful than one might at first think. A similar conclusion can be drawn from studies that have given scientifically naive individuals—typically undergraduates—sets of data that were derived from important scientific advances and show that such individuals can develop similar conclusions to those drawn by the original scientists (e.g., Dunbar, 1995). Here, too, only weak methods can be used, because the undergraduates in such studies do not have specialized knowledge.

Weak Heuristic Methods of Problem Solving and Creative Thinking: Conclusions

Solving problems using weak heuristic methods involves little in the way of top-down or concept-driven processes, as we have used the terms. One is not doing much in the way of applying one's detailed knowledge to the problem. Even so, we have seen that some significant creative advances may have come about at least in part through the use of weak methods. Those weak methods are composed of components of ordinary thinking that were discussed earlier. They involve planning, reasoning, and accessing the past, as encapsulated in memory (i.e., they are composed of general knowledge about how to solve problems).

We now move beyond weak heuristic methods in analyzing problem solving. Most problems that people face are *knowledge-rich* ones, rather than the knowledge-lean problems, such as Towers of Hanoi and Missionaries and Cannibals, where one finds extensive use of heuristics. A person facing a knowledge-rich problem may possess information that is more or less directly relevant to that problem. Possession of problem-specific knowledge allows the use of what are called *strong* methods of problem solving, methods that are attuned to the specific problem that the person is facing (Newell & Simon, 1972). Under such circumstances, problem solving becomes a much more top-down or concept-driven process, with the person's knowledge playing an important role. In Chapter 4, I will examine such top-down methods of problem solving and consider their potential relevance to creativity.

CHAPTER

4

The Cognitive Perspective on Creativity, Part II

Knowledge and Expertise in Problem Solving

In the last chapter we began to examine the cognitive perspective on problem solving and creativity by investigating the role of weak heuristic methods in problem solving; we saw that those methods may have played a role in several creative discoveries. The weak method of working backward from the goal, for example, may have been relevant to both Watson and Crick's discovery of the double helix and Picasso's creation of *Guernica*. We also examined the BACON program developed by Langley and colleagues (Langley, Simon, Bradshaw, & Zytkow, 1987), which was used by those researchers to explore the possibility that Kepler's development of his Third Law of Planetary Motion came about through his use of weak heuristic methods for finding patterns within groups of numbers. When you attempt to solve a problem by using a weak method, such as working backward, hill climbing, or means-end analysis, you are using information relevant to the problem at only a very general level. When one applies a strategy like working backward to a problem, the only information relevant to the problem is "goal" and "try to change the goal." Nothing specific about the problem you are facing plays a role in directing the strategy. One could put this another way by saying that weak methods of problem solving, because they are not relevant in detail to the problem that one is facing, are minimally top-down in nature.

Most of the creative advances that are the primary focus of students of creativity have been based on the use of knowledge of a more detailed nature. We also saw evidence of the importance of knowledge in creativity

in the two case studies in Chapter 1. Watson and Crick's knowledge was crucial to their progress in many areas, including their primary decision that DNA was a helix, as well as to specific conclusions about various aspects of the structure. Similarly, Picasso's knowledge was of critical importance in his creation of *Guernica*, ranging from his use of his own past works to his adaptation of works of others. The present chapter extends the presentation of the cognitive perspective on problem solving to an examination of strong methods of problem solving, which are based on the individual's possessing information that is related more directly to the specific problem that he or she is facing. In such situations, problem solving becomes more top-down in nature, as the person's knowledge about the situation serves to direct his or her problem-solving activities.

Outline of the Chapter

The chapter examines two different uses of knowledge during problem solving, which vary in the degree to which the knowledge fits the problem the person faces. I first review research on *analogical transfer*, which occurs when one solves a problem by transferring information from a previously solved problem to a new one of the same structure. That is, the old and new problems are *analogous* in structure, even though they may have no objects in common. Analogical transfer can be a useful method of solving problems, although sometimes there can be surprising failures of transfer of information from old to new problems. Psychologists have examined factors that influence whether a person will transfer knowledge from a previously encountered problem to a new one. We will also examine situations in which analogical transfer played a role in creative thinking outside the laboratory.

A related area of research has examined the role of expertise—deep knowledge in an area—in high-level problem solving, and that research will be reviewed in the second section of the chapter. It will be concluded that expertise plays a critical role in higher-level problem solving, which leads to the possibility that expertise is important more generally in creativity. In addition, at numerous points in the chapter I will point out components of ordinary thinking that play a role in analogical transfer and the use of expertise in solving problems.

Before we examine the more general relevance of expertise to creativity, it is first necessary to consider several possible objections to the notion that expertise may play a role in creative thinking. In the last section of the chapter, I examine several potential objections that have been made in response to research on expertise, in order to demonstrate that the results are potentially relevant to the understanding of creative thinking.

Use of Knowledge in Problem Solving: Studies of Analogical Transfer

One strong method that can be useful in solving a problem is to try to use *analogical thinking*. In analogical thinking, one uses information from a familiar situation, usually stored in memory, in order to deal with a new situation that is analogous to the familiar one. Two situations are analogous when they have the same structure, although the specific objects involved may be very different. Analogical thinking can be used in understanding an unfamiliar situation, as well as in solving an unfamiliar problem (Holyoak & Thagard, 1995; Klahr & Simon, 1999). An example of the use of analogical thinking in science in order to facilitate comprehension of an unfamiliar situation is an early description of the structure of the atom as a solar system, with the nucleus of the atom as the sun, and the electrons as the planets orbiting that sun, with much of the atom made up of empty space, like our solar system. Even though atoms and the solar system are completely different as far as their components are concerned, the structure of the solar system, a familiar domain, provided a way of understanding the structure of the atom, the new and unfamiliar situation, because the two are analogous in structure. Similarly, in chemistry, when one learns about gases, the gas molecules are often described as billiard balls flying through space, and the notion that these balls undergo collisions is used as the basis for understanding several different phenomena concerning behavior of gases, such as gas pressure and various gas laws. Furthermore, it is interesting to note that one of the core assumptions of the cognitive revolution as discussed in Chapter 3—Newell and Simon's (e.g., 1972) use of computers as a way of understanding human thinking—can be interpreted as an example of analogical thinking. We will now examine the role of analogical thinking in problem solving. Before reading further, please go to Table 4.1.

In problem solving based on analogical thinking, you try to find some familiar problem that you know how to solve that is analogous to the problem you are facing (Polya, 1957), because the strategy you used on the familiar problem may be useful now. In this case you are transferring the solution method from the old problem to the new one that is analogous to it, so this situation is called *analogical transfer*. This is a top-down use of information from memory, and the details of the information involved make this method very different from the weak methods discussed in the last chapter. The weak methods involved information that was relevant to the new problem only at a very general level (“try to work backward from the goal”). The information underlying analogical transfer is more specific in its relevance to the problem. Solving a problem through analogical transfer is

Table 4.1 Problem solving with analogical thinking

A. General problem

A small country was ruled from a strong fortress by a dictator. The fortress was situated in the middle of the country, surrounded by farms and villages. Many roads led to the fortress through the countryside. A rebel general vowed to capture the fortress. The general knew that an attack by his entire army would capture the fortress. He gathered his army at the head of one of the roads, ready to launch a full-scale direct attack. However, the general then learned that the dictator had planted mines on each of the roads. The mines were set so that small bodies of men could pass over them safely, since the dictator needed to move his troops and workers to and from the fortress. However, any large force would detonate the mines. Not only would this blow up the road, but it would also destroy many neighboring villages. It therefore seemed impossible to capture the fortress.

However, the general devised a simple plan. He divided his army into small groups and dispatched each group to the head of a different road. When all was ready he gave the signal and each group marched down a different road. Each group continued down its road to the fortress so that the entire army arrived together at the fortress at the same time. In this way, the general captured the fortress and overthrew the dictator.

B. Radiation problem

Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at a sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays and at the same time avoid destroying the healthy tissue?

an example of *continuity with the past* in problem solving and, therefore, in creative thinking. In solving a problem based on an analogy with another problem, one is using the past to deal with the present.

As an example, consider the Radiation problem in Table 4.1B. When you try to solve that problem, it may seem extremely difficult, with not enough information available, so you may be at a loss as to how to proceed. However, if you read with some care the story in Table 4.1A, then you had information available that could be used to solve the radiation problem relatively directly: The solution to the General's problem in Table 4.1A can serve as the basis for solution of the Radiation problem. The two situations are analogous, and the "convergence" solution proposed by the General in

General problem	Radiation problem
General	Doctor
Fortress	Tumor
Army	Rays
Using whole army \Rightarrow exploding mines \Rightarrow kill innocent people and destroy homes	Using strong rays \Rightarrow kill healthy tissue \Rightarrow patient dies
Break up army into small groups, unite simultaneously at fortress: “Simultaneous convergence”	Use weak-intensity rays, unite at tumor: “Simultaneous convergence”

Figure 4.1 Analogies between Radiation and General problems

solving his problem can also serve as the basis for solution of the Radiation problem. The analogous relationships between the two problems are made specific in Figure 4.1. The fortress is analogous to the tumor; the army is analogous to the rays; capturing the fort is analogous to destroying the tumor; the destruction that results from sending the whole army down a single road at once is analogous to the killing of healthy tissue with a bundle of high-intensity rays; dividing the army is analogous to dividing the rays. Figure 4.1 makes clear the degree of detail that one finds in situations of analogical transfer.

The use of an analogy as the basis for solving a new problem is only one example of the roles that analogies serve in cognition. As noted, there are many instances in the history of science where the use of analogies served to help people understand new concepts. Analogical transfer can also be seen in creative advances; for example, it may have been the basis for Watson and Crick's use of Pauling's alpha-helix as the basis for their assumption that DNA was a helix. It was mentioned in Chapter 3 that Watson and Crick's use of Pauling's helical idea may have been an example of their use of the weak heuristic method of working backward from the goal. At that time it was noted that the question remained as to where they got the idea of assuming that DNA was helical. That is, they first had to define the goal they were working toward in the ill-defined problem that they faced. Analogical transfer may be the answer to that question, because, as noted in Chapter 1, alpha-keratin and DNA are analogous molecules. Both alpha-keratin and DNA are (1) organic (2) macromolecules (3) made up of small units (4) linked to each other (5) that repeat in a regular pattern. So one could hypothesize that Watson and Crick were reminded of Pauling's work when

they were thinking about DNA because of analogical transfer. Thus, when Watson and Crick used the weak method of working backward, because of their knowledge they were also employing a strong method.

Analogies are used by all of us in our ordinary activities, in order to understand and think about new concepts, as well as to solve problems. The familiar notion of a *computer virus* takes what we ordinary folk know informally about how viruses infect other organisms and uses that knowledge as the basis for an understanding of how the programs called viruses work. When you use a familiar situation (e.g., the solar system or a virus) as the basis for understanding a new one that is analogous to it (e.g., the atom or a destructive computer program), the familiar situation is called the *base*, and the new one is the *target*. One can say that the target is understood by using the base, or that the base is *extended to* or *transferred to* the target. Similarly, a *target problem* might be solved by transferring to it the solution from a *base problem*. As noted, solving a problem through analogical transfer is one example of the top-down role of memory and concepts in creative thinking.

Types of Analogies

Cognitive psychologists studying analogical thinking have classified analogies according to the similarity between the base and target information (e.g., Dunbar, 1995). Dunbar classifies analogies as *local*, *regional*, and *remote*. In a local analogy, the base and target come from the same domain. As an example, let us say that a biologist studying HIV has a problem with the design of an experiment, and she uses the design from another HIV experiment as the basis for improving her unsatisfactory one. Her transfer of the design from the old HIV experiment to the new one is an example of use of a *local* analogy. In contrast, if she had used the design from an experiment on the Ebola virus as the basis for repairing the design of her HIV experiment, that would have been a *regional* analogy, since the base and target come from the same “region” of her knowledge: They are both viruses. Finally, in Kekulé’s report of his discovery of the structure of benzene, a snake served to represent a string of atoms. Putting aside for now the questionable nature of Kekulé’s report (see Chapter 2), we can say that he used a *remote* analogy in his thinking, since snakes and atoms are from domains that are only distantly related.

Potential Limitations on Analogical Transfer

Given the wide role of analogies in thinking, including the possible role of analogical transfer in several creative achievements—Watson and Crick’s discovery of the double helix and Newell and Simon’s adoption of the computer as a model of human cognition—one might expect that

analogical transfer would be of general importance in problem solving. Accordingly, it might be expected that giving people prior exposure to the General problem would facilitate solution to the Radiation problem (see Table 4.1 and Figure 4.1). Those two situations have the same structure, and a similar method is used to solve both. In other words, there should be *positive transfer* from the General problem to the Radiation problem. However, there are three potential obstacles to using a base analogy to solve a target problem. First, you may not have solved a related problem in the past, in which case you would not have the relevant base knowledge. That is a question of ignorance, which is not of great theoretical significance in understanding problem solving. The obvious way to overcome this difficulty is to work to acquire a broad and deep personal database that you can draw on to solve the problems that crop up in life.

A second and much more important situation occurs when a person possesses knowledge that *could* be applied or transferred to a problem but does not realize it. In such a situation, the information is *available* in memory (that is, the information has been stored in memory and is potentially usable) but is not *accessible* during problem solving (that is, the information does not come to mind when the new problem is presented; Tulving & Pearlstone, 1966). Put another way, presentation of the new problem does not serve to *retrieve* the relevant base information from memory; one possesses the knowledge, but it is inactive, or *inert*. A failure of analogical transfer due to inert knowledge is of interest on a theoretical level, because it demonstrates limitations on retrieval of information during problem solving. Not all information in memory is usable in problem solving under all circumstances.

Finally, even if the prior problem is accessible during problem solving—that is, even if the person retrieves the base when contemplating the target (“Say, this problem reminds me of . . .”)—that does not guarantee that solution will occur. The person must successfully apply the solution from the base to the target. This requires that *mapping* occur: The analogous concepts in the two problems must be matched up explicitly, so that the solution can be applied to the target. Research has indicated that mapping sometimes causes significant difficulties in solving problems. I will now review research demonstrating the existence of inert knowledge and examining the roles of retrieval processes and mapping in analogical transfer.

Limitations on Transfer of Knowledge in Problem Solving: Inert Knowledge

In a pioneering examination of analogical transfer in problem solving, Gick and Holyoak (e.g., 1980, 1983) used the Radiation problem as a target

problem (Duncker, 1945; see Table 4.1B). The problem is rather difficult: Only about 10 percent of undergraduates usually solve it on their own. This low rate of solution allowed Gick and Holyoak to examine if performance could be facilitated by providing base information concerning how the problem could be solved. Gick and Holyoak first gave participants exposure to the General problem (the *base*, Table 4.1A) and then measured whether the exposure to the base information facilitated solution of the target Radiation problem. The individuals were not told that the General problem could help them solve the Radiation problem; that is, Gick and Holyoak were testing spontaneous transfer, which occurs without external assistance.

The question of whether spontaneous transfer would occur was of primary interest in this study, because that situation is most similar to most real-world problem-solving situations. When you learn something in school and then go out into the world, you do not have an omniscient teacher available to inform you, whenever you are facing a problem, whether you possess information from an analogous situation that might be helpful. In other words, one of the main purposes of education is to turn out students who are able on their own to apply their knowledge to new situations as circumstances require; that is, one goal of education is to foster “spontaneous” transfer.

There were two other conditions in the study. There was a Control group, consisting of participants who were given no exposure to the potentially relevant General analogue. This group provided the “baseline” solution rate for the Radiation problem with no other information provided. That group was necessary to determine whether there was positive transfer from exposure to the General problem. There was also a Hint group, who first worked on the General problem and then, when the Radiation problem was presented, were told that the General problem might help them solve the new problem. This group provided a measure of the effectiveness of the General problem in providing a possible solution to the radiation problem: If the Hint group did not solve the target (Radiation) problem, then the General problem was not useful and the study was a waste of time.

Results of the Gick and Holyoak transfer study are shown in Table 4.2A. First, as expected, the Control group (not shown), with no exposure to a potentially useful base problem, performed poorly. In contrast, the Hint group performed well, which indicated that the General problem could be helpful in solving the Radiation problem if one knew to apply the information from that problem to the Radiation problem. The question of interest, then, is the performance of the Spontaneous Transfer group, who were given the relevant base information without being told that it could help them solve the target problem. Under those conditions, perhaps surprisingly, little transfer was found: Fewer than one third of the participants solved the

Table 4.2 Gick and Holyoak transfer studies

A. Gick and Holyoak (1980, Exp. III) results^a

Condition	Complete solutions (%)	Number of participants
Hint	92	12
No hint	20	15

^a This panel shows percentage of participants solving the Radiation problem after exposure to the General problem, with and without a hint to use the latter to solve the former.

B. Red Adair story

An oil well in Saudi Arabia exploded and caught fire. The result was a blazing inferno that consumed an enormous quantity of oil each day. After initial efforts to extinguish it failed, famed firefighter Red Adair was called in. Red knew that the fire could be put out if a huge amount of fire retardant foam could be dumped on the base of the well. There was enough foam available at the site to do the job. However, there was no hose large enough to put all the foam on the fire fast enough. The small hoses that were available could not shoot the foam quickly enough to do any good. It looked like there would have to be a costly delay before a serious attempt could be made.

However, Red Adair knew just what to do. He stationed men in a circle all around the fire, with all of the available small hoses. When everyone was ready all of the hoses were opened up and foam was directed at the fire from all directions. In this way a huge amount of foam quickly struck the source of the fire. The blaze was extinguished, and the Saudis were satisfied that Red had earned his three million dollar fee.

C. Gick and Holyoak (1983, Exp. IV) results^b

Condition	Complete solutions (%)	Number of participants
Two analogues	39	28
One analogue plus control	21	47

^b This panel shows percentage of participants solving the Radiation problem after exposure to two analogous stories, the General and the Red Adair story, without a hint to use the latter to solve the former, compared with a control group who were exposed to one analogous and one nonanalogous story.

target problem. It seems that most participants did not think of the General problem on their own when the radiation problem was presented. For most of the participants, their knowledge of the General problem was *inert*.

In a second study, Gick and Holyoak presented *two* base analogues before presenting the Radiation problem (the General problem and a problem

concerning oil-well firefighter Red Adair; see Table 4.2B). Gick and Holyoak reasoned that presenting two base analogues would make it more likely that the participants would think about the elements that the two base situations had in common. This would make them think about abstract, or general, aspects of the situations (that is, the need to divide the force and bring the parts together at the same place at the same time), which might make it more likely that they would be able to transfer the solution to the Radiation problem when it was presented. After being exposed to the two base analogues, experimental participants were asked to describe what those situations had in common, as far as the problems that had to be faced and solutions that were produced. This, too, was done to make it more likely that the individuals would think about the base information in general terms.

Gick and Holyoak expected that encouraging the participants to form what one could call the abstract description or *schema* of the solution would result in easier transfer of the solution method to the target Radiation problem. Describing the common features of the two situations required that the participants move away from the concrete objects involved in each situation and think about them in more general or schematic terms. However, as can be seen in Table 4.2C, even though the participants were encouraged to think about the similarities between the solutions to the two base analogues, there was not a large amount of transfer to the Radiation problem without a hint that the base analogues were relevant to the new problem. Lowenstein, Thompson, and Genter (2003) also found only moderate levels of spontaneous analogical transfer in a very different situation, in which people were taught strategies of negotiation.

It thus seems that spontaneous transfer of base information to an analogous target problem does not occur very frequently in the laboratory. In addition, the moderate level of transfer shown in Table 4.2C may be *inflated*, due to the procedures used in the studies just described. In the transfer studies of Gick and Holyoak (1980, 1983) and of Lowenstein and colleagues (2003), all the information was presented in the same context—as part of one experiment. It is therefore possible that the base information was transferred to the target problem because presenting all the information in one context cued the participants that the base information was relevant to the target. That is, when the target problem was presented, the participants might have tried to figure out why all the earlier problems had been presented, and they then might have deduced that there must be some connection between the base and the target. Perhaps if the base had been presented in a context different from the target, there would have been no spontaneous retrieval of the base, and therefore little solution of the target.

Spencer and Weisberg (1986) presented two base analogues—the Gen-

eral and Red Adair—in one context (as part of a psychology experiment on story comprehension, conducted by a visitor at the beginning of a class; students participated for extra credit), and the target Radiation problem in a different context (as part of a class discussion of problem solving conducted by the professor approximately five minutes after the visitor had completed the “experiment” and left). When the base and target were presented in different contexts, Spencer and Weisberg found no transfer of the base analogues to the target without a hint. So, even though all the information was presented in the same physical situation (i.e., in the same classroom), separating them psychologically (by labeling them as an experiment versus a class discussion) completely eliminated transfer. (See also Catrambone and Holyoak, 1989, and Holyoak and Koh, 1987.)

The implications of these results are clear: The memory search that takes place when people try to solve problems is very restricted in nature. We do not range over everything we know when we are trying to determine how to deal with a problem. Furthermore, the negative results concerning analogical transfer of knowledge are not an isolated phenomenon in problem-solving studies; lack of transfer has been found in many other problem-solving situations (e.g., Perfetto, Bransford, & Franks, 1983; Weisberg, diCamillo, & Phillips, 1978).

Laboratory Studies of Transfer in Problem Solving: Conclusions

Laboratory studies of transfer in problem solving have consistently shown either a lack of transfer or modest amounts of transfer. Those negative results, although obtained from experiments using small-scale laboratory problems, may have something general and potentially important to tell us about human creative thought. In analyzing the negative-transfer results, one could say that people have difficulty accessing base information when the target is only distantly related to it. The Radiation problem and the General and Red Adair, for example, are from very different or “remote” domains, and that may be the critical element that makes the base knowledge inert. Put in different terms, one could say that participants do not deal with very abstract principles when they work through problems. Rather, the solution to a problem seems to be tied to the specific objects that were in the problem, and when a new target problem contains different objects it will not retrieve a potentially useful base problem. In other words, the thought processes involved here are not based on abstract principles but are rather concrete in nature.

As an example, let us assume that people who were exposed to the General problem had stored in memory a summary or rule (or Gick & Holyoak’s [1983] “schema”), something like this: “If you are trying to solve a problem in

which you must apply a strong force to destroy an obstacle, and you cannot apply that force all at once, try to break it into smaller parts and apply the parts at the same time.” If the Radiation problem had then been analyzed as a problem with an obstacle to be overcome through the application of a large force, and so on, then positive transfer might have occurred. The consistent lack of spontaneous transfer in the studies that we have examined indicates that people do not typically analyze problems—problems that they have solved and problems that they newly encounter—at a high level of abstraction.

Transfer in the Real World versus the Laboratory: The Analogical Paradox

We have just seen that it is sometimes very difficult to produce analogical transfer in the laboratory. When one examines scientific thinking in the world, however, one finds numerous examples in which analogical transfer does occur (Dunbar, 1995). One already familiar example is Watson and Crick’s use of Pauling’s alpha-helix as the basis of their theorizing about DNA. Thus, according to Dunbar, there is what one could call a *paradox* concerning analogical transfer: Why is transfer so hard to obtain in the laboratory but easy to find in real life? There are a number of possible reasons why analogical transfer might be more likely in the real world than in the psychological laboratory. First, concerning the double helix, both the base (the alpha-helix) and the target (DNA) were part of Watson and Crick’s domain of research. That is, the alpha-helix and DNA comprise a *regional analogy* (Dunbar, 1995). Watson and Crick’s knowledge about the subject matter of their domain included both molecules, which would be expected to facilitate transfer. A number of additional examples of analogical thinking are discussed in the case studies of creativity presented in the next chapter. It will be of interest to examine how “remote” or “distant” those analogies are, since one question of interest in analyzing creative thinking is whether seminal creative advances might be built on analogies that are more remote than those used by ordinary folks in their activities. Based on the perspective underlying this book, one would not expect that to occur; that is, analogies serving seminal creative advances should be no more remote than the analogies used by ordinary folks.

A further point worthy of note concerning Watson and Crick’s use of the analogy between Pauling’s alpha-helix and DNA is that Watson and Crick were experts in their domains, so they possessed formal abstract descriptions of both of the molecules in question, which also would facilitate transfer. Watson and Crick presumably described both the alpha-helix and DNA in abstract terms, which facilitated spontaneous noticing of the possible link

between them. So expertise in an area may make analogical transfer more likely to occur, even if the base and target are from distant domains. I will shortly discuss the role of expertise in problem solving more generally, and the next chapter considers the role of expertise in case studies of creative thinking.

It is worth pointing out that in the analogical transfer situations that scientists encounter in their work, analogical transfer may be easier to accomplish than in the laboratory studies in which naive undergraduates are tested. In the scientists' activities, there is a broad and deep database of local and regional information that can be relatively easily retrieved by a new target situation. In the experimental studies of Gick and Holyoak (1980, 1983) and those following them, in contrast, the base and target are only remotely related, which makes spontaneous transfer much less likely.

Applying Retrieved Information to the Target: Studies of Mapping

Once some base information from memory has been retrieved by a problem, that information has to be applied to or *mapped onto* the new problem. As an example, if presentation of the Radiation problem reminds a person of the General problem, he or she still has to work out the specifics of how the solution to the latter can be adapted to solve the former. The person must realize that the fortress the general is attacking is analogous to the tumor, that the army is like the rays, and so on. Ross and colleagues (e.g., Ross & Kilbane, 1997) have demonstrated the difficulties that sometimes arise during mapping. In Ross's studies, statistics problems were used, and participants were given two sets of problems, with some of the problems from the first set related to problems in the second. In these studies there are thus multiple base-target pairs. Examples of problem pairs used by Ross are shown in Table 4.3. The same principles are involved in each pair, and the principle, in the form of a formula, is presented along with each problem. The objects in the problems may change roles from the base to target problems, however. In another problem pair, for example, in the base problem, each mechanic decides which person's car to work on. In the target problem, the owners of the cars pick the mechanics.

The question of interest once again is whether exposure to the first set of problems will produce better performance on the target problems in the second set, and once again positive transfer is the exception rather than the rule. Ross found that if the base and target problems contained the same objects but in different roles (see Identical story-line test in Table 4.3), then transfer did not occur. This was true even though the same statistical principle was involved in both problems, and even though the formula was presented along with the target problems. In this situation there was no

Table 4.3 Sample study problem and test problems used in Ross's experiments

Study problem (to be paired with each problem below) The knights of Nottingham County were to have a jousting tournament. To test who was the best joust, the 8 knights participating in the joust had to use one of the Prince's 11 horses. The knights randomly chose a horse, but the choosing went by the weight of the knight in armor (heaviest choosing first). What is the probability that the heaviest knight got the biggest horse, the second heaviest knight got the second biggest horse, and the third heaviest knight got the third biggest horse?
Identical story-line test problem^a Nottingham County was known throughout the kingdom for conducting the most unusual jousting tournament. Every year the wizard cast a spell on the Prince's 29 horses so that they could talk. Then, the horses chose from the 24 knights who would have the honor of riding them in the tournament. Each horse randomly chose a knight, but the choosing went by the size of the horse (biggest choosing first). What is the probability that the heaviest knight got the biggest horse, the second heaviest knight got the second biggest horse, the third heaviest knight got the third biggest horse, and the fourth heaviest knight got the fourth biggest horse?
Dissimilar story-line test problem^a The Puppy Pound Palace was having an open house to help find homes for their 29 new puppies. The 24 children who came were very excited about getting friendly puppies. Unfortunately, the children continually fought over who would get which puppy. To be fair to all, the curator decided to let the puppies choose their new masters. Each child's name was scratched into a puppy treat and put in a dogfood bowl. Each puppy went and fetched one of the puppy treats to choose a child. The choosing went by age with the youngest puppy choosing first. What is the probability that the youngest child got the youngest puppy, the second youngest child got the second youngest puppy, the third youngest child got the third youngest puppy, and the fourth youngest child got the fourth youngest puppy?

^a Reversed object correspondences from study.

potential “challenge” to retrieval; since the participants knew which base and target went together, there was no chance for inert knowledge to surface. However, having the objects reverse roles from base to target made it very difficult for people to use the solution from base problem to solve the target. This finding provides further evidence that the formula was not understood as an abstract principle but, rather, was “embodied” in the specific objects from the problem in which it was first encountered. Once again we see that thinking is not being carried out in very abstract terms.

Transfer in Problem Solving: Factors Influencing Retrieval versus Mapping

We have now seen evidence for the importance of the processes of retrieval and mapping in transfer of knowledge to a target problem. Gentner, Rattermann, and Forbus (1999) have sought to determine the factors that play a role in each process. Gentner has proposed that “surface similarities”—objects in common—are critical in retrieval of a base analogue when a target problem is presented. However, once a candidate analogue has been retrieved through overlap of objects “on the surface,” whether people will be able to apply the base to the target depends on the structural relations between the base and the target. The relations among the objects in the base and those among the objects in the target must be the same, or people will have difficulty applying the information from the base to the target. In one study, people were exposed to a set of 32 short stories. About a week later, they were given another set of stories and were asked if any of the new stories reminded them of any of the old ones. When a new story contained the same objects as one of the old ones, that increased the likelihood that the old story would be retrieved by the new one (the new story reminded the person of the old). The participants were then asked about the usefulness of the retrieved old story in understanding the new situation (i.e., the one that had brought it to mind). The people said that the old story was helpful in understanding the new situation only if it contained the same relationships among the objects as in the new one.

So even though a new target problem might remind you of something from your past because the new problem contains the same objects as the previous situation, that old experience might not be useful in solving the target problem. We see here evidence that retrieval and mapping are separate processes, controlled by different aspects of the stimulus situation.

Transfer in Problem Solving: Conclusions

There has been much research examining problem solving based on transfer of information to a new problem from an analogical situation. In carrying out analogical transfer, the person possesses some knowledge applicable to the problem situation that he or she is facing, and the critical questions become (1) whether he or she will be able to retrieve that knowledge when it will be helpful and (2) whether he or she will be able to apply (map) the old solution to the new problem. Studies are consistent in demonstrating the complexities involved in successful analogical transfer: Base knowledge may be inert, and if so it will not be retrieved by the presentation of the target problem. This is especially likely if the base and target are presented in different contexts (Spencer & Weisberg, 1986). Even

when the base is retrieved by the target (i.e., when presentation of the target brings the base to mind or reminds the person of the base), there may still be difficulties in applying the base solution to the target.

Strong Methods in Problem Solving: Studies of Expertise

We have now begun to examine a range of problem-solving methods, which can be looked upon as being on a continuum, depending on how much problem-specific information is involved. At one end are the weak methods discussed in the last chapter; examples included working backward and means-end-analysis, which are very general strategies. In analogical transfer, the overlap between the target and base problems is more specific, but it is still only at the level of structure. The two analogous situations (e.g., the atom and the solar system; the General and Radiation problems; DNA and alpha-keratin) may not have objects in common, but the structural relations among the objects are similar. If one ignores the objects, then the General problem is similar to the Radiation problem. Similarly, ignoring specifics, DNA and alpha-keratin are similar in various ways, as already discussed.

Cognitive psychologists have also examined circumstances in which a person possesses deep knowledge that is directly relevant to the problem at hand: One may be an *expert* in the domain of the target problem. There is much evidence, from a variety of domains, that possession of expertise can greatly facilitate problem solving. The expert, through years of immersion in a domain, is able to apply to a problem what have been called *strong methods*; that is, specific methods directly applicable to the type of problem in question. This would be an example of problem solving using top-down processes, as the strong method serves to direct the individual's activities. We have already seen evidence of this in examining the paradox of analogical transfer proposed by Dunbar (2001). The problem-solving process is changed significantly by the development of expertise. I will now review laboratory studies of the role of expertise in high-level functioning, including problem solving.

Expertise: A Question of Definition

The terms *expert* and *expertise* have meanings in the research literature that are a bit different from those in ordinary language. In the literature, an expert is someone who exhibits consistent superior accomplishment as the result of *practice* (e.g., Ericsson & Smith, 1991). In ordinary conversation, we also use the term *expert* to refer to a person who exhibits a high degree of competence in some area, irrespective of how that competence

was acquired. For example, the professor in the office next to mine is a neuroscientist whose area of specialization is the neural structures underlying learning. According to the definition of expertise typically used in the literature, she is not an expert, because she did not acquire her competence through deliberate practice. Drawing this distinction is obviously difficult when one is examining scholarly domains, for example, where competence comes through study rather than practice. Therefore, in this chapter I will use *expertise* in the ordinary sense, to refer to the capacity to perform consistently at a superior level as the result of experience, without regard to how that capacity was acquired. One can become an expert as the result of practice or study, or both (see also Weisberg, 2006).

Expertise and Problem Solving in Chess

A pioneering study demonstrating the importance of expertise in problem solving was carried out by De Groot (1965), who examined the skills of chess masters—people who play at world-class levels. De Groot's was the first modern work that emphasized the top-down, concept-driven, or knowledge-based nature of problem solving, and De Groot's method and findings attracted many other researchers to the study of expertise. Many different areas were then examined, including expertise in musical performance, medical diagnosis of several sorts, and athletic performance (see, e.g., chapters in Ericsson, Charness, Feltovich, & Hoffman, in press).

De Groot (1965) examined the question of how chess masters choose the moves they make. Chess is a game with a very large problem space, and one might think that chess masters would search that space more extensively than would nonmasters. For example, let us say that it is the middle of a game and it is my turn to move. I pick a possible move, and then I reason in something like the following way: “I could make this move, then she could do that, then I could do this, then she could do that. . . .” That is, I imagine what might happen when I make that move; in other words, I carry out planning, based on imagination. The more possible outcomes that I can imagine for a given move (I do this, then she does that, then I do, then she does, then I do, then she does . . .), the *deeper* is my search. Therefore, one possible explanation of the master's skill is that he or she searches more deeply than do nonmasters. Figure 4.2A presents a concrete representation of this search.

In addition to searching deeply, the master might go through those imagined scenarios for many different possible moves. The more different possible moves one starts with, the more *broadly* one is searching. See Figure 4.2B for a representation of breadth of search. So we have two components to search: *breadth* (how many moves one considers in the first place) and *depth*

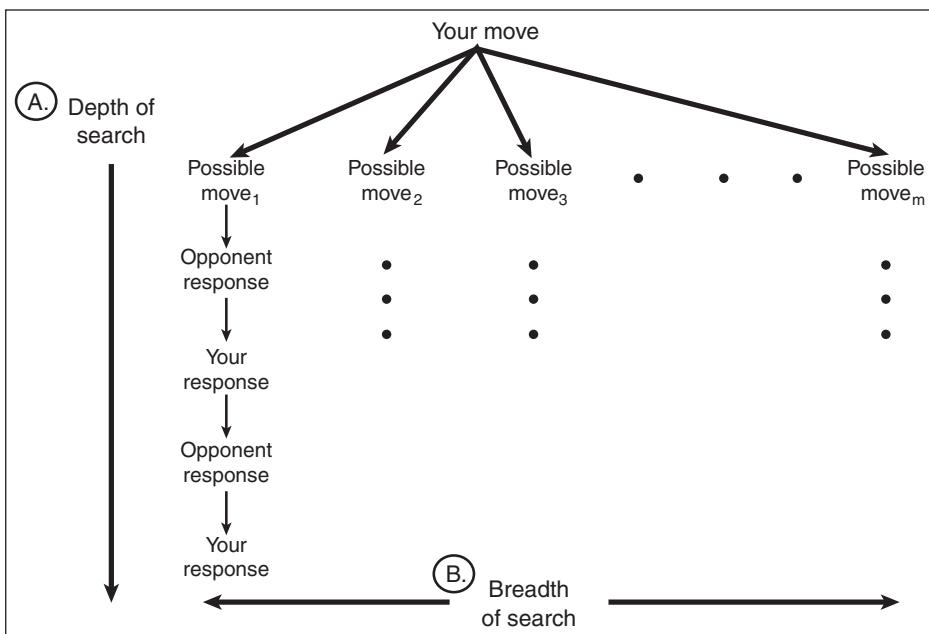


Figure 4.2 Depth and breadth in searching a problem space for chess

(how much detail with which one considers the outcomes of each of those moves). Based on this reasoning, the better a player someone is, the more broadly and deeply he or she might be able to analyze the possible moves.

In order to test the possibility that better players search more broadly and deeply, De Groot (1965) gave chess players of different levels of skill the problem of choosing a move in the middle of a game. Important chess games, such as those from championship tournaments, are recorded in chess books, so there is a whole literature available documenting the history of chess. De Groot used those games as stimulus materials. He had the players produce verbal protocols as they tried to solve the problem of choosing the next move. Based on the analysis in the chess literature, there are agreed-upon “best moves” in those situations. De Groot found that the masters did not examine more possible moves than did the less skilled players. That is, masters did not search more broadly than did players of lesser skill. The masters almost always very quickly found what turned out to be the best or near-best move. Players of lower levels of skill, even though they might be very good players, spent time considering moves that the masters never even considered.

De Groot (1965) concluded that many times the master simply looks at the board and *sees* or *recognizes* the good moves, rather than having to

think about or analyze which moves might be best. The master is able to “see” the best moves because, through years of study and play, he or she has in memory a large number of chess positions and the moves that work best from those positions. That is, the master is able to recognize a new game position as at least somewhat familiar, and this provides information to use in selecting a move. For the chess master, playing chess is at least partially a task in which positions are recognized on the basis of top-down processing, based on memory.

Although master chess players use recognition as an important component of their expertise, once the one or two best moves have been recognized, the master then spends time analyzing those moves in depth to determine what is indeed the best move in that position. This analysis involves search, such as that outlined earlier. Sometimes during this analysis of a possible move the master discovers an even better move. In order to carry out such detailed in-depth analysis, the master must be able to think in complex terms about the game. To use terminology we have already discussed, the master must be able to form and maintain a detailed internal representation of the game (Ericsson, 1999; see Chapter 3). Evidence of the master’s detailed representation of chess games comes from demonstrations that blindfolded masters can play—and win—numerous games simultaneously. In order to do that, the master obviously must be able to maintain in memory detailed information about each game. Thus, as a result of years of studying and playing chess, the chess master possesses rich knowledge of the game, which is used in thinking about chess.

De Groot (1965) used a memory test to obtain evidence of the importance of the chess master’s knowledge in his or her responses to game positions. Chess players of varying levels of skill were presented with chess positions from the middle of master-level games, as shown in Figure 4.3. The positions were taken from chess books, and each contained approximately 25 pieces. The board was presented for 2–10 seconds and then covered. The player was then given an empty board and a set of pieces and instructed to reproduce the just-presented stimulus. De Groot found that masters were essentially perfect in replacing the pieces after only a few seconds viewing the board. Players of lesser chess skill performed less well on the memory test; for example, an expert might replace 15 pieces correctly, while a person with a beginner’s knowledge of chess might replace 5–7 pieces correctly.

One might respond to these memory results with a yawn; so chess masters recall chess positions well, so what? Having a great memory must be one of the requirements for becoming a chess master in the first place. However, Chase and Simon (1973a) replicated and extended De Groot’s study, and they included another condition that demonstrated that chess masters do not

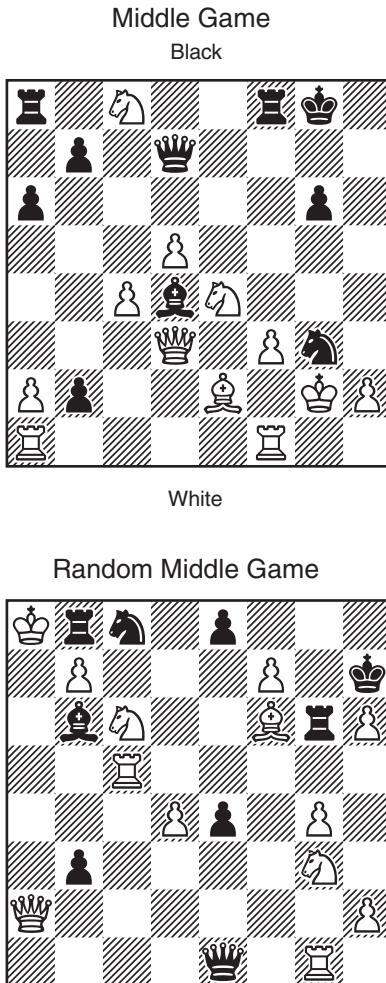


Figure 4.3 Example of chess board position used in memory experiments
 Note: Subjects are shown a 5-second glance and then have to reconstruct as much of it as they can.
 Source: Chase and Simon (1973b).

have great memories, per se. Chase and Simon added a control condition, identical to the one just discussed except that the pieces on the stimulus chess board were placed *randomly*, rather than in positions taken from chess games. Under those circumstances, the chess masters recalled no more pieces than beginners did. Thus, chess masters do not have great memories, they just have great memories for master-level chess games.

The 10-Year Rule

Chase and Simon (1973b), in their extension of De Groot's work, also attempted to determine how the chess masters' knowledge was used in analyzing and recalling chess positions. They recorded eye movements that players made when they were studying the board in the first place, and they also analyzed how the pieces were put on the board during the memory task. In both cases, the players dealt with the board as *clusters of pieces*, or *chunks* of pieces, that were meaningful in chess. When the players initially studied the board that they were later to recall, they looked at groups of pieces that went together in the game, such as a queen and pawns that were protecting each other, and they tended to put those pieces back on the board together during the recall task. Thus, where a person ignorant of chess would see three or four separate pieces, the expert would see one *chunk*, made up of three or four *related* pieces, and would thereby be able to recall several times as much. Thus, expertise or top-down processing plays a role in how one directs one's attention when one is analyzing a complex situation. Once one has looked at one part of that situation, where one looks next—where one directs one's attention—depends on what one knows about the situation. When one is attempting to recall information from that situation, where one directed one's attention predicts what one will recall.

If it is true that chess mastery depends on knowledge about chess that is based, at least in part, on knowledge about chunks of related pieces, the next question concerns the extent of the masters' knowledge. That is, how many different patterns of chess pieces might masters be able to recognize? Chase and Simon (1973a) estimated that the chess master was able to recognize 50,000 chunks from chess games and use those as the basis for playing the game and, in De Groot's (1965) experiment, for recalling the board positions. That number of chunks might seem absurdly large, until one realizes that ordinary adults can recognize more than 20,000 words in their native language. When one considers how much time chess masters spend studying chess games and playing chess, it is clear that they would have ample time to learn that number of chunks. Chase and Simon concluded that in order to reach world-class performance in chess, one needs to spend at least 10 years deeply immersed in chess. Only this level of commitment can result in the development of the knowledge base assumed by Chase and Simon to be necessary for performance at the highest level. This finding, which has become known as the *10-Year Rule*, has been found to hold in many domains, including several that involve creative work, such as musical composition and the writing of poetry (Hayes, 1981; Weisberg, 1999). Those results, to be discussed in more detail in the next chapter, point to a common top-down

thread tying together recognition, attention, memory, problem solving, and creative thinking.

Expertise in Physics

De Groot's (1965) study of expertise in chess led to examinations of the possible role of expertise in problem solving in many other domains, including physics, where problem-solving performance of experts versus novices has been compared. Physics problems are of interest to cognitive psychologists because the problem solver can analyze them in at least two ways: (1) at the *surface* level, on the basis of the *objects* involved, or (2) on the basis of the *underlying principles of physics* that are required to solve each of them. When physics novices (students who have just completed their first course at the university level) are given problems, they often deal with them on the basis of the objects they contain, such as an inclined plane, a spring, or a pulley system, rather than the abstract principles of physics that each problem exemplifies, such as Newton's Second Law of Motion. One can design a pulley problem, an inclined-plane problem, and a problem involving a spring so that they all require Newton's Second Law for solution. The novice students would ignore the Newton's-Second-Law aspect of the problems, however; instead, they would approach in a similar way any problems that contained inclined planes, say, or pulleys, not realizing that two pulley problems can require very different principles of physics for their solution. Physics experts (college physics professors or graduate students), in contrast, are able to look past the specific objects and focus on the principles. Experts have developed knowledge that enables them to analyze a problem at what one could call the conceptual level, and thereby focus on the relevant components of the problem.

Chi and colleagues (1981) obtained similar results when they asked experts and novices to sort a set of physics problems into groups of similar problems. A sample of sorted physics problems is shown in Figure 4.4. The novices sorted problems together that had the same sorts of objects in them, such as springs, inclined planes, or pendulums. The experts grouped together problems that were solved using the same principles, such as Newton's Second Law, even though the objects involved in the problems might not be very similar. Again, the experts were looking past the objects to the underlying concepts.

Practice and Expertise in Musical Performance

The discovery of the 10-Year Rule in the development of expertise in chess led to studies that have examined the development of expertise in other areas. One factor that has been implicated is *deliberate practice*: the

The Cognitive Perspective on Creativity, Part II

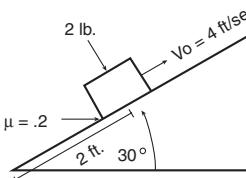
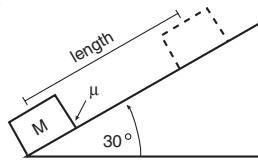
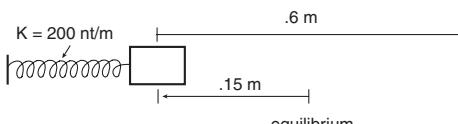
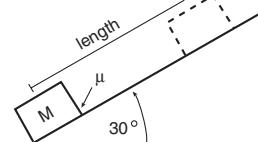
Novices:	Grouping	Explanation
Problem 23		Novice 1: "These deal with blocks on an <i>incline plane</i> " Novice 5: " <i>Inclined plane problems, coefficient of friction</i> " Novice 6: "Blocks on <i>inclined planes</i> with angles"
Problem 35		
Experts:	Grouping	Explanation
Problem 21		Expert 2: " <i>Conservation of Energy</i> " Expert 3: " <i>Work-Energy Theorem</i> . They are all straightforward problems."
Problem 35		Expert 4: "These can be done from energy considerations. Either you should know the <i>Principle of Conservation of Energy</i> , or work is lost somewhere."

Figure 4.4 Example of sortings of physics problems made by novices and experts

Note: The sortings of the novices (top two problems) rely largely upon surface features, such as whether the problems include an inclined plane. The sortings of the experts, however, focus on the underlying principles, such as conservation of energy, for the bottom two problems

Source: Chi, Feltovich, and Glaser (1981).

repetition, often under the supervision of a teacher or coach, of specific elements of skill that the individual wishes to improve. An individual does not reach world-class levels of performance in any domain simply by participating in the activities in that domain. For example, one does not become a great tennis player just by playing a lot of tennis. Rather, one must practice specific aspects of the skills that one wishes to acquire, under the watchful eye of a teacher or coach.

Ericsson, Krampe, and Tesch-Römer (1993) studied the development of expertise and its relation to deliberate practice in four groups of musicians of different levels of skill. One group was made up of elite professional violinists who were members of world-class symphony orchestras; the other three groups were students at a prestigious music school who were classified at three different levels of skill based on performance and teacher assessments. The best students were those designated by their teachers as probably being headed for careers as soloists or members of elite orchestras; the lowest level of students were preparing for careers as teachers of violin playing. All the musicians, professionals and students, were interviewed concerning their activities, musical and otherwise, and the groups of students were asked to keep diaries of their activities over a week.

Results indicated that the professionals spent more time practicing than the students did, and also more time sleeping; this supported the idea that practice was effortful and necessitated sleep for recovery from the effort expended (Ericsson et al., 1993). The better student violinists had begun study of the violin earlier in life than had the other students and had practiced more throughout their careers. The highest-level student violinists had accumulated more than 10,000 hours of practice by the age of 20, compared with approximately 8,000 hours for the good violinists and 4,000 hours for those of lowest skill. (It should be kept in mind that all the students were good violinists, since the music school was one of the best.) A second study, of high-level pianists, found similar results.

Ericsson and colleagues (Ericsson, Krampe, & Tesch-Römer, 1993) concluded that the different levels of achievement were the result of the different levels of practice that the musicians and students had engaged in during their careers. To reach the highest levels of achievement, it was necessary to practice at the highest levels. The same conclusion can be drawn from interview studies conducted by Bloom and colleagues (Bloom, 1985), who interviewed highly successful individuals in each of several fields, including athletes (tennis players ranked in the world's top 10 and Olympic swimmers), musicians (award-winning piano soloists), artists (award-winning sculptors), and scientists (neurologists and mathematicians who had been recognized for excellence in early career development). In all these fields, achievement

of excellence came about only after years of practice in the activity. Bloom and his colleagues also found that, although the individual who achieves the highest level of achievement in any domain must be committed to full-time involvement in the domain, one does not achieve expertise on one's own. Every case of world-class achievement depended on strong support by a network of individuals, including parents and coaches. In many cases, parents rearranged their schedules to allow the developing performer to attend lessons and competitions, often driving for hours to ferry him or her from practice sessions to performances. Sometimes families would move across the country so that the child could study with a renowned teacher or coach.

Expertise and Practice: Questions of Causation

Let us assume that there is a general positive relationship between expertise and practice, as shown by Ericsson and colleagues (1993) in the performance of musicians: More practice is related to higher levels of success. Ericsson and colleagues concluded that the differential levels of practice are what made the groups different in performance; that is, the practice *caused* the differences in abilities. However, the study carried out by Ericsson and colleagues does not allow one to draw conclusions about causal relations among variables. All we have in that study is a correlation between two variables, which does not allow us to conclude that one variable causes the other. For example, it is equally possible that the different levels of abilities are what caused the differences in practice. Perhaps people differ in their native abilities in different areas. We are all familiar with this idea, under the name of *talent*. Perhaps higher levels of talent drive people to practice more, and talent differences caused the results found by Ericsson and colleagues. This is a critically important question in addressing the issues of expertise, practice, and creativity, and it will be discussed more fully in a later section.

Expertise and Performance: Conclusions

It has been demonstrated by many studies that high-level performance in many domains is related to deep knowledge or expertise within that domain, acquired through study or deliberate practice. In carrying out problem-solving activities, such as in chess or physics, the expert is able to home in on the crucial elements of a problem in a top-down manner because of the rich database that he or she brings to the problem situation. The expert's domain-specific knowledge is directly relevant to the problem at hand. This means that retrieval of relevant information presents no difficulty, since the knowledge comes from the same domain as the problem. For example, a chess master uses chess knowledge to solve chess problems; a physics expert uses physics knowledge, and so forth. Similarly, Watson and Crick used their

expertise to grapple with the problem of the structure of DNA. Even in domains that may not involve problem solving, such as musical or athletic performance, individuals use expertise in the domain, acquired through years of deliberate practice, as the basis for their performance. There is little doubt that expert performance and massive amounts of deliberate practice are related; as noted, in a later section we will consider the question of the possible causal relations between expertise, talent, and practice.

Outline of a Cognitive-Analytic Model of Problem Solving: Strong and Weak Methods in Problem Solving

We can summarize the discussion of the cognitive perspective on problem solving, as presented in this chapter and the last one, by saying that problem solving is built on the notion of search through a problem space. Methods of varying degrees of specificity (strong versus *weak* methods) are applied to problems, depending on the amount of problem-specific knowledge the individual possesses. At the highest level of specificity of knowledge, a scientist will typically apply strong methods in carrying out the analysis of a phenomenon within his or her area of expertise; such methods depend on the availability of information directly relevant to the problem at hand. For example, as discussed in Chapter 1, Franklin's information concerning the structure of the unit cell of DNA provided Watson and Crick with information that, because of their expertise, was directly relevant to the determination of the structure of the molecule.

Moving away from situations in which a person has expertise and can apply strong methods to a problem, we come to situations where a person has available a solution from an analogous problem that can serve as the basis for dealing with a new one, through analogical transfer. As noted earlier, in formulating the structure of DNA, Watson and Crick used their knowledge about Pauling's work on alpha-keratin, a molecule analogous to DNA, to guide their work. The information gleaned from the analysis of alpha-keratin was not directly relevant to the problem being solved—as the new information about DNA from Franklin had been—but it was still useful and turned out to be critically important. Finally, a person solving a problem about which he or she has little or no information—say, someone trying for the first time to solve the Towers of Hanoi or Missionaries and Cannibals (see Table 3.3)—must rely on weak heuristic methods, such as working backward from the goal. Applying reasoning processes to a problem, in an attempt to deduce the solution from the information given, is another weak method. Weak methods apply to any particular problem only in general terms and therefore may not facilitate solution.

In this view of problem solving, the first step in attempting to solve a problem is trying to match it with one's knowledge. The method that one attempts to apply to the problem is the result of that match. In using any of those methods, one applies knowledge and reasoning skills, as best one can, to analyze the problem and determine what to do. We can include those various modes of solving problems, based on degrees of specificity of knowledge about a problem, under the general category of *analytic* methods. When using analytic methods, even weak methods, you have at least a general idea as to how you are going to proceed; any specific solution method that develops can be seen as growing out of that idea, and you usually have a feeling as to whether you are making progress.

Based on this summary of the discussion in this chapter, we can outline a model—shown in Table 4.4—that deals with the role of knowledge, as exemplified by strong and weak methods, in problem solving. I call this a *cognitive-analytic* model, because it comes out of the cognitive perspective, and, as noted, the methods that it postulates can be called analytic methods of problem solving. The model assumes that the first step in dealing with any problem is an attempt to match the situation with the person's knowledge; that is, the model is based on the top-down conception of human cognition, discussed earlier (see Figure 3.1B, p. 116). The person analyzes the problem using his or her knowledge about the situation. If the person possesses expertise in the area, there will be a relatively precise match between the problem and the individual's knowledge, which will result in the person's retrieving

Table 4.4 Cognitive-analysis perspective: Stages in solving a problem

Stage 1: Solution through application of strong methods
1. Problem presented \Rightarrow attempt to match with knowledge <ul style="list-style-type: none">A. No solution available \Rightarrow Stage 2B. Successful match with knowledge \Rightarrow transfer solution based on expertise or analogyC. If solution transfers successfully \Rightarrow problem solvedD. If solution fails \Rightarrow Stage 2
<i>Comment:</i> If no match is made with memory, person goes to Stage 2; if match is made, solution is attempted. Can result in solution of the problem.
Stage 2: Solution through direct application of weak methods
2. Failure at Stage 1A \Rightarrow analysis based on weak methods <ul style="list-style-type: none">A. Analysis successful \Rightarrow solutionB. No solution \Rightarrow impasse; problem not solvable
<i>Comment:</i> Person works through problem using weak heuristic methods, trying to develop solution; if successful, problem is solved.

a solution method that fits the problem reasonably closely. This outcome is shown in Stage 1B of Table 4.4, and it results in a solution attempt based on analogical transfer or expertise. If the solution transfers successfully, then the problem is solved. If there is no success, then the person attempts in Stage 2 to apply weak heuristic methods to the problem. If this is successful, then the problem is solved. If no weak methods are successful, then the person fails to solve the problem and gives up. This simple outline serves to summarize the discussion of problem solving presented so far, and it will also, with some elaboration, be useful in later discussions.

Weak Heuristic Methods, Analogical Transfer, and Expertise: Points on a Continuum

We have now examined what seem to be three categories of methods of problem solving: use of weak heuristic methods, analogical transfer, and expertise. However, it may be more useful, as well as simpler, to consider those different categories to be points on a continuum of generality-specificity of expertise, rather than being separate modes of problem solving (Weisberg, 2006). One could say that heuristic methods are very general methods that have developed out of a wide range of a person's experiences. Because they have come out of experience with a broad range of situations, they are not specifically useful in any particular situation, but they are at least potentially helpful in many. As an example, consider the method of working backward from the goal. That is a method that probably either developed out of one's experiences in many different types of problems or was learned from someone else. In either case, one could say that it is dependent on one's expertise, but expertise in a very broad sense. Similarly, consider a circumstance in which a person uses an analogical situation as the basis for solving a new problem. In this case also one is using one's expertise, but again it is of a general nature (although less general than when one uses a method like working backward from the goal or hill climbing). Finally, when a master chess player uses his or her knowledge of chess to choose the next move in a game, the expertise is domain-specific. Because of that domain specificity, it is directly relevant to the problem at hand, but it may be of little use in problems outside the domain of chess.

The Cognitive Perspective on Problem Solving and Creativity: Conclusions and Implications

This chapter and the previous one have examined the cognitive perspective on problem solving. We have considered in several places Newell, Shaw, and Simon's (1962) claim that what we call creative thinking is just one

example of human problem solving. Concerning the general notion that one can describe creative thinking as problem solving, as was discussed earlier, it seems reasonable to use the term *problem solving* to describe the creation of *Guernica* and the discovery of the double helix. In later chapters we shall consider further the question of whether all examples of creative thinking can be considered problem solving. In their original discussion of creative thinking as problem solving, Newell and colleagues were more specific about several additional aspects of the type of problem solving that qualifies as creative thinking. They very briefly review situations in which creativity occurs, and they conclude that problem solving that is called creative has the following characteristics (Newell et al., 1962, p. 145). (1) The product is novel and of value, for the thinker or for the culture. (2) The thinking is unconventional, in that it requires modification or rejection of previously accepted ideas. (3) The thinking requires high motivation and persistence, taking place either over a considerable span of time or at a high intensity. (4) The problem initially posed was vague and ill-defined.

As can be seen from these characteristics, Newell, Shaw, and Simon (1962) qualify their definition of problem solving a bit in order to deal with creative thinking. As noted earlier, my take on the cognitive perspective is a bit different from that of Newell and colleagues, so it will be of interest to examine the specifics of their definition of creative thinking as problem solving in order to make those differences clear. The differences also hold some implications for our understanding of creativity. Let us briefly examine those characteristics, using when we can evidence from the case studies presented in Chapter 1, as well as from other aspects of the discussion in Chapters 1–3 and the present chapter.

1. *The product is novel and of value, for the thinker or for the culture.* We have already discussed in Chapter 2 reasons for concluding that creativity involves novelty, but not value. In my view, the triple helix of Watson and Crick, for example, was a creative product, even though, when its flaws became clear, it was rejected almost immediately (this is also true of Pauling's triple helix). It is my belief, although I have not carried out the relevant analysis, that the problem-solving process in Watson and Crick's development of the triple helix was the same as that in the development of the double helix. In conclusion, we can agree with Newell and colleagues that problem solving as creative thinking produces novel products, and put value aside.
2. *The thinking is unconventional, in that it requires modification or rejection of previously accepted ideas.* If we examine the two case studies from Chapter 1 as possible evidence for this claim, the results do not strongly

support it. In the discovery of DNA, for example, Watson and Crick took a previously accepted idea—Pauling's alpha-helix—and applied it to an analogous situation. The overarching idea that DNA was helical never was rejected. Obviously, the helix idea had to be modified in its specifics in order to fit the double helix, but that is simply because DNA is a different molecule from alpha-keratin: Those modifications are not significant in terms of the application of the helix *idea* to DNA. If we extend this analysis to *Guernica*, we see again that a previously accepted idea (i.e., the structure of *Minotauromacy*) served as the basis for the new painting. Here too one can conclude that previously accepted ideas were not rejected. Again, it is true that the specifics of the idea were modified when *Guernica* was created, but again that was simply because if the idea had not been modified in some way then Picasso would have just reproduced *Minotauromacy*. There was not a rejection of the old idea; it was more like fine-tuning to adapt the old idea to the new situation. Thus, creative thinking as problem solving does not necessitate rejection of old ideas, although rejection of old ideas no doubt occurs in some examples of creative thinking. We will see examples of the rejection of old ideas in the next chapter.

3. *The thinking requires high motivation and persistence, taking place either over a considerable span of time or at a high intensity.* These characteristics were found in both case studies. *Guernica* was created over a relatively short period of time (approximately 6 weeks), and the dating of the sketches indicates that Picasso did not work continuously on the painting throughout that time (see Tables 1.3 and 1.4). However, he seems to have worked at high intensity, as can be seen when one examines the work done each day that he worked. The discovery of DNA took place over a much longer period of time, and there too the work was intermittent, but during the time that Watson and Crick worked on DNA, they seem to have done so at high intensity.

It should be noted, however, that there are many circumstances in which one works at high intensity in which no creative advances are made. For example, I worked very hard yesterday to analyze some data from a study a colleague and I are working on, and the novelty involved was minimal. All I had to do was to organize the already-collected data into a form that could be analyzed, which involved nothing new in the way of thinking. So high levels of motivation are not unique to situations requiring creative thinking. In addition, it is entirely possible that one could quickly and easily produce a creative response to some situation without working either at high intensity or for a long period of time. So the strong motivational aspect proposed

by Newell and colleagues may not be necessary for creative thinking to occur.

4. *The problem initially posed was vague and ill-defined.* As was discussed earlier in this chapter, this was true in both Picasso's creation of *Guernica* and Watson and Crick's discovery of the double helix. In both cases, top-down processes were used to specify more detail as the projects were worked on. However, it is not only ill-defined problems that require creative thinking: A person who faces the Towers of Hanoi problem for the first time and succeeds in solving it has also carried out creative thinking. It may not be creative thinking of a historically or culturally significant sort, but it is creative thinking nonetheless. Whether any culturally significant creative advances have come about through the solution of well-defined problems is at this time an open question.

As we can see, the qualifications placed on problem solving by Newell and coworkers (Newell et al., 1962) in order to apply it to creative thinking are not necessary. The thinking produces novelty, and it may do so through conventional means (i.e., without rejecting old ideas), and the problem involved is typically ill-defined. High motivation and persistence may be required, but that may be a trivial aspect of those situations: If the problem involved could be solved quickly, then it would not be of any broad significance, and its solution would not have been of note historically. That is, the problem-solving successes for which people are remembered involve hard problems, but solving a hard problem per se does not mean that any extraordinary thinking processes are involved.

The Creative Cognition Approach: A Bottom-Up Analysis of Creative Thinking

The cognitive-analytic model in Table 4.4 is based on the assumption of the critical importance of top-down processes in problem solving. It will be informative in this context to examine a cognitively based model of creative thinking that relies much more on bottom-up processes. Smith, Ward, and Finke (1995; see also Ward, Finke, & Smith, 1995) have developed what they call the Creative Cognition Approach to creativity. Smith and colleagues emphasize that all human cognition is basically creative. As we know, this view forms the core of the cognitive perspective (Newell et al., 1962; Perkins, 1981; Weisberg, 1986). Smith and colleagues also assume that one can view creative thinking as the result of application of ordinary cognitive process, again an assumption in accord with the perspective adopted

here. However, the Creative Cognition Approach presents an analysis of the creative process that is different in its specifics from that presented in this chapter: The way those cognitive processes are organized and used in creative thinking, they assert, is bottom-up in nature. This premise is very different from the top-down organization outlined in the cognitive-analytic model of problem solving in Table 4.4, so it is worth discussing.

Smith and colleagues (1995) proposed a two-stage model of the creative process, shown in Figure 4.5. In the first stage, the individual generates “preinventive forms,” which are ideas or objects that might be useful in creative production but are not yet creative products in themselves. In the second or *exploration* stage of the process, the individual explores the preinventive form to determine if it can be used in a creative manner to solve some problem or in some other way. The authors called this model of the creative process the *geneplore* model, a name that was obtained by combining *generate* and *explore*. The authors discuss examples of creative thinking that they believe correspond to their two-stage outline, such as accounts of Beethoven’s composition process (Ward et al., 1995, Chap. 8) that report that melodies spontaneously came to him, which he then “explored” for their potential as compositions. Similarly, one might apply that analysis to what happened when Watson saw Wilkins’s X-ray photo of DNA at that conference in Naples in 1951 and was excited by it because he thought that it meant that DNA possessed a structure that could be analyzed, although he did not know what that structure was (see Chapter 1). One might say that Watson’s response to Wilkins’s photo was a “preinventive form,” in the sense that Watson set to thinking about DNA, without having any answers. In this case, however, the “preinventive form” originated from the outside; Watson “explored” it through his thinking about the possibility of determining the structure of DNA and, ultimately, through his collaboration with Crick.

The *generation* phase of the creative process can be based on any of a number of cognitive processes. For example, retrieval of information from memory can serve to produce a possibly useful idea; the merits of the idea are then determined through *exploration* of its possibilities. Another way to produce a potentially creative idea is through *transformation* of an existing mental representation into a new one. That is, by imagining a familiar object in a novel orientation, or imagining a group of familiar objects in a new configuration, one might produce a useful novel idea. Smith and colleagues (1995) propose that the generate-explore outline occurs in many creative activities, as when a poet generates candidates for a word or phrase, a novelist generates an outline for a plot, an artist sketches the structure of a painting (see *Guernica*), and a scientist develops a hypothesis concerning some experimental result (Watson and Crick’s use of Pauling’s alpha-helix). Once

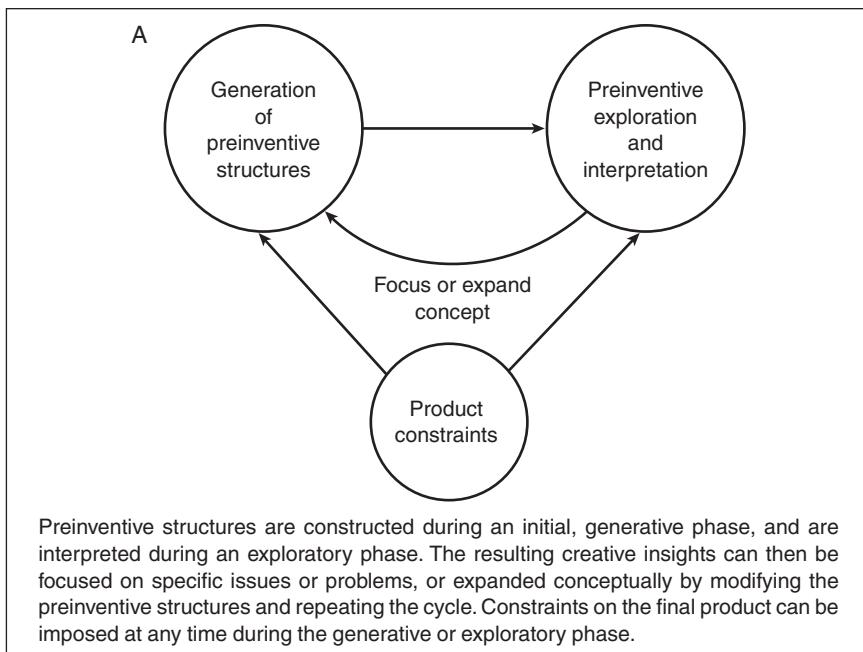


Figure 4.5 Finke's guided-imagery task:
A, Basic structure of the Geneeplore model
Source: For Figure 4.5A, Finke, Ward, and Smith (1992).

a candidate idea has been generated, the exploratory phase might include a poet's search for a metaphorical meaning in a generated phrase, or a scientist's search for experimental results in support of a generated hypothesis.

Ward, Finke, and Smith (1995) have provided support for the geneeplore model of creativity by showing that structured use of generation-plus-exploration in a controlled laboratory setting can facilitate the production of creative products. Experimental participants were shown drawings of simple forms, such as those shown in Figure 4.5A, and were instructed to take three forms randomly chosen by the experimenter and use imagery to combine them into an "interesting-looking" new object that might be useful in some way. This method is based on what one could call guided imagery. No restrictions were imposed on the types of forms to be generated; the only requirement was that the three chosen forms be combined into something new. These forms were preinventive forms, because they did not yet have any use. Some examples of preinventive forms generated by experimental participants are shown in Figure 4.5B.

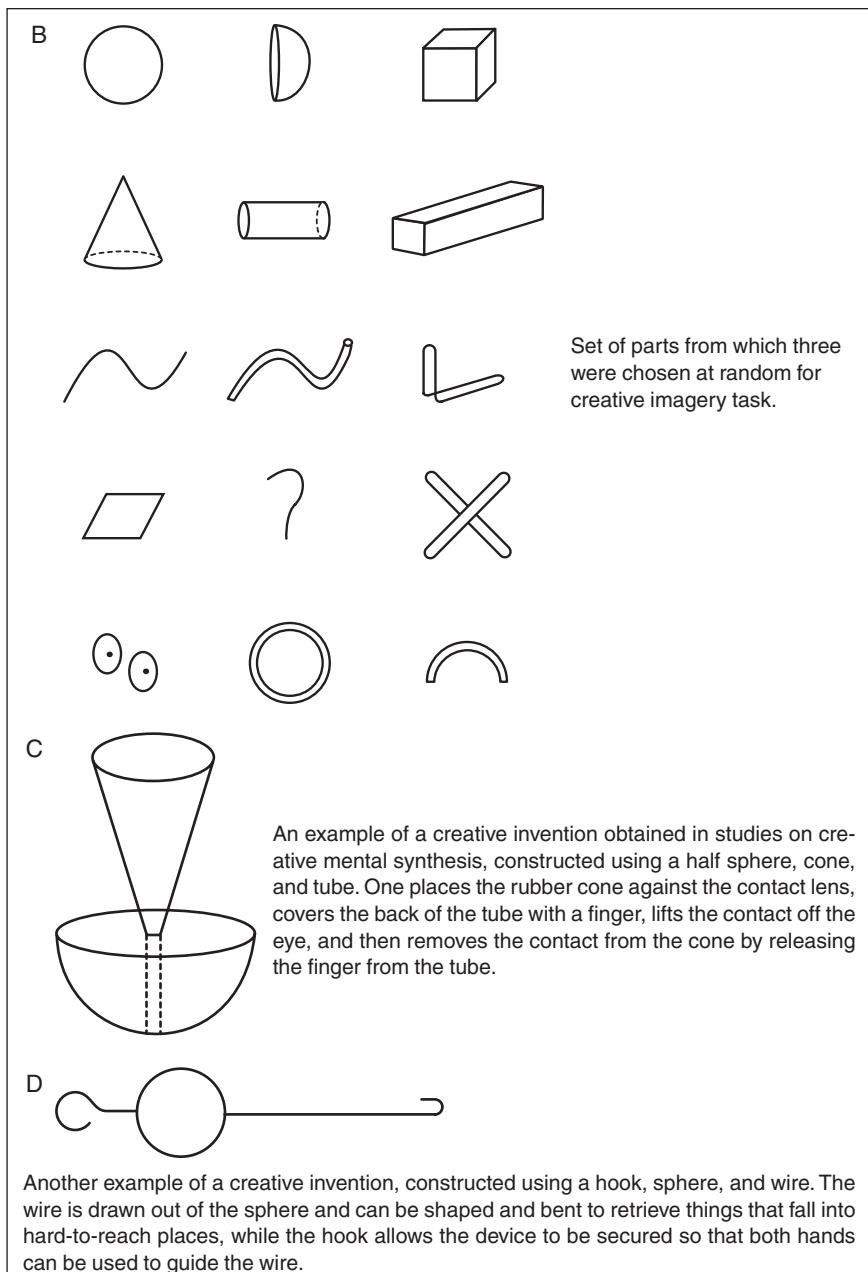


Figure 4.5 (continued) Finke's guided-imagery task: B, Set of parts from which three were chosen at random for creative imagery task; C, "Contact lens remover"; D, "Universal reacher"

Source: For Figures 4.5B–D, Finke (1990).

The second step of the process centered on exploring the potential usefulness of the forms. After the participants generated the preinventive form, they were given the name of one of eight object categories, shown in Figure 4.5C, and were asked to interpret the preinventive form as a member of that category. Participants were not instructed to be creative, but were asked to think of a way that the preinventive form could be used within the chosen category. A minute was allowed for this task. Fitting the preinventive form into the category changed it from a preinventive form into an invention. The inventions were then given to independent judges to be rated for originality and practicality. Examples of possible inventions produced by this method are shown in Figure 4.5D. In one experiment, participants were given a total of 360 attempts at producing an invention, and 65 of the products (approximately 17 percent) were judged as creative inventions with potential use. If more time was given for interpretation of the preinventive form, a much higher percentage of creative inventions was produced. It is also interesting to note that the category for interpretation of the preinventive form was randomly chosen by the experimenter and presented to the participant after the form had been generated. This means that if another category had been picked, the same form might have been interpreted very differently.

Preinventive forms can also be used as the basis for creative thinking on a more abstract or conceptual level. In a variation of the experiment just discussed, the participant was given a randomly chosen *concept* as the basis for interpretation of the preinventive form, rather than the name of a concrete object. The participants were instructed to interpret the preinventive form as a metaphor for the concept. As an example, if the category chosen were *medicine*, the task would be to interpret the form as a metaphor for a way to prevent a disease or cure an illness. This variation on the procedure turned out to be more difficult than that based on concrete object categories, producing creative outcomes less than 10 percent of the time. However, there were some interesting examples of inventions that were new concepts within the domain. As noted earlier, Ward and colleagues (1995) have used the geneplore model to provide a framework for analyzing in more detail the types of generative and exploratory processes that might play roles in creative thinking.

Limitations on Bottom-Up Processes

The research of Ward, Smith, and Finke (Smith et al., 1995; Ward et al., 1995) can be examined on two levels. First, how valuable is the Creative Cognition Approach as a theory of the creative process? Second, how useful is the method of guided imagery as a technique for stimulating cre-

ative thinking? If we examine the second question first, the guided-imagery technique has been shown under controlled conditions to be an effective method for generating creative products. Many methods have been developed that claim to facilitate creative thinking. That literature is too large to be reviewed here, but the program of Finke and colleagues is one of the few that has been subjected to rigorous testing under controlled conditions and has been shown to be useful. This is obviously a positive feature of the Creative Cognition Approach.

A further question is how broadly relevant the guided-imagery method would be to creative work. For example, guided imagery might be useful if one were an inventor trying to produce some new device and had no specific object type in mind. In such a situation, one might simply carry out a structured-imagery task like that shown in Figure 4.5, and one might be successful. However, such a method might not be useful if one had in mind an object of a specific type—that is, if one were trying to solve a specific problem. If one worked for a company that produced lawn-care equipment, for example, and one's assigned task was to improve the company's line of lawn mowers, then a method such as that of Finke and colleagues might be less helpful. Similarly, if one were a novelist trying to develop a plotline from scratch, the method might be helpful; but what if one were trying to develop a specific scene? Similarly, how would the method in Figure 4.5 have helped Picasso in developing *Guernica* in response to the bombing of the town? Overall, there is some support for the value of the technique of guided imagery in the stimulation of creative thinking, although there are questions as to the breadth of the usefulness of the method.

Concerning the question of whether the Creative Cognition Approach is useful as a theory of the creative process, one may be more skeptical. As noted, the geneplore model of creativity is bottom-up in nature; it assumes that the creative process works best when preinventive forms are generated out of elements that are chosen randomly for the individual. Furthermore, the preinventive forms are generated without the individual's having any idea as to what goal he or she is working toward. Indeed, in the studies we just reviewed that used the guided-imagery technique to foster creative thinking, the "goal" (in the guise of the category into which the preinventive form was to be placed) was also provided from without, and chosen arbitrarily. As we have seen in the case studies discussed in Chapter 1, there was little in the way of isolated bottom-up processes in either Picasso's creation of *Guernica* or Watson and Crick's discovery of the double helix. In both of those cases, it is difficult to see a "preinventive form," created out of randomly chosen elements, which was then "explored" in order to assess its creative possibilities.

Picasso, for instance, did not first generate a preinventive form and then explore a use for it. Rather, as can be seen in the earliest composition sketches, from the beginning Picasso had a structure in mind, and that structure was generated from his data bank, as stored in the form of *Minotauromacy*. *Guernica* was not created by combining a set of objects designated arbitrarily by Picasso or someone else. The way Picasso produced composition sketches does not seem to fit the notion of a preinventive form. Similarly, when Watson and Crick discovered the double helix, there was nothing of a bottom-up nature about it; from the beginning, they were working under the assumption that the molecule was helical, which was a top-down conception. Similar top-down processes have been seen in a wider range of problem-solving situations in the last two chapters. Such findings raise questions about any model that assumes that the first stage in creative thinking is bottom-up in nature.

Ultimately, the research of Ward, Finke, and Smith (1995) is of interest because it provides a method for facilitating creativity that seems to have withstood testing under strict laboratory conditions. However, the geneplore model seems to have limitations as an explanation of creative thinking. We have seen in the case studies examples of creative thinking that were based on top-down processes—that is, based on an extensive database—which means that novel products are not generated through the random combination of ideas. Similar conclusions arise from the analysis of strong methods of problem solving in this chapter. Thus, the Creative Cognition Approach seems to be useful as a method for stimulating creative thinking, but that does not necessarily mean that creative thinking is ordinarily carried out using the bottom-up methods exemplified in the geneplore model.

Skepticism about Expertise and Creativity

As we now know, one particularly important development to come out of cognitive research on problem solving is the critical role of knowledge and expertise, sometimes brought about through deliberate practice, in facilitating world-class problem solving. If it is true that at least some creative advances are the result of problem solving, then knowledge, expertise, and practice should be relevant in those situations. It then becomes of interest to determine how significant a role expertise plays in creative thinking, even in domains that might not seem to involve problem solving. Until relatively recently, however, researchers had not specifically addressed the issue of whether expertise might underlie creative achievement. In addition, there has been little interest among researchers on creativity in the possibility that creative thinking might be related to expertise (for an exception, see

Weisberg, 1999, 2003). There are at least three reasons why researchers have been skeptical about a connection between expertise and creativity.

1. We have already briefly considered the possibility that the expertise-practice link represents only a correlation, and causation has not been established (see Chapter 3). There is the possibility that more talented individuals are motivated to spend more time practicing and therefore are more likely to become expert. In this view, world-class problem solving—and, by extension, world-class performance in creative domains in general—is the result of *talent*, with practice and expertise playing a role only because talent is there in the first place. If this objection is valid, there is little purpose in studying the possible relation between expertise and creativity.
2. The second point of skepticism centers on whether creativity is even involved in the domains investigated by researchers who study expertise. Although some of those domains involve creative thinking (e.g., chess playing), other domains, such as athletic performance, performance of music, or expertise in medical diagnosis, might not seem to. Any results from those studies are of questionable relevance to understanding creativity. Therefore, one might believe that results from the study of expertise would have limited applicability, at best, to the understanding of creativity.
3. Finally, it is believed by many researchers (e.g., Amabile, 1996; Ansburg, 2000; Csikszentmihalyi, 1996; Frensch & Sternberg, 1989; Simonton, 1999), as well as by many in our society, that creativity and expertise are antagonistic concepts (Weisberg, 2003). As we saw in Chapter 2, it is assumed by many researchers that thinking creatively requires breaking away from the past and bringing together ideas that usually would not go together. Expertise, on the other hand, is the encapsulation of the past, so expertise would seem to be in conflict with the needs of the creative thinker. We are all familiar with the exhortation to *think outside the box* in situations requiring creativity. This catchphrase is simply the latest version of the idea that in order to think creatively we must break with the past. This perspective is pervasive in present-day theorizing about creative thinking, and it can be summarized as the belief that there is a tension between expertise and creativity.

I will review those three sources of skepticism, and I will then raise questions about them, to show that the possibility of a positive connection between expertise and creativity should not be dismissed out of hand. I

will then in Chapter 5 examine in detail the connection between expertise and creativity, as part of a consideration of the role of ordinary thinking in several additional studies of creativity.

Practice or Talent?

A number of researchers have objected to the conclusion that expertise acquired through practice is the determinant of the high levels of performance demonstrated in the studies reviewed earlier. Those critics have proposed that it is *talent*, rather than acquired expertise, that is the ultimate determinant of performance in many of the domains studied by the expertise researchers (e.g., Sternberg, 1996; Winner, 1996). The related notions of *talent* and *giftedness* refer to the basic idea that the highest level of achievement in any domain is the province of a select few—those who possess a constellation of inherited skills that make them especially suited to excel in that domain. So, for example, the world-class tennis player is endowed with quick reflexes, outstanding hand-eye coordination, quickness of foot, and so on. Those gifts make it possible for the individual to excel in tennis, but they might not be relevant to becoming a world-class discus thrower. Other gifts—a different talent—would be needed there. Presumably there are also talents for chess and physics, say, which enable a select few to excel in those domains also. The claim that innate talent stands at the core of extraordinary achievement also implies that there are relatively fixed levels of performance set by our innate endowments. Advocates of the talent view propose that practice and expertise are at most of secondary importance in the development of world-class levels of performance in any domain. If a person is not talented in the first place, then all the practice in the world is useless.

In contrast to the notion of talent, the findings from the acquired-expertise literature have been used to raise the possibility that there may be few innate limitations on the performance of “ordinary” individuals (Ericsson, 1999). Even in domains such as musical performance or athletics, as well as in painting and musical composition, where high levels of achievement have traditionally been assumed to be limited to those who first and foremost possessed the necessary aptitude—the talent—to excel, it has been proposed that differences in levels of achievement are due to differences in expertise based on practice, rather than being the outgrowth of blossoming talent (Howe, Davidson, & Sloboda, 1998; Sloboda, 1996).

The question of talent versus practice is obviously an issue of direct critical importance in the study of creativity, since creativity involves domains that are often thought to depend on talent—musical composition, the visual arts,

poetry, mathematics, as well as many others. Thus, it is important to examine those issues before addressing the possible role of expertise in creativity. If the critics are correct, then there is no point in considering that role.

No Practice Effects without Talent

As an example of the types of objections that have been raised to the conclusions concerning the critical importance of expertise and practice in the development of the highest levels of performance, Sternberg (1996) notes that many of the studies of expertise and practice are correlational in design, rather than experimental. Consider again the study of Ericsson and colleagues (1993) on the role of practice in the relative stature of musicians who reached different levels of accomplishment or expertise. The results of that study demonstrated a consistent positive relationship between achievement and practice: The musicians who had achieved the highest levels of accomplishment were those who had practiced the most. As we have seen, the study has been interpreted as showing that the different levels of practice caused the different levels of achievement.

The design of the study by Ericsson and colleagues (1993) is called a *correlational design*, because the results one obtains involve a correlation between two variables, in this case achievement and amount of practice. The structure of a correlational study does not allow you to draw conclusions about cause and effect, which in this case means that one cannot conclude that the differences in practice caused the differences in achievement. All one knows is whether the two variables of interest go together. Another equally logical cause-and-effect possibility is that the people who had achieved more started out with more talent than those who achieved less. The people with high levels of talent might then have chosen to practice more than people with less talent. The correlational study's weakness in this case stems from the fact that the researchers took groups that were already in place—the musicians of different levels of accomplishment—and then examined their present and past practice regimens. In order to determine if differential practice *caused* the varying levels of achievement, one ideally should carry out a controlled experiment, in which a sample of people are randomly assigned to conditions in which they are exposed to different levels of practice. The random assignment of relatively large numbers of people to practice conditions would mean that the groups in the various practice conditions would be equivalent in talent before the study began. Any differences in achievement would then be attributable not to talent but to practice. This sort of experiment has usually not been carried out in the study of expertise because, among other drawbacks, it would take years.

Sternberg (1996) also noted that the studies of practice and expertise

lack control groups. This objection is related to the correlational nature of those studies. Because there are no randomly assigned practice groups, one does not know how many people there are who would have been randomly assigned to a high-practice group and would not have achieved high levels of performance. Similarly, one has no idea of how many people in the world have practiced the violin for long hours over many years but have ultimately achieved little. A related problem in interpreting the studies of expertise and practice is that one has no idea of the number of people who dropped out early, perhaps because they were not advancing in spite of practicing, and therefore would have shown no effects of practice. Those missing people could be called *high-practice failures*. All we have left in the high-practice group are the ones who succeeded. Finally, Sternberg also believes that the expertise researchers may have specially chosen to investigate domains in which practice seems to be most effective. Practice may be important in developing skill in musical performance or in swimming, but those domains may not be ones in which talent is crucial. In his analysis, the practice view cannot account for the accomplishments of the young Mozart or Picasso; the extraordinary early achievements of such people cannot be dealt with by invoking practice.

A second set of arguments in support of talent as a causal factor in extraordinary achievement has been proposed by Winner (1996). One critical point made by Winner is that evidence for the existence of innate talent comes from studies of extraordinary young people who show high levels of ability in some domain *without* extensive amounts of practice. The most striking examples of such people are *autistic savants* (or *savants*), individuals who may be severely disabled psychologically (fully autistic savants are pathologically withdrawn, nonsocial, and unable and unwilling to communicate with others) and yet are able to perform at an extraordinarily high level in some restricted domain. In arithmetic calculation, for example, savants have been found who can multiply two very large numbers in their heads (e.g., $43,581 \times 12,446$). *Calendar calculators* are savants who can tell the day of the week for any date (e.g., what day of the week was April 3, 1734? On what day of the week will June 3, 2279 fall?). Most interesting for the present discussion are savants who show exceptional ability in some artistic domain—who can draw with remarkable skill or play music beautifully—without formal instruction. An example of the work of one such person is shown in Figure 4.6.

Savants are presumably able to do what they do because they have innate talent that is isolated from the other aspects of their development. These individuals can be very lacking in most aspects of intelligence, as measured by IQ tests, as well as being totally lacking in social skills, but they

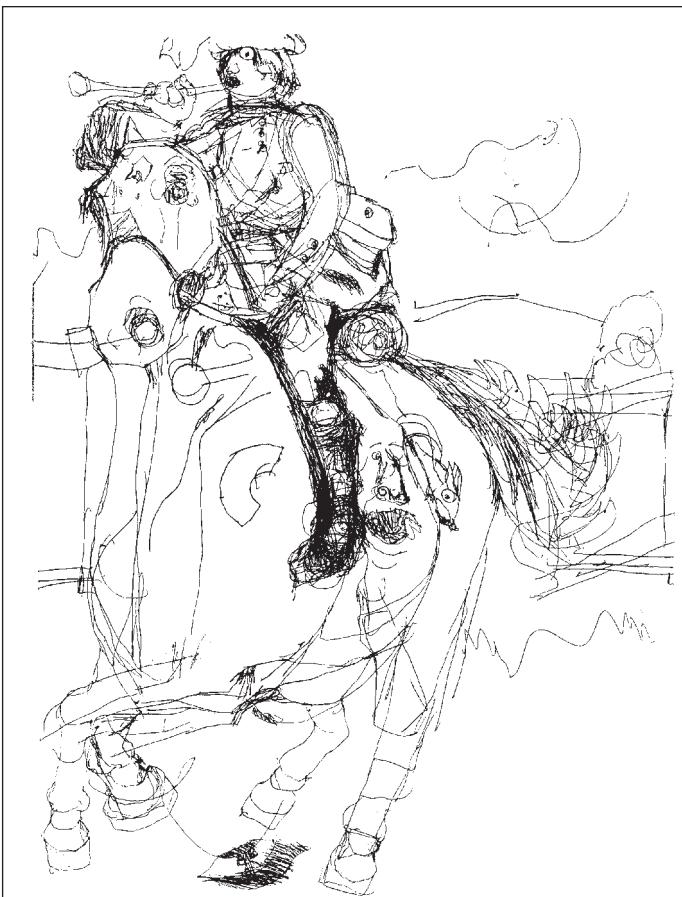


Figure 4.6 An early work of Nadia, age 5½

are able to perform in one intellectual domain at an extremely high level of accomplishment. The savant may be an extreme case of what happens in any person who develops into a world-class performer: An innate talent is funneled through an environment that exposes that talent to the stimuli that serve to nourish it. The fact that talents can flourish in savants, who can be lacking in every other aspect of their intellectual and social development, is taken as evidence that talent is an isolated capacity, which can be inherited and is independent of intelligence and social skills.

Those savants have, in Winner's (1996) view, a "rage to master" the domain for which they are talented, which can sometimes drive parents to distraction. Winner believes that that compulsion to draw in precocious

artists, and the great advances in skill that those children quickly achieve, supports the premise that an innate talent is pushing them and allowing them to develop extraordinarily quickly. Winner also raises a question for those who claim that practice is everything: Why will some people practice compulsively at some activity, starting sometimes at a very young age, with no interest in external rewards? In her view, something like talent is necessary to explain why some people are willing to put in the massive amounts of practice needed to achieve world-class levels of performance, practice that often seems deadly dull to others. So even if practice is the crucial element in producing world-class performance, without talent, no one would be willing to practice in the first place.

Talent versus Practice

A number of research studies directly address some of the objections to the expertise view raised by the talent theorists. Several particularly important findings concerning the role of talent versus practice in the development of musical performance ability have been reported by Sloboda and his colleagues (summarized in Sloboda, 1996), who carried out a study of the development of musical skill in school children in the United Kingdom. The sample consisted of 257 children who were selected to cover a wide range of performance skill on musical instruments. The students represented five levels of achievement. The highest level was made up of students at a specialized music school where entry is based on a competitive examination and whose graduates go on to professional careers. The second level consisted of students who had failed that school's entrance examination, so they were presumably very good, although not excellent, musicians. There were two other intermediate levels, and at the bottom were students who had tried an instrument but who had given it up after 6 months.

In one part of the study, which attempted to uncover early signs of prodigiousness (and, *ipso facto*, talent) in the children, the parents of all the children were asked about ages of occurrence for various possible signs of musical talent. Perhaps surprisingly, even with the large range of abilities—of presumed talent—reported in the sample, there were very few differences among the five groups in the possible markers of musical talent; and in some cases the presence of markers did not favor the high-achievement group. One difference that was significant was in the age at which the child was able to sing a recognizable tune (18 months of age in the high-ability group versus 24 months in the other groups). However, Sloboda and colleagues (1996) noted that the parents of the high-ability group reported more involvement in initiating musical activity for their children. Thus, the musical markers that favored the high-ability group, few though they were, might have been

the result of differences in parental involvement with their children. Bloom and colleagues (1985) reported similar findings.

Sloboda and colleagues (Sloboda, 1996) were also able to examine the role of practice in musical achievement among children of different levels of ability. Children in the United Kingdom are given musical instruction in school and are tested regularly to determine levels of accomplishment. The ultimate accomplishments of students at the various levels differ greatly, of course, as we have already seen, with some students at the highest levels of accomplishment going on to schools that train those who will become professional musicians. Sloboda and colleagues had the students provide estimates of the amount of practice time for each year of playing, and a subset of the sample kept a record of practice activities over a 42-week period. A number of striking findings emerged concerning practice and talent. First, by grade 8, the high-ability group was practicing 800 percent more than the group that would ultimately drop out (15 minutes versus 2 hours). Furthermore, every child in the sample who practiced 2+ hours per day achieved high levels of skill. In other words, there were no children in the lower skill levels who practiced 2+ hours per day. Those "high-practice failures" predicted by Sternberg (1996) were not found. If talent were needed for practice to have effects, then surely there would be some children at the lower levels of accomplishment for whom 2+ hours of practice were useless (or at least relatively ineffective). It should be noted once again that the sample in the Sloboda study included students who had dropped out of musical training, so they provide the missing control group mentioned by Sternberg (1996).

Finally, the estimates and records concerning practice allowed Sloboda and colleagues (Sloboda, 1996) to determine the amount of practice time that intervened, on average, as the students of various levels of ultimate achievement worked through the exam sequence. A talent hypothesis would predict that the more advanced groups would have required less practice to move from any given level to the next. The critical and perhaps surprising finding was that the most accomplished students required just as many hours of practice to advance from one level to the next as the least accomplished ones did. The talented group advanced more quickly because their practice was more concentrated, not because they needed less of it.

There are several other different sorts of evidence that raise problems for the talent view. First, it has been shown that improvements in performance can occur long after the body has reached maturity, sometimes even for decades—that is, long after development ceases (Ericsson, 1996)—so long as the person continues deliberate practice. This finding leads to the conclusion

that level of performance is not limited by bodily development, as the talent view can be taken to imply. Second, if one looks at the developmental trajectory for performance in the various domains in which it is possible to measure performance level objectively—in chess, for example, where players' levels of skill are rated based on performance against established players in tournaments—one finds that even the most talented individuals show gradual improvement over many years of development. This sort of function implies that development is the result of accumulated practice rather than the blossoming of innate talent, which might be expected to be relatively early and relatively sudden.

Thus, it seems at the very least that the case for talent is not as strong as one might have supposed. It follows from this that the blossoming of talent might be less than critically important in creative domains as well. This makes the research on expertise and practice potentially much more interesting in the context of the study of creative achievement.

Talent, Practice, and the 10-Year Rule: Rethinking Talent

There is strong evidence that extensive practice is positively related to world-class performance in many (perhaps all) domains. Let us assume that practice is, as Ericsson and colleagues propose (1993), necessary for development of skill in any individual. That is, let us assume that practice causes the development of expertise and world-class skill. According to the advocates of talent, we are still left with Winner's (1996) basic question: Why would anyone want to dedicate themselves to the high level of practice needed to develop skills of the highest level? According to the advocates of the talent view, a person will be attracted to some domain in the first place, and will commit to years of deliberate practice in that domain, only if he or she possesses talent—that is, an innate skill—in the domain. Winner's (1996) notion of a child's "rage to master" some domain, which is independent of parental encouragement or assistance, describes this phenomenon. Only the talented person will respond so strongly upon exposure to the domain that he or she will be motivated enough to fully commit to the demands of a life of deliberate practice. In this view, Ericsson and colleagues have only answered the question of *how* someone achieves world-class skill; they have not answered *why*, and that is where talent must be brought in again.

At present there is no way to distinguish between these two interpretations, one of which says that practice alone will produce world-class performance, and the other of which says that only a talented individual will put in the practice needed to reach the top, so that practice ultimately works through talent. This is an area of active interest among researchers,

because of the potential importance of the findings. It is important to note that this research may lead to a whole new definition of talent. Originally, as we have seen, talent was held to encompass whatever *abilities* were needed to well in some domain (Howe et al., 1998). Now, in order to understand the “rage to master,” we might speculate that talent is the responsiveness of a person to the domain itself, independent of any skills; that is, “talent” at the piano might involve a responsiveness to the sounds of notes from a piano, to the feel of the keys under one’s hand, and so forth. Similarly, a budding painter might be attracted to the sight of the colors of the paint, to the smell of the paint, or perhaps to the feel of the brush in the hand. Based on this reasoning, there might be no differences in ability between talented and nontalented individuals, just differences in the appeal of the domain. Those differences in appeal might lead to differences in motivation to engage the domain, which might lead to differences in willingness to practice, which might lead to differences in accomplishment.

This view, if accepted, would completely change our conception of what being “gifted” means. Some shift of this sort may be necessary, however, for us to begin to understand how practice can play an important role in the development of creative skill. Thus, the notion of talent may not present an insurmountable obstacle to the idea that expertise can play a critical role in creativity.

Expertise and Achievement: Reproductive or Productive?

The second potential difficulty in applying the notion of expertise to creative thinking is that the skills studied in expertise research may not involve creative thinking. Swimming and playing the violin, for example, even at world-class levels, are not skills that seem at first glance to involve creative thinking. Therefore, finding that high levels of performance in such domains are dependent on domain-specific expertise may be irrelevant to an understanding of creative thinking.

There is no doubt that some domains in which expertise is studied do not involve much in the way of innovation; however, that is not true of all such domains. Chess playing, which has already been mentioned, is a domain in which creativity is critical. Furthermore, it can also be argued that even domains such as musical performance and athletics do in some cases involve creative elements (Ericsson, 1996). Therefore, studying the development of expertise in those domains may contribute to our understanding of creativity. Let us therefore examine in more detail the types of domains in which expertise has been studied, and the possible role of creativity in each.

Reproductive Expertise

In some domains in which individuals develop expertise, such as swimming and figure skating, the goal of the activity is that the expert be able to reproduce a sequence of movements in the same way each time. A swimmer, for example, may work for many years in order to perfect his or her form, to strengthen the relevant muscles, and to increase stamina. The individual may, after years of work, reach the point where he or she breaks new ground in performance by swimming a given distance faster than anyone ever has. However, groundbreaking achievements like this one usually involve perfecting skills and carrying them incrementally beyond what others have done, rather than producing something new. One could call such an advance, which seems not to involve creativity, a *reproductive advance*, since it entails reproducing (repeating) a set of actions to the point that results in new achievement but does not involve changing the structure or characteristics of the actions.

On the other hand, if a coach or a swimmer were to develop a new technique of stroking, or perhaps a new training technique, he or she could be looked upon as having carried out a creative act (Ericsson, 1996). An example of such a development appeared in a newspaper article I recently read about a world-class swimmer who, when swimming the backstroke, starts by going an exceptionally long distance underwater after pushing off from the pool wall. This innovation in technique results in his being far ahead when he surfaces, since swimmers can go faster underwater than on the surface, at least when doing the backstroke. Thus, although it would seem that in domains involving reproductive expertise the research literature has little to contribute to our understanding of creativity, even in those domains there may be situations in which people go beyond the accepted wisdom (i.e., beyond the expertise as handed down to them) and develop innovative techniques.

Behavioral Adjustments: Beginnings of Innovation

The role of expertise in innovation becomes more important if we consider some other athletic activities, such as basketball, hockey, soccer, and tennis. Carrying out those activities requires much in the way of innovation. A skilled basketball player, for example, is able to change a shot to meet the specific demands of the situation: She can adjust her shot, for example, if the defensive player is positioned to her left versus her right, is in her face or a bit farther back, and is alone or has other defenders to provide assistance. In such a circumstance, we can talk about adjustments to the shot, and we can use the phrase *behavioral adjustments* to refer to a situation in which a

person has acquired a system of behavior that is not fixed and rigid. Near-continuous innovation is involved here, in contrast to the reproductive expertise involved in the performance of a swimmer.

In addition, in situations in which a system capable of behavioral adjustments is acquired, the individual can also develop innovations in technique that go beyond the expertise that has been handed down by previous generations. As one example, in the 1930s and 1940s, several basketball players independently and for different reasons began to jump into the air before shooting the ball into the basket (Christgau, 1999). Earlier players had all shot with one or both feet on the ground. Thus, the jump shot was an innovation in technique. So we can make a distinction between the system that has been taught to the player (which allows him or her to produce novel responses through behavioral adjustments) and innovative changes to that system. In both cases, creativity is involved.

Flexibility and Creativity in Musical Performance

Performing music seems on the surface to be a skill that involves only reproductive expertise: With years of practice, involving thousands of hours, the skilled musician learns to respond to notes on a page with appropriate movements. Ericsson (e.g., 1996), however, has proposed that the performance of music is more complicated than it might seem at first glance, and he suggests that creativity is involved. Most critical to this premise, the world-class musician is able to express emotion through his or her playing and can consciously change the interpretation of a piece. So, for example, if a musician decides that her playing is too emotional, she can immediately change how she plays the entire piece so that it projects less emotion. The skill that has been developed here is more flexible than might have been thought, and musical performance is therefore an example of a system capable of behavioral adjustment, similar to that of the basketball player. As in the other domains discussed, further innovation is also possible in the case of musical performance. A musician can develop a new interpretation for a piece of music—or for a whole class of pieces of music—which may result in future generations playing previously familiar pieces in new ways.

In the discussion so far, we have seen that, even for the more “reproductive” skills, expertise and innovation are not necessarily antagonistic notions. Furthermore, many skills are capable of behavioral adjustments, which entail creativity. We now turn to domains involving expertise in which innovation is more vital; in those domains, creativity and expertise are more obviously related. One such domain is chess playing, which, as we know from the discussion earlier in the chapter, has been at the center of research on expertise.

Expertise and Creativity

When a world-class chess player proposes a move that surprises not only his or her opponent but also other members of the chess-playing community, there is no doubt that a creative act has been carried out. The basic motor skills involved in chess are trivial—pushing small pieces around on a board—but the game is so complex conceptually that the intellectual skills involved in deciding on a move take years to acquire. Ericsson (e.g., 1996) has proposed that chess masters acquire complex mental representations of their domains and that those representations serve as the basis for their high levels of performance. As noted earlier, evidence for the chess master's detailed and complex representation of chess games comes from the fact that blindfolded chess masters can simultaneously play—and win—multiple games of chess. Think for a minute about how much information must be available in order to carry out such a feat. Those complex representations depend on the master's years of study and practice. There is a vast literature on chess, which reproduces and analyzes famous games from tournaments and world championship matches. Expert chess players study those games, often playing along and trying to anticipate the champion's next move. If they do not correctly anticipate the move, the would-be masters then analyze the situation in more depth to try to determine why the champion did what he or she did. As we know, in analyzing the developing skills of chess players, Chase and Simon (1973b) concluded that no one became a chess master without at least 10 years of such study and practice, and thus was born the 10-Year Rule.

A similar analysis can be applied to a doctor who is an expert in diagnosis in some area—say, an oncologist. The expert diagnostician is able to extract relevant information from the complex of symptoms that a patient presents and to reason about possible alternative diagnoses before deciding on the best one. Again, the physician is representing complex information mentally and using it to support complex reasoning processes. In Ericsson's (1999) view, similar processes occur when an expert radiologist reads an X-ray.

Expertise of this sort is obviously relevant to the understanding of creative thinking: The chess master is carrying out a creative act when he or she decides on a move, as are the oncologist and the radiologist when they make diagnoses of cases presenting a specific complex of symptoms that they have not seen before. Furthermore, in a manner comparable to an athlete's developing a new technique, the chess player can use his or her expertise in one of two ways. One is to stay within existing methods of play, carrying those methods to new levels of “perfection,” say. In this case, the chess player is developing his or her own style within the framework of existing styles of play. However, as noted in the other domains already discussed, players can

also develop new strategies of play in chess, where they go beyond the kinds of strategies that have been used in the past.

Creativity and Expertise: Summary

Table 4.5 presents a summary of the discussion to this point. I have arbitrarily proposed that the activities considered so far can be ordered on a scale of novelty. The specifics of the scale are of no concern; the important point is that we agree to order activities according to the degree of novelty involved in their execution. The reproductive activity of a swimmer entails less novelty than the behavioral adjustments made continuously by players of basketball, which in turn involve less in the way of novelty than does the chess master's choosing a move in the middle of a hard-fought game. Concerning the skills of the expert physician and the expert radiologist, let us assume that they involve a degree of novelty that falls somewhere between that of the player of basketball or tennis and that of the chess master. In addition, Table 4.5 includes the development of new techniques in the various domains discussed, which we assume to be more innovative than working within the accepted wisdom.

The summary in Table 4.5 indicates that the second point of skepticism

Table 4.5 Classification of domains studied by expertise researchers concerning degree of novelty (creativity) involved (1 = low; 4 = high)

Degree of novelty	Domain
1. Reproductive—perfecting handed-down techniques; carrying them incrementally beyond the old	Swimming
2. Behavioral adjustment—innovation within handed-down techniques	Basketball shots/musical performance Radiologist Medical diagnosis
3. Producing one's own style within established style, techniques, or knowledge	Chess master: excellence within existing styles
4. Developing new style or techniques	Basketball/swimming/musical performance: innovation in technique Chess master: innovations in strategies or techniques

concerning the possible role of expertise in creative thinking—the idea that domains in which expertise has been studied do not involve creativity—is mistaken. We now turn to the final point of skepticism concerning expertise and creative thinking, the idea that true creativity cannot be based on expertise. According to this view, creativity demands that the thinker reject the past and develop ideas that are independent of what came before. Since expertise by definition depends on what came before, then creativity cannot depend on expertise.

Expertise, Knowledge, and Experience versus Creativity: The Tension View

There is a long-lived tradition in psychology, very much alive today (e.g., Frensch & Sternberg, 1989; Simonton, 1999), in which creative thinking is assumed to require breaking away from experience; that is, there is assumed to be a tension between past experience and creativity. The tension applies also to expertise: Creativity should come about as the result of breaking away from expertise. This *tension view*, which is over 100 years old, has become part of our common heritage (recall “out of the box” thinking from Chapter 2). In an early presentation of the tension view, James (1880, p. 456) characterized the thinking patterns of the “highest order of minds” as involving associations that can be brought together or broken in an instant, where habit is disregarded.

Instead of thoughts of concrete things patiently following one another in a beaten track of habitual suggestion, we have the most rarefied abstractions and discriminations, the most unheard of combination of elements, the subtlest associations of analogy; in a word, we seem suddenly introduced into a seething cauldron of ideas, where everything is fizzling and bobbling about in a state of bewildering activity, where partnerships can be joined or loosened in an instant, treadmill routine is unknown, and the unexpected seems only law.

This description of the functioning of minds of the highest order looks at the positive aspects of their functioning: the ability to put together, as needed, combinations of ideas that are beyond the capabilities of lower-order minds. There is also a negative side to this view: If higher-order minds do not follow the “beaten track of habitual suggestion,” then the lower-order minds who do follow that track are doomed to mediocrity.

Calling on experience when dealing with a problem that requires a creative response was also dismissed by the Gestalt psychologists as *reproductive* thinking, since it reproduced something that had been done earlier and

therefore was assumed to be incapable of dealing with situations requiring innovation (Wertheimer, 1982). Here is a modern presentation of the same view by Simonton (1995, pp. 472–473), who is one of the most influential current researchers studying creativity.

For the kinds of problems on which historical creators stake their reputations, the possibilities [i.e., possible solution paths] seem endless, and the odds of attaining the solution appear nearly hopeless. At this point, problem solving becomes more nearly a random process, in the sense that the free-associative procedure must come into play. Only by falling back on this less disciplined resource can the creator arrive at insights that are genuinely profound.

A person who solves one of the problems alluded to by Simonton is viewed in our society as a significant creator. Examples of such problems are the following. (1) What is the structure of the DNA molecule? This question led Watson and Crick to the double helix. (2) How can one produce a painting to express the horror arising from the massacre of innocent people during war? This problem led to Picasso's creating *Guernica*. (3) How can one produce abstract (nonrepresentational) sculpture that will move freely in space? This problem led the sculptor Alexander Calder to produce the first mobiles. (4) How can one produce a heavier-than-air machine that will fly? The Wright brothers answered this question 100 years ago. (5) How can one produce a viable electric light? Edison answered this question by inventing the light bulb in 1879. These sorts of problems, in Simonton's view, demand that the thinker move away from habitual modes of thinking and use instead a "free-associative" procedure that is less tied to the past. This view echoes that of James and posits that the great innovations in our society must have been brought about by thinkers who were able to abandon habit and well-worn associative pathways in order to bring together ideas that had not been brought together before.

This perspective has also been advocated by Frensch and Sternberg (e.g., 1989), who showed that experts at bridge were limited in their ability to adjust to changes in the rules of the game. As part of an experiment, Frensch and Sternberg made two sorts of changes in the rules of bridge. *Surface* changes involved changes in the names and order of suits; such changes are not central to playing the game. In contrast, *deep* or *conceptual* changes brought about a basic reorganization in how the game was played. As an example, one change had the player who *lost* the last trick, rather than the *winner*, lead the next one. Relatively wide-ranging changes in strategy are required in order to adapt to conceptual changes. Both novices and experts were tested on the two types of changes. The performance of the experts was most affected by the deep changes, and they had a harder time adjust-

ing to them than did the novices. Thus, knowledge made for less flexible thinking in adjusting to changes in the world.

A similarly negative conception of the relation between experience and creativity can be seen in the psychometric or mental-testing approach to creativity, launched by Guilford (1950) in his groundbreaking and extremely influential presidential address to the American Psychological Association. As mentioned in Chapter 2, Guilford proposed that at the heart of creative thinking were *divergent-thinking* skills. Those skills enable the person to produce ideas that “diverge” from the past—that is, from the ordinary—and thereby make it more likely that the thinker will produce a creative response to the situation he or she is facing. Although Guilford did not cite James or the Gestalt psychologists in his address, the philosophy behind his proposal is the same as that which motivated them. The whole creativity-testing movement and the large number of studies that were spawned by Guilford’s ideas, which will be discussed in Chapter 9, have been based on the idea that measuring and cultivating creative thinking depends on measuring and facilitating divergent-thinking skills.

Still further evidence in support of the tension view has been adduced by Simonton (1984, Chap. 4), who examined the relationship between education and creative accomplishment. It follows from the tension view that, while education may be necessary to allow a person to deal with some domain in the first place, too much education might be a bad thing. The person could become entrenched in the beliefs and methods of the domain and might become trapped in the old ways. Thus, one might expect to find a curvilinear relationship between education and creativity: Those who produce the most innovative advances might not be the most educated. Simonton carried out a study of the education level of more than 300 outstandingly creative individuals born between 1450 and 1850, including Ludwig van Beethoven, Wolfgang Amadeus Mozart, Leonardo da Vinci, Galileo Galilei, and Rembrandt van Rijn. He found that the peak creators in this outstanding group had reached a level of education equivalent to about halfway through a modern undergraduate program. More or less education than that was related to lower levels of creative accomplishment, so the curve was an upside-down U, with the peak at an intermediate level of higher education. Those results would argue that too much training is indeed a bad thing.

Another stream of research supporting the negative relation between knowledge or expertise and creativity has been carried out by Ward (1995), who examines what he calls *structured imagination*. Ward has looked at ordinary people’s ability to imagine new creatures—say, on a distant planet very different from Earth. He found that most of the imagined creatures

contained the same basic features as those on Earth, such as symmetry and pairs of sense organs. It is very difficult to get people to break away from the creatures with which they are familiar. Ward also examined creatures in science fiction and found that most of them are also closely related to Earth creatures, even though most science fiction authors are expressly trying to get away from Earth. In order to produce something new, Ward concludes, the individual must consider in detail unique aspects of the imagined environment in which the creature will function. To the degree that the new environment is different from Earth, the individual will be able to imagine new aspects of the creature. However, without this detailed background, the deeply ingrained knowledge about Earth creatures inhibits people's imaginations.

The Tension View: Conclusions and Implications

The tension view, which has had many advocates and has been presented in several variations over the years, is based on the idea that thinking creatively—producing novel ideas—requires that we move away from our old ideas. If the tension view is correct, then there is no point in investigating the possible relationship between expertise and creative thinking, because any such efforts are doomed to failure. A corollary of the tension view is that if we examine the development of creative products, especially creative products of the first rank, we should see examples of thinkers' wholesale rejection of the past.

Although the tension view has been with us for 100+ years, and although it seems to make clear predictions concerning how creative advances should come about—through rejection of the past—until relatively recently investigators rarely examined cases of creative thinking to see how creative advances actually come about (Weisberg, 1986, 1993, 1999, 2003, 2004, 2006). Contrary to the idea that creativity involves breaking away from the past and thinking outside the box, there is evidence that creative thinking can build on the past: New ideas can come about as the result of an individual's building on old ideas (e.g., Weisberg, 1999, 2003). I have called this the *foundation view* of the relation between experience and creativity: Knowledge serves as the foundation on which the creative process builds the new (Weisberg, 1999, 2003). Both case studies presented in Chapter 1 provided support for this idea. We have already discussed how Watson and Crick built their theory about DNA on the prior work of Pauling, how Picasso built *Guernica* on the foundation of his own work, and how he used others' works as the basis for some of the characters. Thus, the idea that creative thinking depends on the past is not necessarily a contradiction in

terms, and it is compatible with the suggestion that expertise might play a role in creative thinking.

Such results raise the possibility that expertise (and, perhaps, even deliberate practice) can play a critical role in creativity. Chapter 5 will explore that possibility in more detail. I will review several case studies, in science, in the arts, and in invention, that provide support for the foundation view. We will begin by examining several pieces of evidence that point to relatively direct parallels between development of expertise and development of creative achievement. Most importantly, there is evidence that the 10-Year Rule—including deliberate practice—applies to some creative thinkers.

The Cognitive Perspective on Problem Solving and Creativity: Conclusions

The last two chapters have examined the cognitive perspective on problem solving and have considered some of its implications for our understanding of creativity. The cognitive analysis of problem solving is based on the notion of searching through a problem space. That search can be directed in a top-down manner by knowledge that the person is able to bring to the problem (see Table 4.4). We have examined a continuum of methods, which can be ordered according to the specificity of the overlap between the problem and the knowledge that the person brings to it. At the most general level, weak methods involve basically no problem-specific information. Because of their general nature, they may not be relevant to a given problem, but they can sometimes be useful. We saw several examples of weak methods playing a role in genuine creative advances.

Moving to a closer match between the person’s knowledge and the problem he or she faces, we come to situations in which analogical transfer plays a role in problem solving. Here the match between the problem and the person’s knowledge is closer, since the base and target have a common structure. A number of factors can influence whether analogical transfer will be successful: the closeness of the analogy between the base and target, and the ease with which the base solution can be mapped onto the target. We have also seen examples of analogical transfer in the case studies. Finally, one comes to the situation where the match between the person’s knowledge and the problem is relatively precise: The person has expertise in that domain. With expertise come strong methods of solving problems—problem-specific methods—that enable the expert to home in on the critical conceptual components of the problem. We saw a number of examples of the importance of expertise in creativity in the case studies examined earlier.

So far, we have examined only two case studies of creative accomplishments. Those have provided much valuable information that has informed the discussion in many places. However, returning again and again to the same two case studies obviously raises questions about the generality of any conclusions that one hopes to draw. Accordingly, in Chapter 5 we will examine a set of case studies in creativity from a variety of domains in order to demonstrate the broader relevance of the cognitive perspective on creativity.

CHAPTER

5

Case Studies of Creativity

Ordinary Thinking in the Arts, Science, and Invention

The cognitive perspective on creativity that underlies this book assumes that we do not need to bring forth any sort of extraordinary thought process in order to understand creativity. Ordinary thinking alone can produce extraordinary outcomes (Simon, 1966; Klahr & Simon, 1999). The two case studies of creative advances presented in Chapter 1 have provided evidence that one does not need to go beyond ordinary thinking in order to understand seminal creative advances. There is one critical limitation to the support presented for the ordinary-thinking view, however. We have so far examined only two case studies of creative advances, which severely limits the strength of any conclusions that we hope to draw about the thought processes underlying creativity. One of those case studies came from painting (Picasso's creation of *Guernica*), and one was from science (Watson and Crick's discovery of DNA). Can the conclusions concerning ordinary processes drawn from those studies be generalized to other examples within those domains and, perhaps more important, to other domains, such as music, invention, and sculpture?

It is also of interest that the two advances discussed in Chapter 1 are not radical advances, as far as the histories of their domains are concerned. That is, *Guernica* did not represent a radical advance in Picasso's style and therefore did not represent a sharp break in the history of art. Similarly, the double helix was built firmly on what had come before—as exemplified by Pauling's work on the alpha-helix—and therefore was not a “revolutionary”

advance (Kuhn, 1962). In order to provide stronger support for the ordinary-thinking view of creativity, it would be of value to investigate a wider range of case studies, and specifically to consider case studies that represent a significant break from then-current ideas, beliefs, or styles of thinking. Examining a number of such “radical” advances should provide a stronger test of the idea that all creativity rests on ordinary processes.

Outline of the Chapter

This chapter addresses the question of whether creative achievement in science, invention, and the arts is dependent upon ordinary thinking. The chapter examines several case studies of creative thinking through the lens of the possible role of ordinary thinking in creative accomplishments at the highest level. Included are several examples of radical creative advances with outcomes that seemed to make clean breaks with the past. Such examples provide a relatively strong test of the idea that ordinary thinking underlies all creative advances. The conclusion drawn in the chapter is that ordinary thinking does underlie even the most radical creative advances. In the next chapter I begin an examination of the opposite view, the idea that creativity is the result of extraordinary thinking carried out by extraordinary people.

Basic Components of Ordinary Thinking

In order to test the hypothesis that ordinary thinking underlies creativity, it will be valuable to consider the sorts of data that would support that hypothesis. As a preliminary step, we can consider again the basic components of ordinary thinking originally presented in Chapter 3.

- Ordinary thinking depends on the past: Our thinking exhibits *continuity* with the past.
- Knowledge and concepts direct ordinary thinking: Our thinking is directed by top-down processing.
- Our thoughts follow one another, or are related to one another, in comprehensible ways: Our thinking has structure. That structure can be the result of the use of logic (induction and deduction), analogical thinking, or thinking based on similarity or on contiguity.
- Ordinary thinking can be influenced by environmental events: Our thinking is sensitive to environmental events.

Ordinary versus Extraordinary Thinking

The components just reviewed can serve as the basis for formulation of empirically testable predictions based on the ordinary-thinking view, which can be contrasted with predictions based on the variations on the extraordinary-thinking view presented in Chapters 6–10. First, if creative thinking depends on ordinary thinking, then creative thinking, like ordinary thinking, should be dependent on the knowledge and expertise that come from experience. We should see creators developing their skills over the course of their careers as they acquire expertise in their domains, perhaps through deliberate practice, and we should see creators drawing on their experience in the course of creative production. We should be able to find antecedents for creative advances, and those antecedents should be traceable to the lives of the creators. In addition, we should see evidence for the top-down role of knowledge in creativity, as in ordinary thinking; for example, we should be able to find evidence of knowledge playing an important role in planning as creative achievements are carried out. The extraordinary-thinking view, in contrast, asserts that creators have to break out of the bonds of their knowledge in the process of creation. This need to break from the past should especially be true in the case of radical creative advances. According to this view, we should not be able to trace creative advances in any direct manner to the experience of the creative thinker.

The ordinary-thinking perspective on creativity also leads to the expectation that creative thinking should have structural coherence, which can come about through the use of logic, analogical thinking, and/or similarity and contiguity. Again, in contrast, the extraordinary-thinking view leads to the expectation that creative thinking lacks that structural coherence, sometimes defying logic. Concerning the specifics of the relations among thoughts during creative production, the ordinary-thinking perspective hypothesizes that links between ideas should be based on local and regional analogies. The extraordinary-thinking view assumes that in analyzing creative thought we will find the use of distant analogies and remote associates, which are unique to the creative individual and may make no obvious sense to anyone but that specific person. Finally, the ordinary-thinking view proposes that we will see the influence of environmental events on creative thinking; creative advances should in some cases be traceable to environmental events.

We can now examine these predictions in detail. I begin with the hypothesis derived from the ordinary-thinking view that knowledge and experience, perhaps based on practice, set the stage for creative accomplishment. In a parallel to the research on expertise discussed in Chapter 4, even creative

individuals of the first rank should achieve world-class levels of creative accomplishment only as the result of acquiring expertise. Put another way, the 10-Year Rule should apply to creative achievement.

The 10-Year Rule in Creative Development

As discussed in Chapter 4, the results of many studies across varied domains indicate that world-class problem-solving performance is the result of a highly motivated individual employing domain-specific expertise that has been developed over years of immersion in the domain. Those results lead to the expectation that expertise will play a role in world-class creative achievement in domains beyond those studied in the expertise literature. That expectation has been upheld: Hayes (1989) has demonstrated that the 10-Year Rule is relevant to outstanding creative achievement in many domains, including composition of classical music, painting, and poetry.

Musical Composition

Hayes (1989) studied what he called “preparation” in the careers of creative individuals of outstanding achievement. He used a standard musical reference book (Schoenberg, 1970) as the basis for his choice of composers to study; he assumed that a composer mentioned in such a book was important in Western classical music. He examined the biographies of 76 composers for whom enough information was available to determine when they began the study of music. Hayes calculated the time between the beginning of the composer’s career, as defined by introduction to musical instruction, and production of the individual’s first notable work or masterwork. He used a relatively simple objective definition of a masterwork: a composition with at least five recordings available in the Schwann record catalog. Based on that criterion, more than 500 masterworks were produced by his sample of 76 composers, only 3 of which were composed before year 10 of the composer’s career, and those three “early” works were composed in years 8 and 9. The average pattern of career productivity began with what Hayes called 10 years of silence before the first masterwork.

Even Mozart, perhaps the most precocious and undoubtedly one of the most prolific of all composers, fit this profile. Mozart’s father, a professional musician, began giving him music lessons when the boy was very young (reportedly at the boy’s insistence). Mozart’s first musical compositions were produced at age 6 or so, but they are not played very frequently today; they are like the early drawings by children that today adorn the doors of refrigerators. Mozart’s first masterwork by Hayes’s criterion was the Piano Concerto no. 9, which was written in 1777, approximately 15 years into his career, when

he was over 20. Thus, although Mozart began his career very early, he still required a significant amount of time before he made his mark.

Painters

To study career development in painters, Hayes (1989) again used standard reference works, examining the biographies of 131 painters in order to determine the time when each individual's painting career began. The career development of painters showed the same pattern as musicians: There was an initial 6-year period with no notable works, defined as those reproduced in at least one of several standard histories of painting. Here, too, this description fit the careers of even the most precocious and productive individuals, such as Picasso. Picasso began to paint under the tutelage of his father, also a painter, at about age 9; his first notable works were produced at about age 15. Picasso proclaimed that he painted like the great painter Raphael (1483–1520) from the very beginning, meaning that he did not need to develop as a painter, but this does not seem to have been true (Pariser, 1987; Richardson, 1991). Pariser examined the childhood drawings of three world-famous painters, Picasso, Paul Klee (1879–1940), and Henri Toulouse-Lautrec (1864–1901), and concluded that all three went through the same developmental sequence in which they learned to draw and paint. Contrary to what Picasso claimed, he too had to grapple with the problems that all children must go through before they can accurately represent objects through drawing. Hayes (1989) also reported similar results from a study of poets: a significant period of time between the beginning of the career and production of significant works.

The 10-Year Rule in Creativity: Conclusions

Hayes's (1989) results parallel the discussion in Chapter 4 of expertise in problem solving: Years of commitment to a discipline are required for creative achievement. Composers, painters, and poets, like the chess masters studied by de Groot (1965) and by Chase and Simon (1973a, 1973b), require significant periods of time to acquire sufficient knowledge and skills to perform in their fields at world-class levels. Within each field examined by Hayes, the analysis included individuals from very different historical periods, and yet the same overall pattern of long-term development was seen. Hayes's basic conclusions have been supported by similar findings reported by other investigators (e.g., Bloom, 1985; Gardner, 1993). We thus have support for one of the critical assumptions of the idea that ordinary thinking underlies creativity: The development of individuals who make world-class creative contributions depends on acquisition of domain-specific expertise.

What Happens in the Years before the Masterworks?

There is one limitation if one wishes to equate Hayes's results with those from the literature on expertise: Hayes presented no evidence, direct or indirect, that anything like deliberate practice was occurring during an individual's foundation years—those 10 years of preparation. That is, there was no evidence that they were acquiring expertise during those years. While that conclusion may seem reasonable, there was no evidence to support it. In order to provide further evidence on this issue, I recently extended Hayes's study, examining in more detail the development of Mozart as a composer (Weisberg, 2003).

Mozart: So Good So Young?

Mozart is often cited by researchers as the prototypical example of the creator whose abilities are impossible to understand without invoking a concept like talent or giftedness. An example of such a belief can be seen in Sternberg's (1996) analysis of Mozart's (and Picasso's) accomplishments.

Why was Mozart so damn good? . . . What made Picasso so good so young? . . . [W]hat Mozart did as a child most musical experts will never do nor be able to in their lifetimes, even after they have passed many times over the amount of time Mozart could possibly have had for deliberate practice as a child. . . . We fail to see evidence all around us—scholarly and commonsensical—that people differ in their talents, and that no matter how hard some people try, they just cannot all become experts in the mathematical, scientific, literary, musical, or any other domains to which they may have aspired. . . . The truth is that practice is only part of the picture. Most physicists will not become Einstein. And most composers will wonder why they can never be Mozart. (pp. 350–353)

Thus, Sternberg proposed that Mozart's accomplishments as a child could not be matched by others even after unlimited practice. One piece of evidence that raises questions for Sternberg's view of Mozart is Hayes's (1989) finding, just mentioned, that the 10-Year Rule holds even for Mozart. As noted, Hayes's method of analysis provides no information about the individual's formative years, the years before the first masterwork was produced, and there might be valuable information to be gleaned from those early years. For example, one would expect to find all creators—even Mozart—developing their skills, which might be reflected in increased production of compositions and in their increasing quality. In addition, we might be able to find evidence for the occurrence of deliberate practice, or something analogous, during the formative years.

Who Wrote Mozart's First Seven Piano Concertos?

We already know that Mozart's first masterwork as identified by Hayes (1989) was the Piano Concerto no. 9, approximately 15 years into his career. Is there evidence for Mozart's acquisition of expertise through practice before he produced his first masterwork? Did his skill as a composer gradually develop (which would be further evidence for the role of practice in creativity)? We can begin to answer those questions by examining Mozart's early piano concertos. Mozart's first four piano concertos (nos. 1–4) were produced in June–July 1767, when he was 12. Those works, however, contain no original music by Mozart: They were constructed out of works of five other composers. Perhaps those works should not be called Mozart's piano concertos, since he did not write the music. Mozart's father may have had the boy copy works by others as a way of exposing him to ways in which one could write. In other words, Mozart's father may have used others' music as the basis for practice by the young man in writing for groups of instruments. Furthermore, if some of the published works by the young Mozart are based completely on the works of others, then it seems reasonable to assume that Mozart's private tutelage from his father must also have been based on study of the works of others.

In addition, examination of the original written manuscripts of Mozart's earliest compositions that are still in existence (Cavett-Dunsby, 1990), indicates that, perhaps not surprisingly, much of the handwriting, including musical corrections, is that of Mozart's father. This raises questions about the role that the elder Mozart played in those early compositional exercises carried out by the boy. That is, some of the "composing" may have been carried out by the elder Mozart. At the very least, it seems reasonable to conclude that the young Mozart learned his craft over many years, under the watchful eye of a teacher who was a professional. This training, based in part on the study of other composers' music, is not very different from the training aspiring composers receive today in schools of music.

Mozart's next three piano concertos, written in 1772, when he was 16, also contain no original music by him: They were based on works of Johann Christian Bach (1735–1782; the youngest son of J. S. Bach and an important composer in his own right) and were merely arranged by Mozart for a new combination of instruments. Those pieces are not included in the series of Mozart's numbered piano concertos. So again we see something like practice occurring. In addition, by this time Mozart was no longer a young child, and he had been immersed in music for some 10 years. The first piano concerto by Mozart that contained original music by him was no. 5, produced in 1773 when he was 17; this work did not achieve mas-

terwork status by Hayes's (1989) criterion. This pattern of development indicates that Mozart's earliest musical experiences involved study of the works of others, and probably involved use of the earlier composers' works as models for ways certain compositional problems could be handled. It is not unreasonable to call this activity deliberate practice.

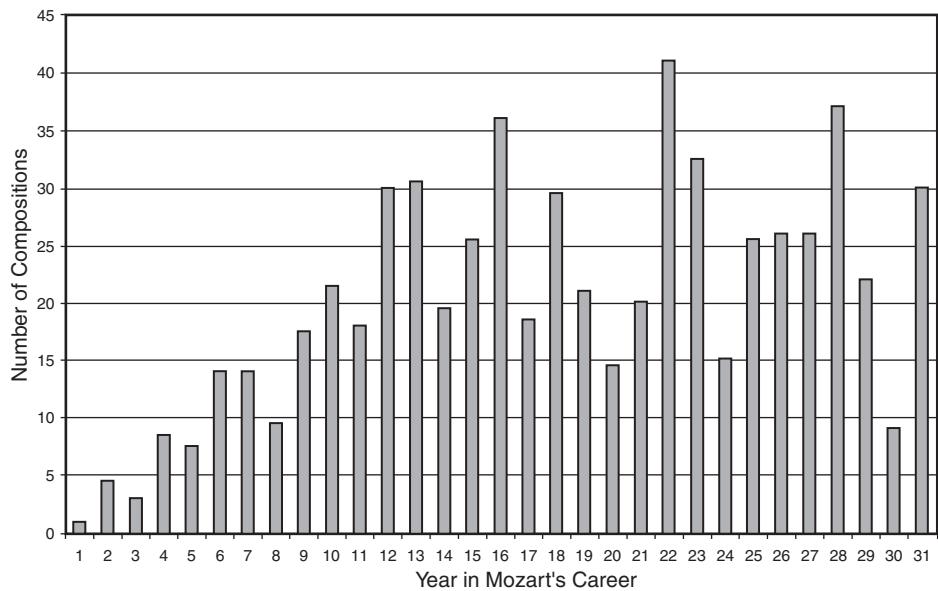
Additional evidence for slow development of Mozart's skill can be seen if we apply a variation of Hayes's (1989) analysis to Mozart's career development. Hayes found that Mozart's first masterwork was produced in year 15 of his career. Since Mozart produced no masterworks during the first 14 years, Hayes called those early years "years of silence." However, Mozart did produce some compositions of his own during those years, as shown in Figure 5.1A, which presents the number of compositions produced by Mozart in each year of his career. Over the first few years of his career, production gradually increased, until after about 10 years it more or less leveled off, although there was much variability in productivity from year to year. That increase in productivity early in Mozart's career is support for the notion that he was developing his skill as a composer, since it would be expected that an increase in skill would lead to an increase in productivity.

It would also be of interest to determine if there was improvement in the quality of Mozart's works before his first masterwork. If we change Hayes's measure a bit, we can use the number of recordings of each of Mozart's compositions as a measure of their relative quality; this will allow us to examine how quickly Mozart developed as a composer. Figure 5.1B presents the average number of recordings for each of the compositions for each year of Mozart's career; over the first 15+ years this measure increases, indicating that according to this criterion the compositions got better over those years. However, it is also interesting to note that there is hardly any increase for the first few years, and then there is a more or less sudden increase in quality. This indicates that Mozart spent several years at the beginning of his career at a "mediocre" level (at least for him), before really beginning to develop his skill.

These results call into question Sternberg's (1996) claim that most composers will never approach the accomplishments of the young Mozart. We have just seen that a number of Mozart's early compositions show nothing in the way of originality on his part. Many of Mozart's other early works, which do contain original music by him, have been more or less ignored by musicians and audiences, which means that one can argue that those works are not terribly good. They have nothing distinctively Mozartean about them. Thus, while it is true that most composers will not match Mozart's ultimate achievements, it does not seem far-fetched to say that his early achievements are matched by most composers as they advance through

Case Studies of Creativity

A



B

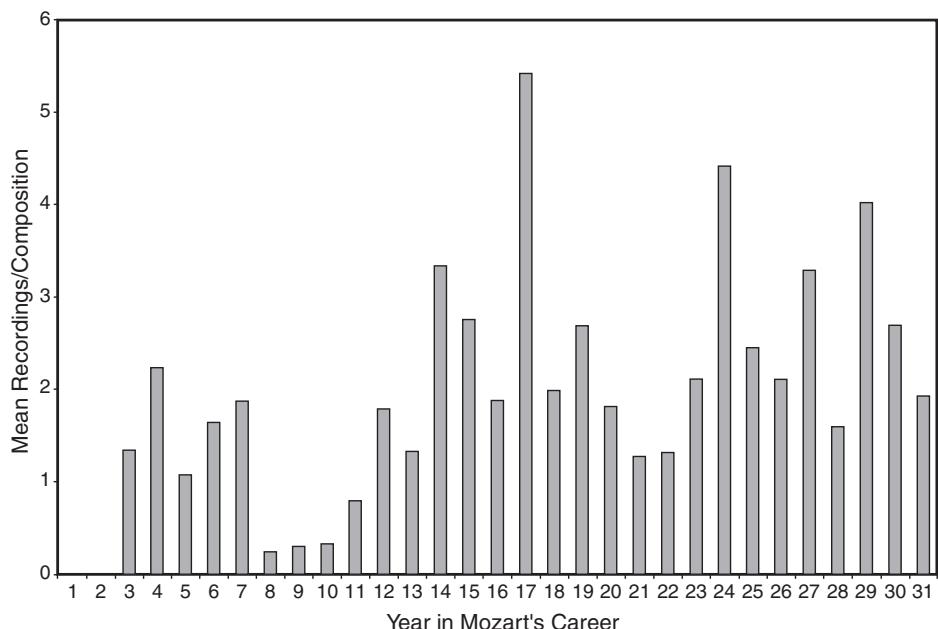


Figure 5.1 Development of musical composition expertise:

A, Number of compositions per year of Mozart's career;
B, Mozart's development: Mean recordings/composition/year

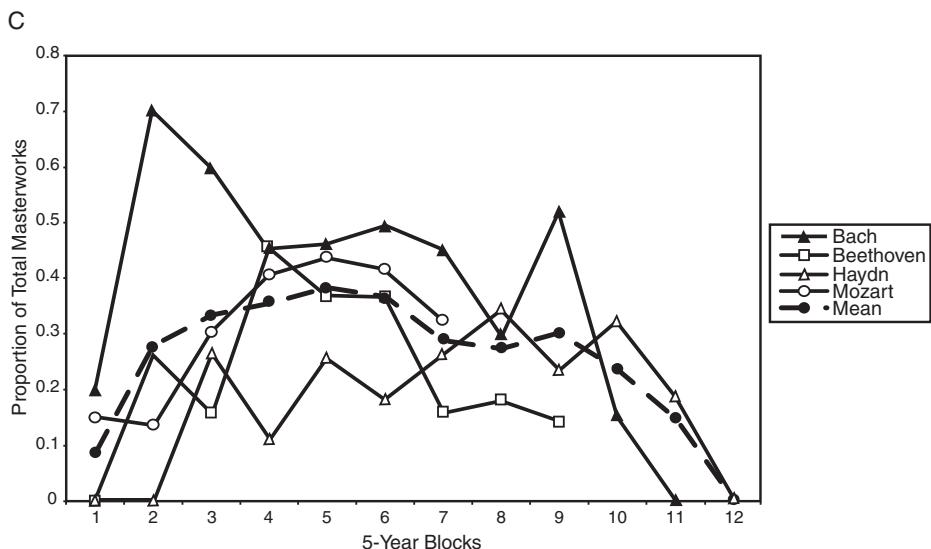


Figure 5.1 (continued) C, Proportion of masterworks per 5-year block of career for the best-known classical composers

music school. As we have seen, Mozart gradually learned his craft, and it took a significant amount of time for him to do so.

Recent analyses of the career development of other seminal classical composers by Weisberg and Sturdivant (2005) support the findings from the study of Mozart. The pattern of productivity over the early years for J.S. Bach, Beethoven, and Joseph Haydn (1732–1809), for example, mirrored that of Mozart: There was an increase in quantity and quality of compositions, indicating that those individuals too were developing the skill of writing music (see Figure 5.1C). Kozbelt (2004) analyzed the career development of Mozart and 17 other classical composers of renown, and he concluded that the development of skill over the career occurred in over half of them. Additional support for the importance of acquired expertise and the 10-Year Rule in creative thinking comes from the study of the development of the Lennon-McCartney songwriting team, whose songs for the Beatles broke new ground in popular music in the 1960s (Weisberg, 1999).

The Beatles: Learning to Write Hits

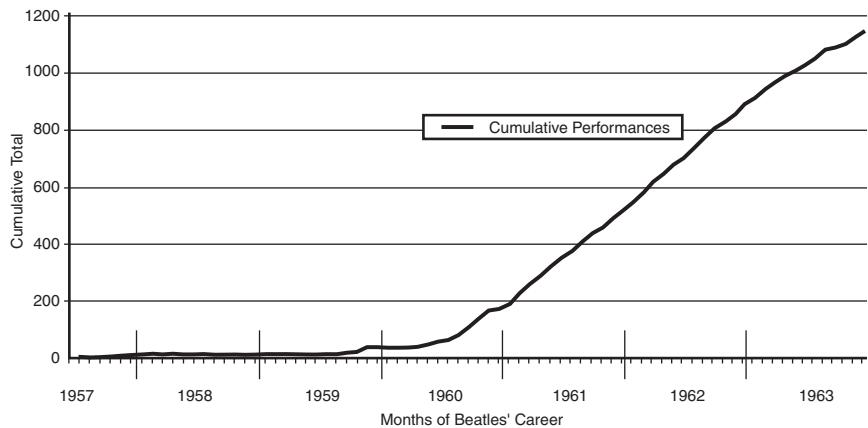
The Beatles hit the big time with a bang. In 1963, they had four number 1 hits on the British and American *Billboard* music charts: “Please Please

Me,” “From Me to You,” “She Loves You,” and “I Want to Hold Your Hand.” The excitement caused by their songs, performances, and personas resulted in the worldwide frenzy that came to be known as “Beatlemania,” which finally became overwhelming: The crowds were so large and noisy that the musicians could not hear themselves, nor could the audience hear them. So in August 1966 they gave up performing in public.

There are several ways in which the Beatles’ career trajectory corresponds to the findings from the studies of expertise. As far as the world was concerned, in 1963 the Beatles came out of nowhere. However, closer analysis indicates that this outburst of creative activity was the result of much prior work (Davies, 1968; Everett, 2001a; Lewisohn, 1992; Weisberg, 1999, 2003). In this prior work we can see what one might call the role of practice as well as the gradual improvement in their skill as composers. John Lennon had formed the Quarry Men in March 1957 at age 17, soon after he received his first guitar. In July, Paul McCartney, whose father was a musician and who had had some experience with the trumpet and guitar, joined the group; George Harrison and Ringo Starr joined later. By 1963, when the Beatles hit the big time, Lennon and McCartney had been working together for over 5 years.

What had Lennon and McCartney been doing before their great year of 1963? No detailed information is available on how much time the Beatles actually spent practicing, but historical records of their public performances can give us a feeling for the activities they engaged in (Weisberg, 1999). When the Beatles performed, they played the same songs repeatedly, so we can look upon those performances as public practice. The number of Beatles performances is shown in Figure 5.2A. Beginning in mid-1960, when they were known only around Liverpool, they were performing approximately 400 times per year on average; that is, more than once per day. Based on records of the performances, one can estimate that the total amount of time they spent onstage during those years, without taking into account any offstage rehearsal and practice at all, approached 2,000 hours. Thus, when they burst on the scene, they were already seasoned professionals, and that seasoning had come about through practice.

In addition, although this early prehit period did not involve deliberate practice in the sense of formal tutelage under the supervision of a teacher, Lennon and McCartney began their careers by immersing themselves in the works of others. If one examines the music played by the Beatles in their early years, one finds that a large majority of the songs were cover versions of hits of the day that were written and originally performed by others. That immersion in the works of others served as a kind of unstructured practice. Furthermore, there were numerous examples of what one could call teaching and explicit practice in the development of the Beatles. Everett

A. Number of Beatles performances

Source: Weisberg (1999).

B. Proportion of Lennon-McCartney songs in Beatles' performance repertoire, by year

	1957	1958	1959	1960	1961	1962	1963	1964	1965/1966
Number of new songs in repertoire	53	20	20	98	50	46	15	11	10
Proportion of Lennon-McCartney songs	0.23	0.10	0.05	0.02	0.06	0.17	0.67	1.00	0.80

C. Proportion of Lennon-McCartney songs released on records during performance career

	First half of career (1957–1961)	Second half of career (1962–1966)
Number of songs written	20	37
Proportion recorded	0.16	0.92

Figure 5.2 The Beatles as composers: Development of expertise

(2001a, Chap. 1) notes that Lennon and McCartney (as well as Harrison, the third Beatle guitarist-composer) spent much time in their early years in what one could call active teaching of each other. If one of them acquired a significant piece of information that would allow them to play some other artist's hit of the day, such as a new set of chords for the guitar, he would share it. Those new pieces of information, obtained usually from another musician or from close listening to a recording, quickly became the source

for new compositional possibilities. Everett has traced many of the musical devices found in original Beatles songs to the songs of other artists with which they were familiar.

Figure 5.2B presents a summary, over the Beatles' performance career, of the proportion of Lennon-McCartney songs in their performance repertoire. For the first 6 years (1957–1962) they performed more than 250 different songs in their stage shows; of those, approximately 90 percent were cover versions of songs written and recorded by others. From 1963 to 1966, in contrast, over 80 percent of the songs that they performed were their own; almost everything new that they sang had been written by them. Thus, one can say that Lennon and McCartney first learned very well the works of others before they produced significant works of their own. The pattern follows that of Mozart and again provides evidence for the importance of practice in the development of creative skill.

It should also be noted that the very earliest songs written by the Beatles were not hits, and most of them are forgotten today except by Beatles collectors. That is, as with Mozart, the works that Lennon and McCartney were writing in the early portion of their career were of lesser quality than those written later. I have analyzed how frequently early versus later Lennon-McCartney compositions were recorded by the Beatles, and the results are shown in Figure 5.2C. Of the total of 23 Lennon and McCartney songs the Beatles performed during the first half of their performing career, about 25 percent were recorded. In contrast, over 90 percent of the Lennon-McCartney songs written during the second half of their performance career were recorded. Thus, if we use a song's being recorded as an index of its quality, then the later works were of higher quality than the early ones. Lennon and McCartney clearly learned something about writing songs during the years of playing all those songs written by others.

Furthermore, several additional years passed after their first big hits before Lennon and McCartney made their major contributions to popular music. The most significant work produced by the Beatles is not the hits of 1963–1964 that precipitated Beatlemania. One can examine the amount of innovation involved in various Beatles songs by considering critics' and historians' assessments of various works (e.g., Everett, 2001b; Lewisohn, 1992; Reising, 2002). There is general agreement that the Beatles' unique contribution to popular music occurred in the period 1965–1967, beginning with the albums *Rubber Soul* and *Revolver*, and reaching a high point with *Sgt. Pepper's Lonely Hearts Club Band*. Thus, the Beatles' innovations occurred in what one could designate as the third stage of their career: Stage 1 was cover versions of others' works; stage 2 was production of their own works but within the existing styles; stage 3 was significant stylistic innovation.

Stage 3 occurred approximately 10 years into their careers. Development of the Beatles parallels that of Mozart, as well as that of the groups studied by Bloom and colleagues (Bloom, 1985) and Ericsson and colleagues (Ericsson, Krampe, & Tesch-Römer, 1993; see Chapter 4): Years of study and/or practice in a discipline seems to be necessary for the development of the capacity to produce novel work.

Picasso's Development as a Painter

We have already extensively examined Picasso's creation of *Guernica*, which is one of the best-known paintings of the twentieth century. *Guernica* was created when Picasso was over 50 years old. We now turn to a more detailed analysis of the development of Picasso's skill, which was briefly mentioned earlier (Pariser, 1987), and a pattern similar to that of Mozart emerges. Picasso's father was a painter, as well as a teacher of painting, so Picasso, like Mozart, was exposed from an early age to training from a professional (Richardson, 1991). In addition, Picasso attended art school, and some of his early works that have been preserved show him practicing drawing eyes, facial profiles, the human body in difficult poses, and so on. Thus, we have here concrete evidence of the young artist carrying out deliberate practice to learn his craft. As noted earlier, Pariser's analysis (1987) of the juvenilia of several painters known for precocity, including Picasso, Klee, and Toulouse-Lautrec, concluded that they all went through stages of development that were the same as those traversed by all painters.

This analysis of Picasso's development also calls into question the claims made by Sternberg (1996), quoted earlier, concerning the degree of Picasso's early development. Again, it is not absurd to say that the paintings produced by Picasso over the first 10 years of his career are also matched by most painters as they work their way through art school. In addition, the 10-Year Rule also applies to Picasso: The first works that show a unique Picasso style—the Blue Period works—did not occur until more than 10 years into his career (Richardson, 1996).

Creativity and the Development of Expertise: Preliminary Conclusions

The three examples of career development examined so far—Mozart, the Beatles, and Picasso—provide support for the theory that the acquisition of expertise through deliberate practice plays a role in creative development, which is not unlike what occurs in the domains traditionally studied by researchers examining expertise. Thus, creative individuals who ultimately reach the highest levels of achievement do so through a slow learning process. We now turn from the examination of career development to several case studies of specific creative advances to further examine the role of

Case Studies of Creativity

ordinary thinking in a wider range of situations. Some of the case studies to be presented will encompass advances that broke radically with the past, and, as noted earlier, these are therefore particularly important in testing the idea that ordinary thinking underlies creativity.

Case Studies of Creativity in the Visual Arts

I will begin with several case studies from the visual arts, all of which can be looked upon as seminally important breakthroughs: Alexander Calder's creation of mobiles; Picasso's creation of the painting *Les Demoiselles d'Avignon* and his participation in the development of Cubism; and Jackson Pollock's "poured" paintings of the later 1940s. In each case, we will find evidence of the important role of ordinary thinking in providing the foundation for the advance.

Ordinary Thinking in Calder's Creation of Mobiles

Abstract wind-driven sculpture—the mobiles with which we are all now familiar (see Figure 5.3)—were created in the early 1930s by Alexander

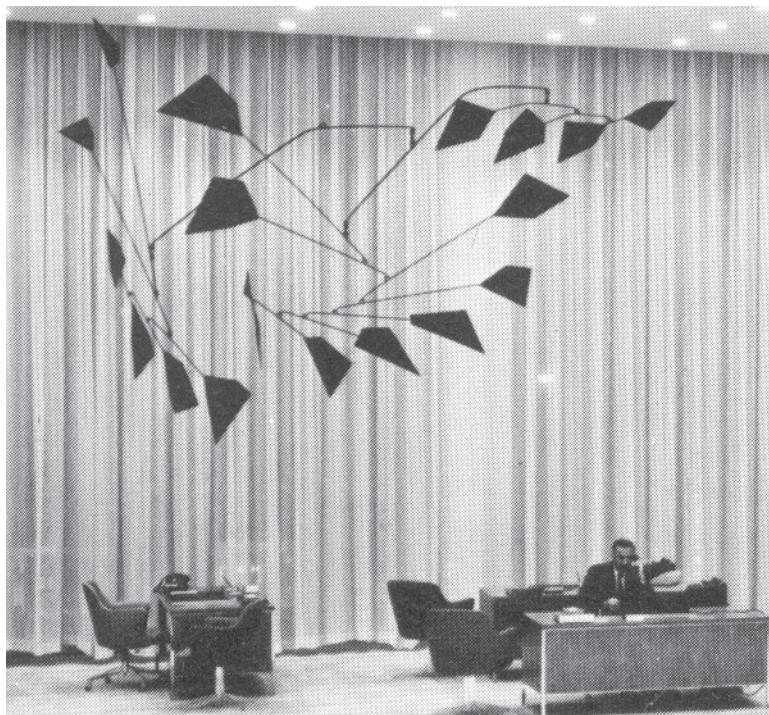


Figure 5.3 A Calder mobile

Calder (1898–1976), a young American artist living in Paris (Marter, 1991; Weisberg, 1993). Calder's mobiles were a radically new art form. No one had ever before seen anything quite like them, with their colored pieces of metal, held together by wire frames, gently floating through the air in response to the breeze. Calder, a mechanical engineer by training, came from artists on both sides of the family: His mother was a painter, and his father and paternal grandfather were sculptors. He had been immersed in art from the beginning of his life. After earning his college degree in engineering in 1919, he worked as an engineer for several years. Overall, Calder's engineering jobs were not satisfying, and he decided to follow a career in art.

Calder spent the next several years traveling between New York and Paris, studying in art school, and painting and sculpting. His early sculptures, which usually represented people or animals, were often constructed out of wire and involved movement (see top row of Figure 5.4A). In the 1920s Calder constructed a “circus” with a cast of miniature performers made out of wire, bits of wood and cork, and pieces of cloth (Figure 5.4B). The circus consisted of three rings, in which an animal trainer and his wild charges, as well as trapeze artists, a sword swallower, a chariot drawn by horses, and acrobats and clowns, were put through their paces by the artist. Calder's circus became the hit of Parisian art circles, and many artists and their acquaintances came to the Calders' apartment for performances. Calder had also earned money during the 1920s designing “action” toys

A

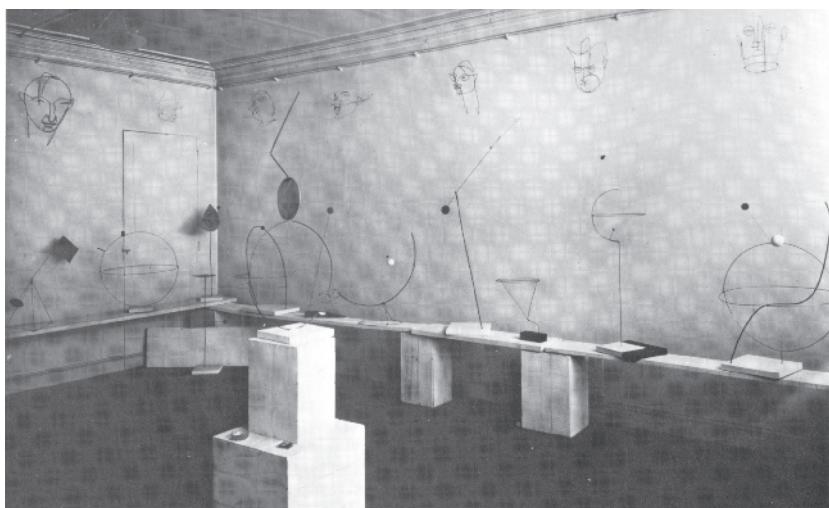


Figure 5.4 Examples of Calder's work: A, Early representational painting and sculpture: Top row at Galerie Percier; B, Circus performance (1929); C, Calder articulated fishbowl (1928, Private collection)

Case Studies of Creativity

B



C

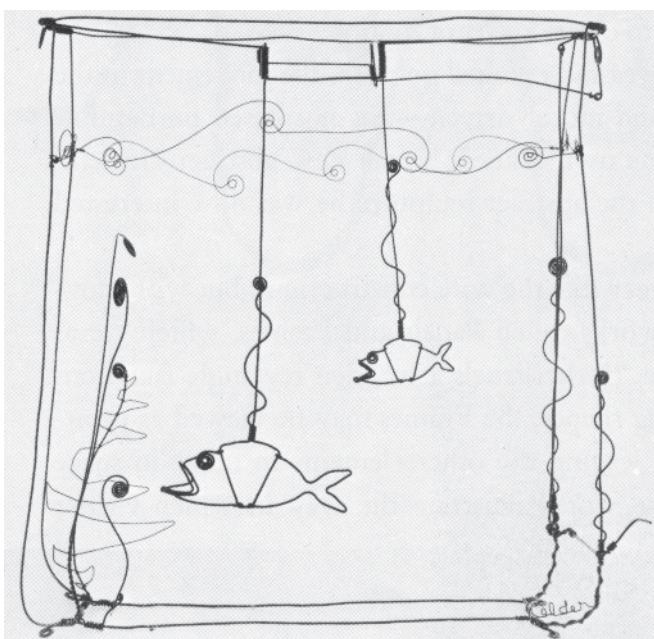


Figure 5.4 (continued)

for American manufacturers. One such toy was a kangaroo that rolled on wheels, whose hind legs were moved by the motion of the wheels. Many of those toys can be seen in altered form in the circus. Another example of a Calder sculpture that incorporated movement, produced by a hand crank, is shown in Figure 5.4C.

Around 1930, Calder's work took a radical turn, becoming *abstract* or *nonrepresentational*; that is, one could no longer see people or animals or any familiar objects in the pieces he created. The photo from the 1931 Calder exhibition at the Galerie Percier in Paris shows Calder's representational and nonrepresentational work together at that exhibit (compare the top and bottom of Figure 5.4A). This relatively sudden shift in style was triggered by Calder's visit to the apartment-studio of Piet Mondrian (1872–1944), another of the many artists living in Paris at that time, who had met Calder though a visit to Calder's circus. Mondrian, a painter, was one of several artists in Paris at that time working in a nonrepresentational style. His best-known works are completely nonrepresentational: grids made out of black lines on a white canvas, with some of the spaces in the grid filled in with blocks of primary colors (blue, yellow, red). Examples of Mondrian's works could be seen hanging on the white walls of his studio. In addition to his works, pinned on the walls of Mondrian's studio were paper rectangles of primary colors (see Figure 5.5A). When Calder saw Mondrian's white walls

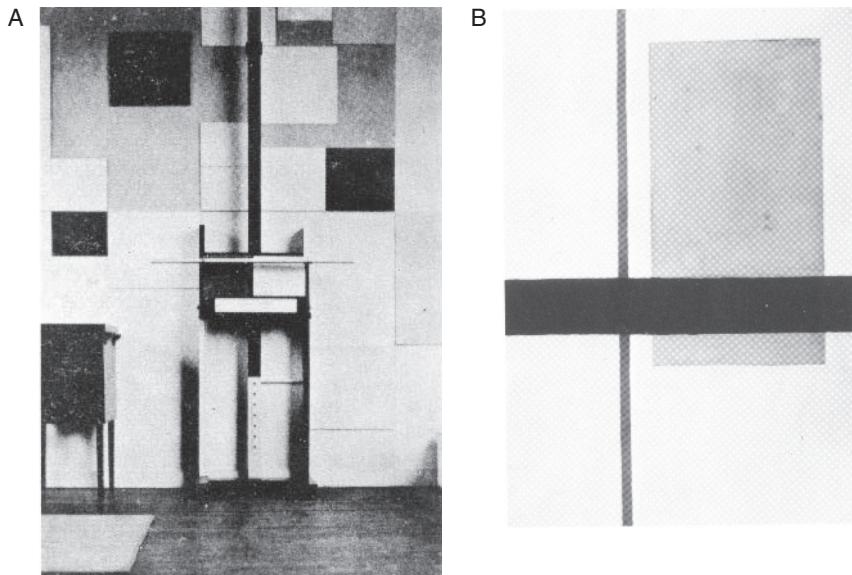


Figure 5.5 Calder and Mondrian: A, Mondrian's studio, rue du Départ, Paris (photographer unknown); B, Abstract Calder painting ("Composition," 1930)

with their blocks of primary colors, he is said to have remarked to Mondrian that the colored blocks should move.

Soon thereafter, Calder began to paint in an abstract style similar to Mondrian's (Figure 5.5B), but he quickly turned to sculpture, using wire, with which he was more comfortable (see nonrepresentational sculptures at the bottom of Figure 5.4A). He produced numerous abstract works of sculpture, and he soon began to incorporate movement into nonrepresentational works, first produced by hand cranks and then by electric motors. One can see an interesting progression in the development of one of Calder's sculptures, called *Universe*. An early version (1931), shown at the bottom right of Figure 5.4A, consisted of several "planets" and a wire and steel-rod frame, but nothing moved. A later version (1934) is similar in appearance, but it incorporated an electric motor, which resulted in cyclical movement of the "planets" and of the curved steel rod. One sees here Calder's transition over several years from static to dynamic nonrepresentational sculpture. However, motorized sculptures were difficult to keep working (the mechanisms kept breaking), and even when they did work the possible movements were restricted and soon became repetitious and boring, especially for Calder. He then decided to structure the sculptures so that they would be moved by the wind, a simpler and therefore more reliable, as well as a less predictable, source of movement. And so the first mobiles were created (Figure 5.3).

In Calder's creation of mobiles, we see several streams of his experience coming together. Many of his early sculptures, including the circus and the action toys, involved movement, which was a constant component of his works. Importantly, some of his early representational works were designed to swing in the air, so the use of air currents as a potential source of movement was known to Calder. Those aspects of his own work served as antecedents to the mobiles and were incorporated relatively directly in them. It is also of interest that the incorporation of air currents as the motive power for the mobiles came about at least in part as the solution to a problem faced by Calder: that is, because of difficulties using motors. The switch to an abstract subject matter was stimulated by an external event: Calder's exposure to Mondrian's studio. So here we see an artist building on his own work and changing it radically on the basis of exposure to work by others.

Marter (e.g., 1991) has proposed that Calder's education and experience as an engineer were also important in shaping his art, including his interest in movement and the "mechanical" aspect of many of his creations. Marter has also proposed that a number of the pieces of equipment used in demonstrations in the physics classes that Calder attended served as bases for some of his abstract sculptures (see Figure 5.6). Finally, it is no accident

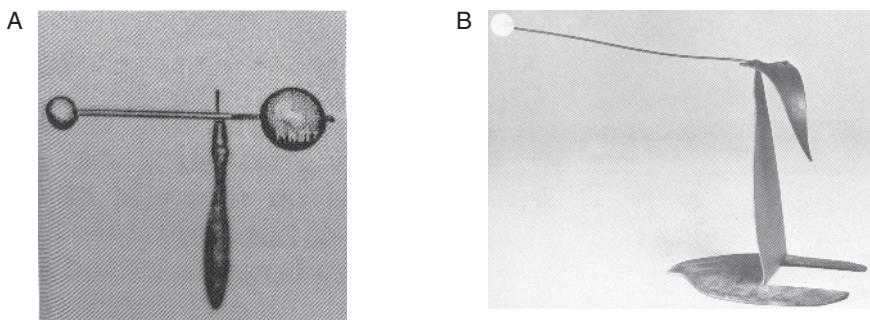


Figure 5.6 Calder and physics:
A, Physics demonstration device;
B, Calder sculpture

that Calder's radical breakthrough occurred a number of years into his art career (i.e., the 10-Year Rule applies once again).

As we can see, we have here an example of an individual who produced groundbreaking innovation and whose development nonetheless is consistent with what might be expected on the basis of the present view, with its emphasis on the components of ordinary thinking in creativity. We have seen structure in Calder's thinking, as well as evidence for the importance of expertise, antecedents, and influences.

Picasso's Radical Advances

We have examined in much detail Picasso's creation of *Guernica* and have found evidence for the role of ordinary thinking in Picasso's creative work. However, as noted earlier, that painting was not a radical advance beyond Picasso's work at that time. In order to examine the possible role of ordinary thinking in radical advances in Picasso's art, it is necessary to go back to two earlier developments in his career: the painting *Les Demoiselles d'Avignon*, painted in 1906–1907, and his collaboration with Georges Braque in 1911–1912, which resulted in the development of Cubism.

Les Demoiselles d'Avignon

This painting, shown in Figure 5.7, has been called the most important of the twentieth century (e.g., Rubin, 1994), because it made a break between reality and the depiction of the objects in the painting. Up until the mid-nineteenth century, the overarching philosophy behind painting, as advocated by the art establishment, was that a painting should at least faith-



Figure 5.7 Picasso, *Les Demoiselles d'Avignon* (June–July 1907)

fully represent reality, and in some cases should present an idealization of reality. There was no attempt to represent reality faithfully or to idealize it in *Les Demoiselles d'Avignon*; those women are painted as they are because Picasso wanted the viewer to respond to them in a certain way. Picasso's painting mirrors his *conception* of those women, not his *perception*. This reliance upon the painter's conception in a painting, presented through visual means, was what made it so new. Picasso was one of a handful of young artists in Paris in the early years of the twentieth century who were exploring this mode of expression, and *Les Demoiselles d'Avignon* was by far the most radical of their works.

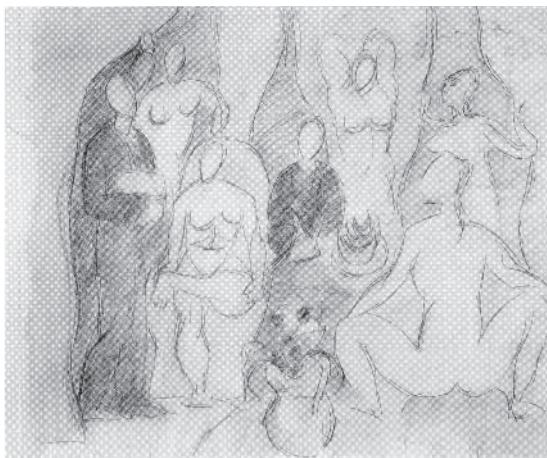
The painting portrays the parlor of a brothel, where five prostitutes in various stages of undress are presenting themselves to the viewer. Because

of the structure of the painting, with a table protruding halfway into the painting at the bottom, the viewer gets a sense of being in the space of the painting. We are participating in the scene: The women are presenting themselves to us. The woman on the left, whose masklike face is in profile and whose hand is visible behind her head, is drawing the curtain as if to close off the scene from us. The two women in the center, the most realistic of the five, are notable for their faces, with almond-shaped eyes with heavy lids, as well as flat noses and small turned-down mouths. Their scrolled ears are also notable. The woman entering the scene through the heavy curtains from the upper right also has a masklike face. Finally, the woman at the lower right is the most distorted of all, with her masklike face twisted around to face us, while her body faces into the picture.

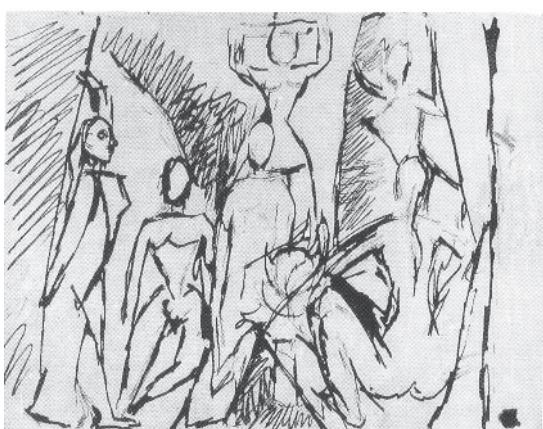
As with *Guernica*, Picasso made numerous sketches for *Les Demoiselles d'Avignon*, composition sketches as well as sketches of individual characters. I will discuss here two aspects of the development of the painting: its overall structure and the appearances of the faces of the three peripheral demoiselles (for more detailed discussion, see Weisberg, 1993, Chap. 7). In the earliest composition sketches, one sees the five women arrayed much as they are in the final painting, except for two differences: There are also two men in the early sketches, one in the center and one drawing the curtain (see Figure 5.8A). After making many sketches with seven characters, Picasso began to draw sketches with six characters (five women and one man) and then five (only the women). In the painting, he concentrated on the five women alone; from the beginning the painting contained only the five women. We see here an example of planning on Picasso's part; he seems to have spent much preliminary work deciding on the final structure of the painting. As with *Guernica*, the final structure of *Les Demoiselles* is not a complete rejection of his initial idea and a move in an entirely new direction. Instead, and again as with *Guernica*, the final structure of *Les Demoiselles* could be more accurately described as a fine-tuning of Picasso's original idea. (See Figure 5.8B and Figure 5.8C.) So again we see evidence for structure and planning in Picasso's thought.

It has been proposed that the change from men plus women to women alone was the result of a decision Picasso made concerning the story he was telling in the painting (Rubin, 1994). The scene is one of sexual license—set, as we have noted, in a brothel—and the male character at the center has been identified from some sketches as a sailor, a customer of the brothel. The other man has been identified as a medical student (in some sketches he carries a skull and a large book), who may be warning the sailor about the risks of involvement with the women. At the turn of the century, venereal disease was of great concern, and Picasso, a notorious hypochondriac, was especially concerned

A



B



C



Figure 5.8 Sketches for
Les Demoiselles d'Avignon
(March–June 1907):
A, Seven-person sketch;
B, Six-person sketch;
C, Five-person sketch

about the consequences of untreated venereal disease. It was rumored that he might have contracted venereal disease at about that time, although there is no definitive evidence for that. He had visited a hospital where prostitutes in the last stages of untreated venereal disease were suffering greatly, and he may have sketched some of them. So the first version of the painting tells us that the sailor is taking a grave risk and that we too should be concerned. In the version without the men, the same message is transmitted, but more directly: We are repelled by the grotesque appearance of the women, so we are inclined to stay away. So it seems that Picasso had a story that he wanted to tell when he began to paint, and that story remained more or less intact through the changes in the structure of the painting. We see here that it is not necessary to postulate some sort of “leap” on Picasso’s part in order to understand the development of the painting. Picasso’s ideas about the overall structure of the painting followed a comprehensible course.

Concerning the faces of the demoiselles, in the earliest sketches all the women had faces similar to those of the two demoiselles in the center of the finished painting. That style of face can also be found in many of Picasso’s works at about that time, and the model for them seems to be a piece of antique Iberian sculpture that Picasso had come into contact with at about that time. As with other examples that we have considered, then, Picasso’s



Figure 5.9 Iberian sculpture

stream of thought was affected by his contact with an external stimulus. Similarly, the scrolled ears in the central demoiselles are very similar to the ears on another piece of antique sculpture with which Picasso was also in contact at about that time (see Figure 5.9; for further discussion, see Rubin, 1994; Weisberg, 1993).

Finally, a similar process seems to have been at work in bringing about the radical changes in the faces of the three peripheral demoiselles; those too seem to have come about in response to an external stimulus. In the winter of 1906–1907, Picasso visited an ethnographic museum in Paris, where he viewed primitive sculptures from the South Pacific that featured masklike faces. Those sculptures elicited a strong emotional response from Picasso, and they stimulated him to change the appearance of several of his women in order to increase the emotional response to their appearance. He did not simply copy masks from the ethnographic museum, however; he used aspects of the masks' construction as the basis for his own work (see Rubin, 1994, for discussion). Examination of Picasso's sketchbooks for *Les Demoiselles* (Rubin, 1994) indicates that he spent much time planning the appearance of each individual character. For further discussion of planning in problem solving, see Mumford and colleagues (2001).

Thus, we can understand the development of one of the most innovative paintings of the twentieth century as being the result of ordinary thought processes, although those processes reached an extraordinary end. *Les Demoiselles d'Avignon* came about through Picasso's incorporation into his art of several ideas from other works, and his elaboration and extension of those ideas produced something that looked radically new. However, the fact that a creative advance seems, to outside observers at least, to have arisen from nowhere, with no precedents, is usually a comment on the observer's ignorance rather than a description of the creative process underlying that advance.

Cubism

Only a few years after the radical advances encapsulated in *Les Demoiselles d'Avignon*, Picasso, in collaboration with Georges Braque (1882–1963), developed Cubism, which sent modern art in an entirely different direction. This new style did away with traditional perspective and means of representing depth (see Figure 5.10A), sometimes portraying objects from multiple viewpoints at once. When they began to work in collaboration, Picasso and Braque spent time together most days, analyzing the new work each had done. The early Cubist paintings produced by the two artists are so similar that it is very difficult for the untrained eye to tell who painted a given work. Although he is the lesser known of the two artists, at the begin-

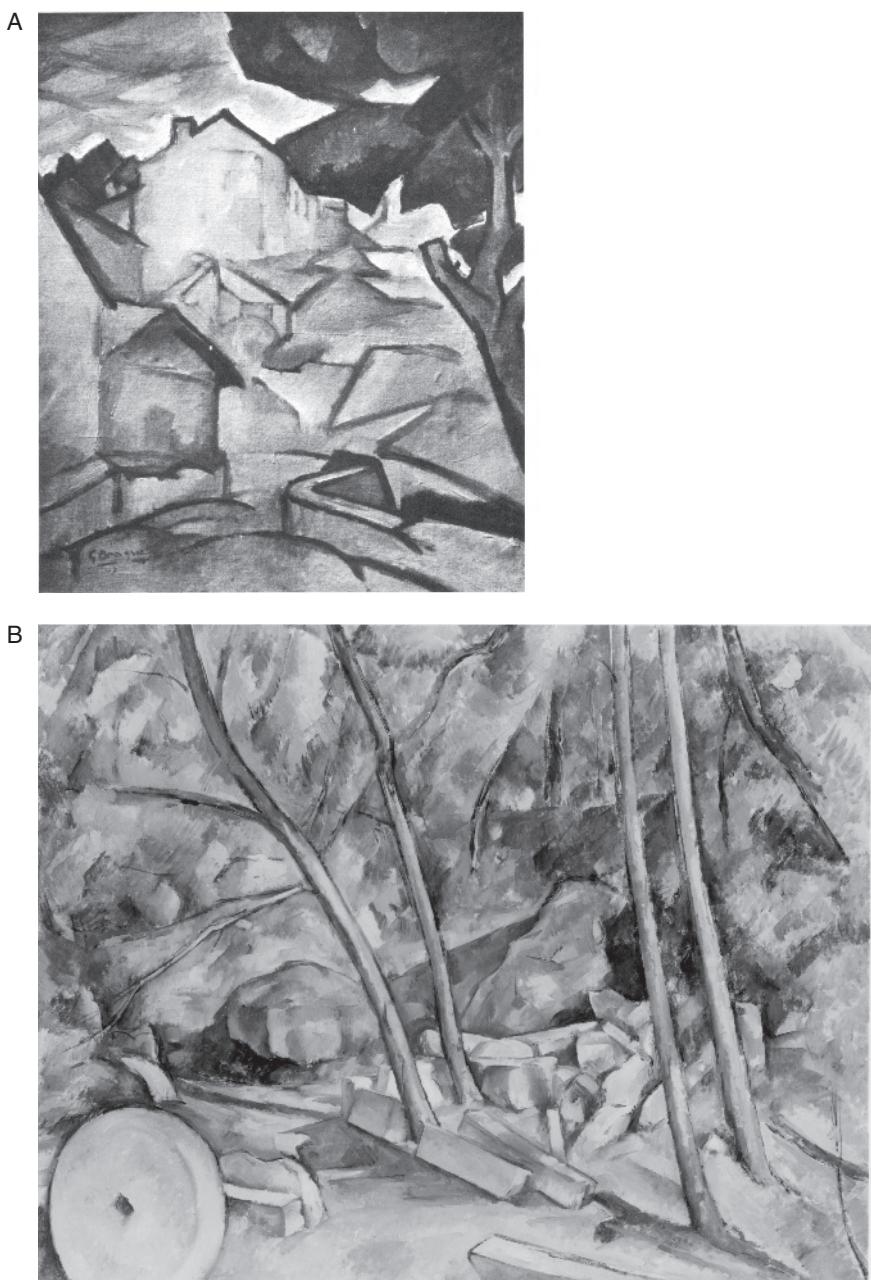


Figure 5.10 Cubism and Cézanne: A, Early Cubist work: Georges Braque, *Landscape with Houses* (1907); B, Cézanne late landscape: *Millstone in the Park of the Chateau Noir* (1898–1900)

ning of the collaboration Braque was in some ways in advance of Picasso in development of the style (Rubin, 1989). Braque was at that time strongly influenced by the late style of Paul Cézanne (1839–1906), who was admired by many of the young artists in Paris at the turn of the twentieth century. When one examines Cézanne's late works, especially his landscapes, one sees clear antecedents for the Cubist works of Braque and Picasso (see Figure 5.10B). So here we have still another example of a radically new development that can be traced to an antecedent with which the innovators were familiar: Picasso and Braque's development of Cubism was an extension of Cézanne's work. However, as we saw with *Les Demoiselles*, Picasso and Braque did much more than simply copy what Cézanne had done. They developed a much more complex manner of representation in their Cubist works, and they extended it to portraiture, which Cézanne had not done.

This analysis of two of Picasso's radical advances in painting has produced conclusions similar to those arising from the analysis in Chapter 1 of his creation of *Guernica*. This indicates that radical creative advances can be brought about by processes that are not radical in nature.

Jackson Pollock's Poured Paintings

The developments in art that we have just discussed—Calder's creation of mobiles, Picasso's creation of *Les Demoiselles d'Avignon*, and Picasso and Braque's creation of Cubism—all took place in Paris, which was the center of the art world until the middle of the twentieth century. In the late 1940s, the world center of art shifted from Paris to New York with the rise of the Abstract Expressionist School, or New York School, of painters (Sandler, 1978). One of the leaders of that school was Jackson Pollock (1912–1956), who developed a “pouring” style of painting in which he abandoned the traditional method of painting (using a brush to apply paint, squeezed from tubes, onto the canvas). Pollock used his brushes, as well as sticks, as means for dripping, spraying, and pouring paint on the canvas, and he also poured the paint directly from cans onto the canvas, which was lying on the floor. He used that technique to produce paintings that were totally nonrepresentational, with no hint of objects in them (see Figure 5.11). Those works were very different from anything Pollock had produced earlier in his career, and they were also different from works produced by the other New York School artists. However, once again we can trace a radical innovation to the creator's knowledge and expertise. We do not need to invoke extraordinary thought processes to understand how Pollock's innovative style developed.

In 1943, Pollock and other young artists living in New York attended a government-sponsored workshop given by David Alfaro Siqueiros (1896–1974), a Mexican artist who, along with his compatriots Diego Rivera

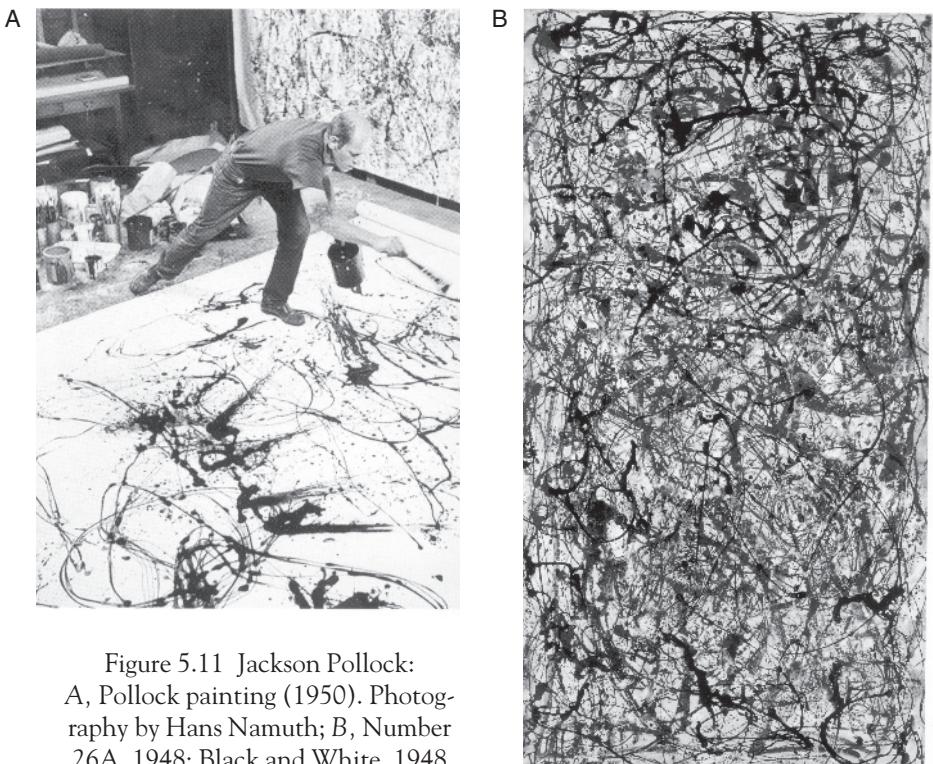


Figure 5.11 Jackson Pollock:
A, Pollock painting (1950). Photog-
raphy by Hans Namuth; B, Number
26A, 1948: Black and White. 1948

(1886–1957) and José Orozco (1883–1949), had established a presence in the New York avant-garde art scene. The Mexican artists were strongly left-wing in their politics, and one of their goals was to remove art from what they perceived as an elitist position in society and make it accessible to the masses. In order to do so, it was necessary to break with tradition and to use modern materials and techniques. Traditional oil paints in tubes and their application to the canvas by brush were to be eliminated. The brush was derided as the “stick with hair.” Siqueiros and his compatriots, as well as other modern artists in New York, experimented with modern materials and techniques, such as air-brushing industrial paints from cans onto non-canvas surfaces. In addition, Siqueiros himself developed works in which he applied paint to canvas by throwing, spilling, and pouring it. The young New York artists were familiar with those works. At the workshop attended by Pollock, those techniques were undoubtedly talked about and perhaps even demonstrated (Horn, 1966). At about that time, Pollock and several peers collaborated on a painting in which pouring of paint played a part. Pollock then began to use pouring as a technique, although his early uses

of it were very much simpler than the complex compositions that he was able to create when the style “matured.” Thus, Pollock’s development of his new style, based on the advances of Siqueiros and his colleagues, led to a system capable of behavioral adjustments (see Chapter 4), which Pollock himself then had to master.

Here we see still another example in which a radically new advance, which may seem to an outside observer to have come from nowhere, had its basis in the knowledge and expertise of the person who created it. Again we see a radical advance that did not break with the past but was built on it, and the thought processes involved do not seem to be extraordinary in nature.

Case Studies of Creativity in Science

This brief survey of several seminal advances in twentieth-century art has indicated that ordinary thinking plays a critical role in artistic advances, even those that seem to break cleanly with the past. I will now examine two examples of scientific creativity, to show that the same pattern is seen in that domain.

The Double Helix

As noted several times earlier, the discovery of the double helix is also relevant to the question of the role of ordinary thinking in creativity. Watson and Crick’s initial strategy grew out of their expertise: They decided early on that they would work on the problem of deciphering the structure of DNA by attempting to build models of the molecule, a method adopted from Pauling, a world-famous chemist who, they knew, had used that method with great success in his recent research. Thus, we have clear evidence of antecedents to Watson and Crick’s work. Watson and Crick also adopted a more specific strategy from Pauling by assuming on the basis of Pauling’s work that DNA was a helix. As noted in Chapter 4, this use of expertise can be looked upon as an example of analogical transfer. Watson and Crick used information from a closely related area in their expertise as the foundation on which they constructed their model (a regional analogy; Dunbar, 1995; see Chapter 4). Thus, Watson and Crick’s thought process was highly structured when they began their work.

In addition, we have seen that various specific components of the double helix also came about through the exercise of ordinary thinking, sometimes in conjunction with external information. Franklin’s photo 51, for example, provided an important piece of information, as did her report on the dimensions of the unit cell of the molecule. In order to understand the development of those components, it is not necessary to assume that any

extraordinary thought processes were involved. For further examples that fit the same pattern, see Figure 5.12, a reproduction of Figure 1.7, which presents several of the important components of the double helix and notes how they were derived. That presentation becomes of additional interest in the present context, where it makes clear the “ordinary” nature of the processes involved.

It should be acknowledged in this context that Watson and Crick’s advance was not a radical one, because they built relatively directly on work that had come before. A more groundbreaking scientific advance was Darwin’s development of the theory of evolution through natural selection. Therefore, it would be of particular interest to examine that case study.

Darwin’s Creation of the Theory of Natural Selection

If one can question whether the discovery of the double helix was a radical creative advance, there is no doubt about the revolutionary nature of Darwin’s theory of evolution. Indeed, the broad ramifications of Darwin’s view are still being felt today, in more ways than one. We see the wide-ranging philosophical implications of Darwin’s theory in the debate between proponents of evolutionary versus “intelligent design” views on the origin of species. We also saw in Chapter 2 that Darwin’s theory of evolution has served as the basis for the development of the neo-Darwinian theory of creativity (Campbell, 1960; Simonton, 1988, 1999, 2003), in which creative thinking is seen as a two-stage process, in which “blind variation” in the production of ideas is followed by selective retention of the valuable ones. The Darwinian view of creativity will be discussed in detail in Chapter 11.

What Did Darwin Do?

As a creative act, Darwin’s formulation of the theory of evolution through natural selection has sometimes been dismissed with faint praise by psychologists. Davidson and Sternberg (1986, p. 178), for example, say the following about Darwin: “The facts needed for the formulation of this theory had been available for some time. What had eluded investigators was a way of combining these facts into a coherent theory of evolution.” Davidson and Sternberg propose that Darwin used the insight process of *selective combination* to achieve the insight needed to develop the theory. That is, Darwin selectively combined facts in a judicious manner until the theory was formed. (See the discussion and critique of Sternberg and Davidson’s [1995] insight processes in Chapter 11, in the context of the discussion of Sternberg and Lubart’s [1995] investment theory of creativity.)

In this view, Darwin did not do much in the way of thinking; he simply

TIMELINE ⇒	COMPONENT
	Pauling's method ⇒ Model building as method of attack
	Pauling's alpha-helix ⇒ Helical shape of molecule
(Incorrect density)	⇒ 3 chains (2 chains fall short of density) ⇒ Problems with triple helix; Franklin's A ⇔ B length change and A-form density ⇒ Watson's reasoning ⇒ 2 chains
	Problems with sizes and tautomeric forms of bases ⇒ Chains inside ⇒ Problems with bases-inside models + Franklin's opinion + Franklin's photo 51 + Donohue's opinion about tautomeric forms ⇒ Chains outside
	Franklin's unit cell discussed in her report ⇒ Same space group in Crick's research ⇒ Crick's deduction ⇒ Chains antiparallel
	Antiparallel chains + repeat from X-rays + shape of nucleotides ⇒ 36° Pitch of helix
Mg ⁺ ions in triple helix	⇒ No Mg in DNA ⇒ Crick: bases might match up ⇒ H bonds holding chains together
Watson's "like-like"	⇒ torn to shreds by Donohue ⇒ Watson manipulating shapes on his desktop ⇒ H bonds holding bases and chains together ⇒ Complementary base pairings

Figure 5.12 Timeline: History and development of components of DNA

combined what was known until he hit upon a useful combination. Davidson and Sternberg (1986) interpret Darwin's accomplishment as being a relatively bottom-up one; there is little in the way of top-down or conceptual involvement in a merely combinatorial process. Gruber (1981), in contrast, describes Darwin's activity in a much more dynamic manner. In Gruber's view, Darwin was "constructing a new point of view" (p. 97) and "structuring an argument" (p. 150), which seem to involve much more in the way of complex thinking processes. The question also arises as to whether we can understand what Darwin accomplished without having to invoke extraordinary thinking processes. Thus, it would be of interest to consider exactly what Darwin did accomplish. In order to do that, it is necessary to review what was known at the time that Darwin did his work, so we can understand how far he went.

Darwin's autobiography, which was written for the edification of his children, also leads one to believe that he did not do much in the way of thinking when he developed his theory (Gruber, 1981, p. 173). Darwin's comments support the idea that his great insight came to him more or less all at once, as the result of the reading (or rereading, since he had read it before) of a critical passage in Thomas Malthus's (1766–1834) *Essay on Population*, in which Malthus argues that the population of organisms will always tend to outstrip resources, so that there will be competition for limited resources, such as food. Darwin reports that on contemplating Malthus's argument, he realized that any animals that were "more fit" would survive in this competition for food. Those animals would pass on their characteristics to their offspring, which would result in the population's evolving. Darwin (1958) wrote the following about his reading Malthus.

In October 1838, that is, fifteen months after I had begun my systematic enquiry, I happened to read for amusement Malthus on *Population*, and being well prepared to appreciate the struggle for existence which everywhere goes on from long and continued observation of the habits of animals and plants, it at once struck me that under these circumstances favorable variations would tend to be preserved and unfavorable ones to be destroyed. The result of this would be the formation of a new species. Here, then, I had at last got a theory by which to work. (p. 120)

There is an ambiguity in the last sentence of this passage. When Darwin says that he finally had "a theory by which to work," does he mean that until then he had had no theory, or does he mean that until then he had had an unworkable theory? We will see that the situation seems to have been closer to the latter case than the former; Darwin had been theorizing about evolution for a significant amount of time before reading Malthus, but he had not yet developed a theory that he was satisfied with.

Soon after reading Malthus, Darwin wrote the following in his notebook: “Three principles will account for all. 1. grandchildren like grandfathers, 2. tendency to small change especially with physical change, and 3. great fertility in proportion to support of parents” (Darwin, notebook E, p. 58; cited in Gruber, 1981, p. 156). Those notes provide a succinct summary of the theory of evolution through natural selection. First, each generation passes its characteristics on to the following generations. Second, organisms within a given generation vary in many different small ways. Those small changes allow for adaptation to the environment. The phrase “especially with physical change” is a vestige of earlier theorizing, in which Darwin assumed that changes in the environment could stimulate changes in organisms. That assumption is an example of an earlier *theoretical* idea that had to be rejected before Darwin could develop the theory of natural selection; that is one indication that Darwin was doing more than combining facts and that his development of his theory entailed more than simply responding to Malthus. Finally, because of fertility, there are many more offspring than parents, which results in competition among offspring for limited resources (that was from Malthus). From those premises, Darwin drew the conclusion that any variation that helps a given organism compete and survive will be passed on to the next generation.

Based on this analysis, one could argue that logical thinking played a critical role in Darwin’s development of his theory (see also Perkins, 1981). Malthus provided a key premise in a deductive argument. The question that then arises is what the other premises were and where they came from. We can begin to answer that question by considering the historical context of Darwin’s achievement.

Darwin in Historical Context

The mid-nineteenth century was a time of great controversy in the sciences of biology and geology concerning the development of earth and the creatures on it (Eiseley, 1961). The *orthodox* view, based on a literal interpretation of the Bible, held that the earth and all its creatures were created in 6 days and that species had not changed since. It was acknowledged that there had been one change since the original creation, Noah’s flood, which had wiped out all life except that which had survived on the ark. Based on a count of generations in the Bible, it had been concluded that the earth was created some 6,000 years earlier. In addition, the orthodox view held that living creatures could be ordered into a “scale of being,” from the simplest to the most complex and perfect (humans, naturally). This scale corresponded to the order in which the various species had been created by God. It is obvious that not all organisms within a given species are identical, and the

orthodox view acknowledged that there was some variability within species, but it was also believed that species could not change. That variability was around the ideal that had been created originally by God.

However, the mid-nineteenth century was also a time of great scientific activity, and this activity had discovered facts that seemed to at least raise problems for, and in some cases contradict, the orthodox view. Explorers investigating ever-more-remote areas of the earth had discovered new species of animals and plants that were nothing like those in Europe. It was difficult for orthodoxy to explain the far dispersion of those species, which, according to orthodoxy, must have occurred after the flood. Fossils also came under increasing study and raised other questions. Fossil records were found of organisms different from existing species, which raised questions about whether species had undergone extinction or had evolved into other species. In addition, the geological explorations involving fossil study seemed to indicate that the earth was much older than the 6,000 years that orthodoxy, on the basis of the Bible, allowed.

In response to those sorts of findings, the orthodox view underwent modifications. First came the suggestion that there might have been multiple floods, with Noah's being only the most recent. That could explain the existence of fossil records of species that did not exist in the nineteenth century, as well as the age of the earth. This view, which proposed that in its history the earth had been subject to upheavals or catastrophes, such as multiple floods, was part of a doctrine called *catastrophism*. So the orthodox view was not completely rigid and was modified in response to scientific findings.

Pre-Darwinian Evolutionary Theorizing on Origins and Change of Species

As with many of the creative advances that we have considered in this book, Darwin was not nearly the first scientist to think about how species originated and how they might have changed over time; that is, Darwin was not the first to think about questions concerning evolution. Over 100 years before Darwin, the Comte de Buffon (1707–1788) had grappled with the same questions that Darwin did, and he came up with answers that are in many ways similar to Darwin's (Eiseley, 1961). In Buffon's *Histoire Naturelle* (1749), he discussed the following facts. Life sometimes multiplies faster than the food supply, and this implies that there will be a struggle for existence among organisms. Here, Buffon also precedes Malthus. In addition, Buffon noted variations in form within species, and he was also aware that those variations can be inheritable. It was also common knowledge among breeders that such inherited characteristics could be taken advantage of by

selective breeding, or *artificial selection*. Thus, the concept of artificial selection—which, as we shall see, played a role in Darwin's thinking—was well known long before Darwin. Buffon also noted that there was an underlying similarity of structure among animals that are on the surface very different, such as bones in the fins of seals that look like the bones in human hands. This might indicate evolution from a common ancestor. Concerning the age of the earth, Buffon noted that long stretches of time are necessary to explain how life developed on earth, beyond the time allowed by a literal interpretation of the Bible. There was also evidence that some animal life had become extinct, which raised questions in his mind about the constancy of species. Finally, Buffon's overall philosophy was oriented toward an experimental approach to the study of questions concerning evolution, rather than deductions based on an assumption of the literal truth of the Bible.

All these aspects of Buffon's thinking are similar to ideas that one finds in Darwin. However, before we conclude that Buffon produced Darwin's theory before Darwin did, it is important to consider several important differences between Buffon and Darwin. Most critically, Buffon did not propose a mechanism to produce *change* in species (Eiseley, 1961). He simply noted that evolution might have occurred, without saying how. Although he mentioned artificial selection, he did not mention *natural selection*, or anything like it, as a positive factor in evolution. As far as changes in species were concerned, Buffon only suggested in general terms that climate could affect the structure of species. As we shall see, that was an idea that Darwin rejected before he developed his theory. So, in considering Buffon and comparing his thinking with Darwin's, we have evidence that the development of the theory of evolution was more than selective combination of facts; it was also the development of a theory—a mechanism to explain the facts—and that is where Darwin went beyond anything done before him.

It is also important to note the reaction to Buffon's ideas by the intellectual establishment in Europe. The *Histoire Naturelle* was judged by the Faculty of Theology at the Sorbonne as contradictory to the Bible. Buffon was required to repudiate his own ideas and, like Galileo some 300 years earlier, to affirm in print that he believed in the literal truth of the Bible and that he abandoned everything in his book that was contradictory to the biblical story of creation. Such strong reactions to evolutionary theorizing—which, as we shall see shortly, continued well into Darwin's day and beyond—had the effect of enforcing caution on everyone who was thinking about questions of the origin and change of species. Darwin worked for many years on *The Origin of Species*, the great book in which he laid out his theory and the evidence supporting it. Some have wondered why he waited for years to publish it (see Eiseley, 1961), and, indeed, he seems to

have been pushed into making his ideas public by the receipt of a communication from Alfred Russell Wallace (1823–1913). Wallace presented to Darwin his thinking on evolution, which had resulted in his developing, independently of Darwin, the same theory as that which Darwin had developed. Darwin shortly thereafter presented Wallace's and his own ideas before a scientific meeting, and he published *The Origin* soon thereafter. It has been hypothesized that Darwin's reluctance to publish might have been the result of neurotic anxiety arising from unconscious Oedipal fears concerning the possible effects of his theories on the establishment (which might, without his consciously realizing it, have represented Darwin's father; see Gruber, 1981, for discussion). However, if indeed there were fears that delayed Darwin from making his ideas public (Gruber, 1981), they were anything but irrational: He had seen the strong response that evolutionary theorizing could arouse.

Pre-Darwinian Theories of Evolution: Antecedents to Darwin

In the years preceding Darwin's groundbreaking theory, there had been several attempts to develop theories of evolution, the most important of which was developed independently by Jean-Baptiste Lamarck (1744–1829), who was supported by Buffon, and Erasmus Darwin (1731–1802), Charles Darwin's grandfather. What became known as the Lamarckian theory proposed that characteristics acquired during an organism's life could be passed on to its offspring, resulting in evolution. Those changing characteristics were developed as a result of the struggle among organisms to survive. That is, both Lamarck and E. Darwin assumed, in a parallel to Malthus, that there was a struggle for relatively scarce resources in the lives of all organisms. Some organs that were used extensively in the struggle for survival tended to increase in size, and those changes could be passed down to the next generation. Lamarck also emphasized that changes in domestic animals could be brought about by selective breeding. The inherited changes brought about by the struggle for survival resulted in evolution of species.

The Lamarckian view can be contrasted with Charles Darwin's final view, that evolution occurs through natural selection. Charles Darwin assumed that changes in organisms occur all the time; that is, the changes do not take place in response to or as a part of the struggle for existence. Those changes are "blind," or random. Some of those random changes result in some organisms being better able to compete for the limited resources discussed by Malthus. Those changes, preserved in the genetic material, are passed down to the next generation. In Charles Darwin's early thinking, however, he proposed that changes in organisms can be stimulated by environmental conditions, an idea that came from earlier theorists.

Charles Darwin's Interest in Evolution

In Chapter 1, we considered the question of why an individual who makes a significant creative contribution might have been drawn to that area in the first place. How does the creative individual choose to invest his or her intellectual resources? We saw that in the case of DNA, questions about the structure of the genetic material were critical in the intellectual environments in which Watson and Crick developed, so it was not surprising that they were interested in that question. No special intuition was needed. A similar situation holds concerning Darwin's interest in the question of the evolution of species. The question of evolution had been of interest for many years before Darwin began to think about it. The problem of the evolution of species had been in the center of some individuals' thoughts for more than a century. Furthermore, since one of those individuals was Darwin's grandfather, it is highly likely that, even though Erasmus Darwin died before Charles was born, evolution of species and related questions were discussed in the Darwin family as Charles was growing up, especially since those were issues that many middle-class Victorian families discussed. Furthermore, the fact that Wallace independently developed the theory of evolution by natural selection provides further evidence concerning the relatively broad interest in the problem.

In addition, both Darwin and Wallace were beaten to the theory of natural selection by Patrick Matthew (1790–1874). In 1831, Matthew published a sketch of the same theory in an appendix to a book he had written on techniques for raising trees to produce timber of optimum quality for construction of ships for the English Royal Navy (Eiseley, 1961). Darwin, who seems to have been unfamiliar with Matthew's work, later acknowledged that Matthew had anticipated him and Wallace. So here is further evidence of the relatively wide interest in questions of evolution. There are several reasons why Matthew's work had no effect on the scientific establishment and why he is accorded at most a footnote in history. First, the theory was presented in an appendix in a book that was probably not read by most people interested in questions pertaining to evolution. Darwin's and Wallace's ideas were presented in a more visible forum, where they were accessible to people interested in the questions being addressed. Also, Matthew presented only an outline of the theory, rather than the theory and voluminous support that Darwin provided.

Darwin's Education and His Creative Achievement

Based on the ordinary-thinking view, one would expect Darwin's knowledge to have played an important role in his formulation of the theory of evolution through natural selection. However, if one examines Darwin's

educational career, one might conclude that he did what he did without expertise. Perhaps, as the extraordinary-thinking view would propose, since Darwin's radical advance required that he break away from established ideas, a lack of education might have even been useful to him. In support of the idea that Darwin broke away from established knowledge we have his own assertion that he did not enjoy college and found very little of value in his courses. His education ended with a Bachelor of Arts degree, which some have taken to mean that he achieved what he did without having developed expertise of the sort that comes with postgraduate training (de Bono, 1968; Simonton, 1999, pp. 119–120). A gifted person can overcome the burdens imposed by the failure of the educational system, goes this view, and his lack of advanced training allowed him to go beyond accepted wisdom; he was not trapped in it. As we shall see, however, although Darwin did not *formally* advance beyond the bachelor's degree, his education did not end with his graduation. Furthermore, his education during college was much richer than his comments on his courses might lead us to believe. There is, as we shall see, no doubt that Darwin's great creative advance was solidly grounded in education that resulted in expertise.

Darwin enrolled in Edinburgh University in 1825 to study medicine, but he left after completing only two years of study. He then entered Cambridge University to study for the ministry, but he came out a scientist. At both Edinburgh and Cambridge he met many leading scientific thinkers of the day, and he became close to several of them, thereby receiving a firsthand introduction to many of the important ideas and theories of the day. Those ideas and theories would have critical effects on his own thinking. Some of the scientists whom he got to know believed in the orthodox view of the development of the earth; others, however, did not (Eiseley, 1961). For example, in Edinburgh he became close to Dr. Robert Grant, a zoologist who believed in Lamarckian evolution; at one point Grant confessed to Darwin his belief. In 1826 a journal article by Grant in support of Lamarck was published anonymously. During his close contact with Grant, Darwin must have learned of that article (it was published just a year before Darwin entered the university), and Grant's beliefs must have stimulated Darwin to think about the question of evolution. In addition, Grant's fear of others' reactions to his ideas, which caused him to submit his article anonymously, probably also impressed Darwin.

At Cambridge, Darwin had many close contacts with faculty and students in the natural sciences (Eiseley, 1961). He became part of the circle of students around John Stevens Henslow, a well-known professor of botany and geology. Henslow held a weekly open house where faculty and students met to discuss ideas of common interest. Darwin and Henslow became so close

that Darwin became known as “the man who walks with Henslow.” In the summer of 1829, after Darwin’s second year at Cambridge, he went on an entomological expedition to North Wales with Professor F. W. Hope; and in August 1831, after his graduation, he went on a geological expedition with Professor Adam Sedgwick, also to North Wales. On those expeditions he learned techniques of observation and data collection. Thus, Darwin seems to have pursued an active undergraduate career and to have had a rich education, far beyond that obtained by most undergraduates. It is not unreasonable to say that he left Cambridge as a scientist sophisticated in methods of data collection and modern theory, and part of that theory was evolutionary theory. Soon after he left Cambridge, as we shall see shortly, he got the opportunity to obtain an extensive postgraduate education by serving as naturalist on the voyage of the HMS *Beagle*.

Darwin’s “Education” after Cambridge

As is the case with many people, including those who take up careers in research, Darwin’s education did not end when he left Cambridge (Eiseley, 1961). A most important educational influence after Cambridge was his reading of Charles Lyell’s (1797–1875) *Principles of Geology*, published in 1830–1833. Darwin read this three-volume work during the voyage of the *Beagle*, and he became an admirer of Lyell. When Darwin returned to England after the voyage, they became friends. Lyell wrote that science should not be based on literal interpretation of Bible, and his book discussed scientific theories of the origins of the earth and its inhabitants. Lyell therefore expressed ideas that became important in Darwin’s theorizing.

Concerning geological processes and the development of the earth, Lyell opposed catastrophism, the notion that the earth was subject to large-scale upheavals such as Noah’s flood. In its place he advocated *uniformitarianism*, a view advocated by James Hutton (1726–1797), who proposed that there had been a *uniformity* of natural processes throughout history. Lyell pointed out that there were no catastrophes evident at the present or in recent times, and therefore such events should not be postulated as explanations for natural phenomena. Explanations for natural phenomena, he felt, should be limited to those causes that are seen working at present, such as erosion and volcanic action. At the front of his book Lyell had included a picture of the ruins of the temple at Serapis in Italy. Near the tops of the temple’s columns was damage caused by mollusks, which meant that those columns must have been under water in the not-so-distant past. There had been no catastrophic events, such as a flood comparable to Noah’s, during the time that the temple was standing. This showed that noncatastrophic, “normal” conditions could produce relatively wide-ranging changes in the earth.

Although Lyell was a geologist, his book also discussed biological issues. He presented a full discussion of Lamarck's views, but because he did not believe in evolution he attempted to refute them. One difficulty that Lyell had with Lamarck's views was that if evolution was true then religion was not, and human beings' place as the moral focus of society would be wiped out (Eiseley, 1961). Lamarck's writings were not at that time available in English, so Lyell's discussion also had the effect of introducing Lamarck's ideas to many who would not have been familiar with them. Lyell also used the phrase "struggle for existence" in discussing competition brought about by large numbers of organisms and limited food supply. He also considered natural selection, but only as a negative process: He proposed that unhealthy organisms are displaced by the healthy in the struggle. That idea, which did not originate with Lyell, was sometimes called "nature's broom" (that is, nature sweeps aside the unhealthy). Lyell did not, however, realize that natural selection could have a positive role in evolution; that remained for Darwin to do.

The fact that Lyell discussed nature's broom raises the question of why he failed to see that natural selection could work in a positive manner. In addition to objecting to a theory of evolution on moral grounds, Lyell may have been lacking a critical piece of information: an awareness of the tremendous variation that could occur within a species. (This parallels the discussion of Watson and Crick versus Franklin in Chapter 1.) Darwin became aware of the tremendous potential for variation within species during the *Beagle* voyage, so he was in a position to expand on Lyell's views. During the voyage, which will be discussed in the next section, Darwin gathered data on phenomena discussed by Lyell. Eiseley (1961, p. 103) has concluded that Lyell composed and presented the problem that Darwin and Wallace solved.

The Voyage of the Beagle

A critical point in Darwin's development and in his postgraduate "education" was his service as a naturalist on HMS *Beagle* during its 5-year journey around the world, from December 27, 1831, to October 2, 1836. The *Beagle*'s mission was to gather information on animal and plant life, paying particular attention to South America. It was on that voyage that Darwin acquired information that convinced him that evolution was a fact (Eiseley, 1961, Chap. 6). That set the stage for his attempt to solve the problem of how evolution occurred, which is different from coming to the belief that evolution occurred. As we have already seen, a number of individuals who believed that evolution occurred—including Lamarck and Erasmus Darwin—developed explanations of how evolution came about that were very different from

the theory developed by Darwin. This is further evidence that Darwin did more than “selectively combine” facts, as Davidson and Sternberg (1986) propose—although, as we shall see shortly, by the time he returned to England at the end of the *Beagle* voyage he probably had in his possession more facts relevant to the question of evolution than anyone else in the world. That is, his expertise was probably greater than that of anyone else.

During the voyage, there were two critical influences on Darwin. The first, as already noted, was his reading of Lyell’s *Principles of Geology*. The second was the observations that he made on the voyage, especially, as is well known, his observations of animals on the Galápagos Islands. According to Darwin’s diary and notebooks, he was leaning toward accepting the existence of evolution when he began the voyage (Eiseley, 1961, Chap. 6). His belief in that idea was strengthened by the observations he made while on the voyage. As one example, as the ship moved south along the coast of South America, he observed a series of similar animal groups. The close physical proximity of physically similar groups suggested that a single species at some earlier time had differentiated into series of highly similar forms. Also, while exploring the Argentine Pampas, Darwin discovered fossils of huge animals that were anatomically very similar to extant armadillos in the same region. Again, those similarities suggested that the modern species might have evolved out of the ancient one.

Those two sets of observations, one of similarities over space (similar organisms in closely related physical spaces) and the other of similarities over time (similar organisms existing in the same place at different periods of time), were surprising if one believed the literal view that all species had been created at once. Why had the Creator put similar-appearing species together? If, on the other hand, one believed in an underlying relation among the species, then those similarities became comprehensible.

The most important observations that Darwin made were those in the Galápagos Islands, a group of approximately 20 volcanic islands in the Pacific Ocean off Ecuador. Here Darwin found even more remarkable similarities and differences among species, especially the species of finches inhabiting the various islands. The human inhabitants of the islands could tell from the birds’ appearance which island Darwin’s various specimens came from. That meant that the species were not stable; that is, the species had become separate. Darwin was especially impressed with the variability in beaks of the finches, which ranged in size and shape from small and pointed to large and thick. Those observations pointed to great variability within groups of animals, even when the physical environment and climate were essentially identical. Here was a mystery: What was the mechanism whereby all this variation came about?

Darwin's "education" on the *Beagle* voyage had several important influences on his later activities. First, it convinced him that evolution occurred and that it was therefore a phenomenon demanding explanation. Second, it provided him with detailed information about the structures of plants and animals that would serve as data to support his theoretical work. When Darwin returned from the *Beagle* voyage, there is no doubt that he was an expert concerning matters of evolution, due to his knowledge of the previously proposed theories and his discovery of the data, many of which he had recently collected, that were potentially relevant to them.

Darwin's First Theory of Evolution: The Monad Theory

On his return to England in October 1836, Darwin began to organize the material he had collected on the voyage, with help from colleagues who were interested in the new information that he had gathered. In addition, he began to think in a systematic way about evolutionary theory (Gruber, 1981). We have seen that Darwin's task was more than simply collecting and combining facts: He had to produce an explanation for how species developed—that is, for how organisms evolved. In July 1837, almost a year after he returned, he began keeping the first of four notebooks on *transmutation of species*, that is, on evolution. As we have seen with several other creative advances, Darwin first produced an inadequate theory, which then was rejected as the correct one was constructed. That rejection/construction process took more than a year to accomplish.

Darwin's first theory was based on the idea of the "monad," which had been brought forth earlier by Gottfried von Leibniz (1646–1716) in a different context. Monads are simple living particles that spring to life from inanimate matter. That meant that there was no need to assume that there is separate supernatural creation for each. Each monad has a fixed life span, during which it differentiates (i.e., becomes more than the simple particle from which it began), matures, and reproduces. During this life span, each monad becomes a whole group of related species. Those organisms respond to environmental changes with adaptive changes in their structures, a process that results in evolution of the species. When a monad dies, all species it has become, at all levels of complexity, die at that moment; new species then develop from other monads to replace the extinct species. In his monad theory, Darwin assumed that the total number of species was constant, which was a vestige of orthodoxy in his thinking, since one of the assumptions of orthodoxy was that God had created a constant number of species and that there could be no more or less than that number in existence at any time.

If we look at the components of monad theory, we can see that little of it was original to Darwin (Gruber, 1981). First, the idea of the spontaneous generation of life was seen in Leibniz's original discussion of monads 150 years earlier; in addition, Lamarck had also argued that spontaneous generation occurred continuously. The idea of spontaneous generation of life was disproved by Pasteur in 1861, at just about the time that Darwin published *The Origin of Species*. The idea of the fixed life span of the monad, again seen in Leibniz, could also be found in Lyell's *Principles of Geology*, in which he claimed that species were created in succession and endured for a fixed period. The notion of the simultaneous deaths of all descendants of a single monad was again another idea taken from Leibniz's original discussion. Also, fossil evidence seemed to indicate that whole groups of species disappeared suddenly. However, that conclusion was mistaken, because it was based on fossil evidence that was much more fragmented than investigators realized. The more detailed record indicated a more gradual disappearance of groups of species.

One reason supporting Darwin's belief in the sudden deaths of monads and their related species was that it provided a simple mechanism whereby extinction of species could be brought about. The alternative was that extinction came about through environmental change. However, in order for extinction to come about through environmental change, relatively large-scale environmental change was required. Postulating large-scale environmental change would have represented acceptance of a version of catastrophism, which Darwin had already rejected, under the influence of Lyell. Also, if environmental change produced extinction, it followed that any change in species could be erased through environmental change. This would mean that there would be no overall evolution. Darwin therefore looked for a nonenvironmental cause for extinction, which was provided by the monad. So we see that there was very little of Darwin's original thinking in monad theory, which was his first attempt to explain the phenomena he was facing.

Monads to Natural Selection

In developing the theory of natural selection, Darwin also had to reject the monad theory. Several factors played roles here (Gruber, 1981, Chap. 8). One critical change involved Darwin's orientation to the question of the origins of life. As we have seen, the monad theory attempted to account for origins of life; the monads possessed the capacity for spontaneous generation. In the theory of natural selection, Darwin shifted his perspective to the consideration of life as an ongoing system, rather than one involving

the constant creation of new forms. A factor in bringing about this change was the discovery of fossils of unicellular forms. That meant that some organisms had remained simple throughout their life spans. Therefore, the development from simple to complex within a species did not always occur. One did not have to assume that simple organisms now alive were newly created; rather, one could assume that life was an ongoing system and those organisms had been in existence for a long while. Another important change in Darwin's thinking involved his attitude toward variation in members of a species. In his early thinking, variation was a result of or a *conclusion* drawn from his assumptions: He assumed that changes in the environment produced changes in organisms, which resulted in monads developing into complex organisms. In this view, accidental encounters with the environment result in new evolutionary lines. Darwin's final theory incorporated variation as a premise (recall Darwin's note presented earlier, concerning the "tendency to small change").

That shift in orientation toward variation was a critical change in Darwin's viewpoint, because any proposed theory of evolution that assumes an inherent tendency of organisms to become more complex and adapt to changes in the environment (as monad theory did) seems to beg the critical question. That is, the monad theory can be restated as saying that evolution occurs because monads evolve, which assumes the very phenomenon that it has been designed to explain, thereby explaining nothing. One reason for Darwin's change in attitude toward variation is that, as noted earlier, through his developing expertise he had become impressed with the amount of variation in nature, and also with the fact that that variation was not necessarily in response to environmental change. We saw examples of that in the species in the Galápagos, where there was tremendous variation in species from island to island, with little change in climate or other environmental factors. Thus, variation in species in nature became a given in Darwin's thinking.

Another factor of increasing importance in Darwin's thinking was the idea of *fecundity*, or the reproductive capacity of species in nature. As we saw earlier, what one could call *superfecundity*—the tendency for organisms to produce more offspring than the environment could support—had been emphasized by Malthus, as well as by E. Darwin and Lyell, and so it was familiar to Darwin from several sources. C. G. Ehrenberg (1795–1876), a biologist, had published findings indicating that microorganisms reproduced at great rates, and Darwin had been impressed with these findings (Gruber, 1981, pp. 161–162).

It should also be remembered that natural selection was already known

before Darwin's theory; we are already familiar with the concept of nature's broom, which is the negative slant on natural selection. Darwin's contribution was the critical realization that natural selection could work in a positive direction. Also, we have seen that artificial selection was well known at the time. One can see an analogy between the human use of artificial selection in breeding and the struggle for survival in natural selection. That analogy was not clear to Darwin when he started theorizing, but it became so later, after he developed his theory of natural selection. Those influenced by orthodoxy believed that there might be a limit in artificial selection set by God's creation. This was parallel to the orthodox idea that there was a limit to the natural variability in species.

Thus, when we turn again to Darwin's rereading of Malthus, we see that it was the last step in a long process (Gruber, 1981). Before Darwin turned to Malthus, he had undergone several critical modifications in his thinking, based on new data as well as logical problems with the monad theory. Darwin's views had to change before Malthus could have the right effect on him. Those changes in Darwin's views did not come about in a sudden and complete restructuring of the way in which he thought about evolution. Rather, we see a slow and incremental change in his ideas, as we would expect according to the ordinary-thinking view of creativity. It is also interesting to note the effect that Darwin's Malthusian insight had on him. We saw that in his autobiography Darwin said that, on reading Malthus, he had at last gotten a theory by which to work. However, his notebooks tell a story that is a bit different. Furthermore, more than a month elapsed between his reading Malthus and his writing the three principles that "accounted for all." Therefore, Darwin seems to have thought that there was some further work or thinking to be done after he read Malthus. Once again we see something like gradual change in Darwin's thinking.

Darwin's Creativity: Conclusions

Having examined the evidence, we can turn again to the question of whether Darwin was a combiner of facts. Development of monad theory and then the theory of natural selection indicates that the issue was more than one of facts: The critical issue was one of interpretation or understanding or explanation of facts. The monad theory had to be rejected before the correct theory could be developed. Also, some of the changes that occurred in Darwin's thought were changes in emphasis and orientation, which is something more than combining facts. In addition, as we have seen, many facts were available to others, but Darwin also had different facts, due mainly to the *Beagle* voyage. In explaining Darwin's accomplishment, then,

one must also take into account his individual expertise, which made him unique. However, the issue was more than facts: Darwin's *interpretation* of the facts was also different from anyone else's.

Scientific Creativity: Scientific Discovery as Problem Solving

We have now considered two examples of scientific creativity, Watson and Crick's discovery of the double helix and Darwin's discovery of the theory of evolution through natural selection. In both cases, we have concluded that it is not necessary to assume that extraordinary thought processes were involved. Klahr and his colleagues (e.g., Klahr & Dunber, 1988; Klahr & Simon, 1999) have proposed that scientific thinking is one example of problem solving, as was discussed in Chapter 3. The scientist uses weak and strong methods of various sorts, ranging from hill climbing and means-ends analysis on the weak end, through analogical thinking, to domain-specific expertise. Scientific thinking is more complex than the problem solving discussed in Chapter 3, in which the individual searched through a problem space of varying degrees of complexity, using weak-to-strong methods. In analyzing scientific thinking as problem solving, it is necessary to consider several spaces that must be searched by the scientist. For example, when a scientist has a hypothesis that he or she wishes to test, the next step is to design an experiment that will produce relevant data. Designing such an experiment is one sort of problem solving; it requires a search through the scientist's "experiment space," which represents the scientist's knowledge of the structure and design of different experiments and the functions of each type. That knowledge must be used to construct an experiment as the solution to the problem of producing data relevant to the hypothesis being considered.

A different situation occurs when the scientist has a set of data available, perhaps the outcome from a just-conducted experiment, and is not able to understand them. Sometimes, for example, collected data may contradict the hypothesis that stimulated the scientist to conduct the experiment in the first place. In such a case, the scientist has to generate a new hypothesis that can deal with those data. Again problem solving must occur, but in this case the scientist must search his or her "hypothesis space," as a new hypothesis is being constructed. Again, weak and strong methods come into play, depending on how much knowledge the person has about the domain in question. Klahr and Simon (1999) propose that when scientists are working at the limits of current knowledge, their work will be more "data-driven" than "hypothesis-driven," and therefore they will have to rely on weak methods (methods that we have called "bottom-up" methods

in several earlier chapters). The analysis of Klahr, Simon, and colleagues has examined scientific thinking as problem solving from several perspectives, in support of the hypothesis that scientific thinking is simply ordinary thinking applied to specialized subject matter.

We have now seen that it was not necessary to postulate anything beyond ordinary thinking in order to understand several radical creative advances in the arts and in science. We now turn to invention. We will consider the invention of the airplane by the Wright brothers and several of Edison's groundbreaking inventions, among other examples. All of them will provide further evidence for the critical role of ordinary thinking in creativity.

The Wright Brothers' Invention of the Airplane

The Wright brothers' first successful flights, on December 17, 1903, at Kitty Hawk, North Carolina, came after several years of intense work. Wilbur and Orville Wright's interest in flying was kindled (or rekindled, since they had had some interest in flying machines earlier in their lives) by news accounts of the death of Otto Lilienthal in August 1896 in a gliding accident (Heppenheimer, 2003). Lilienthal, a German engineer, had for several years been experimenting with gliders of his own design, as part of a long-range project that had as its ultimate goal the production of a powered flying machine. Lilienthal's gliders had wings shaped like those of bats, and he flew by hanging suspended from the wing. Lilienthal controlled the gliders by moving his body, thereby shifting the center of gravity of the apparatus, to counteract the lifting force of the wing. During one flight, a gust of wind brought up the front of the wing of the glider, and the craft went into a stall (it stopped moving, thereby losing *lift*, the capacity to stay aloft). Lilienthal was unable to bring the glider under control by shifting his weight, and it crashed, breaking his back. He died the next day. Lilienthal's death was reported in newspapers and magazines, and the Wrights read about it.

The Question of Control

Although their interest in flight was rekindled by Lilienthal's death, it was not until 3 years later, in 1899, that Wilbur Wright wrote to the Smithsonian Institution to inquire about the availability of information on research on flight. He received a list of the then-available materials, including several books, and he also received several pamphlets published by the Smithsonian. The Wrights read this material, and they had also read several books in their local library that dealt with issues related to flight. At that time several research projects on flight aside from that of Lilienthal had been carried out or were ongoing. Octave Chanute, a retired engineer, was head-

ing a team carrying out research using gliders in the United States, and several investigators had worked on powered flying machines, including Samuel P. Langley, the secretary of the Smithsonian.

On reading the accounts of those research projects, including Lilienthal's research and death, the Wrights were most struck by something lacking in all of them: control of the machine in the air (Heppenheimer, 2003). No one had attempted to develop a system that would enable the pilot to control a successful glider or airplane once it was airborne. The obviously ineffective attempts by Lilienthal to control his glider by shifting his weight, and similar attempts by Chanute's team, were as far as anyone had gone. As an example of the lack of focus on a control system, the steam-powered airplanes—called *aerodromes*—that Langley had under development had wings and a tail designed to automatically keep them stable in response to changes in wind velocity and direction. There were no controls to enable the pilot to actively control the craft. Chanute's gliders were constructed so that their wings would move automatically in response to gusts of wind, which he believed would allow the craft to adjust without the pilot's intervention to changes in wind velocity and direction. From the perspective of the Wrights, anyone who attempted to take to the air without knowledge of how to control their machine was being totally reckless, as evidenced by the death of Lilienthal (and he was not the first to die gliding). Thus, on reading the available material, the Wrights acquired little beyond information about the unsuccessful projects being carried out by others.

The Wright Brothers' Expertise: Wheeling and Flying

On analyzing the Wright brothers' invention of the airplane, the first question that arises is why they were so concerned about a control system for their aircraft when other researchers were not. First, the Wrights had recent history as concrete evidence of the dangers involved in flight; also, unlike the workers already engaged in research on flight, they had invested no time and effort in the design of flying machines without active control systems. The veteran researchers might have become inured to the dangers, whereas the Wrights, as newcomers to the area, might have been more sensitive to them. The already-active researchers might also have believed that the automatic components built into their craft would be effective, even though Lilienthal's specific design might not have been. The incorporation of components designed to allow the craft to automatically remain stable was based on a further critical assumption: Earlier researchers were concerned that a pilot in the air would not be able to respond quickly enough to changes in wind direction and speed, and so would be useless in an emergency. The Wrights, in contrast, felt that the issue of control was

so important that a method had to be devised to permit a human to pilot the craft (Heppenheimer, 2003). Otherwise, any attempt to fly would be doomed to failure.

The Wrights' belief in the necessity for control, and in the ability of a human to ultimately carry out that task, probably arose from their expertise with the bicycle, another vehicle that required active control by a person in order to maneuver safely (Heppenheimer, 2003). As is well known, the Wrights were experienced bicycle mechanics, although the term *mechanic* is too limiting in that it may be taken to mean that they merely fixed flat tires and oiled rusty chains. The Wrights had actually built and sold bicycles of their own design, so they were well versed in the specifics of bicycling, which had begun as a craze in the 1890s. It is critical in this context that bicycles as vehicles are analogous to airplanes in important ways, because a bicycle requires relatively complex control on the part of the rider. A person riding a bicycle makes constant adjustments to speed, body position, and orientation of the front wheel (through the handlebars) in order to maintain equilibrium and to proceed in the chosen direction.

However, and this is most important, the rider also at times deliberately upsets equilibrium—most specifically, in order to turn. When one turns on a bicycle, one steers the front wheel in the direction one wishes to go by moving the handlebars, but one also leans to the side that one is turning to, so that the bicycle tilts to the inside of the turn. That is, one upsets the equilibrium of the bicycle—one begins to *fall*—when one is making a turn. The experienced rider keeps the bicycle's speed high enough that it leans into the turn but does not fall; a novice rider when making a turn is likely to go too slowly and will have to put his or her inside foot on the ground to prevent a fall. When the turn is completed, the rider reestablishes equilibrium, by straightening the front wheel and sitting straight on the bicycle.

Most people when riding a bicycle are not aware of the subtle control they maintain as they maneuver through a turn, but the Wrights were. They surmised that control of a plane in flight might be like control of a moving bicycle, and they also believed that they had to develop a system that would afford a pilot active control of the machine in flight. One might say that, in another example of analogical transfer based on expertise, the Wrights thought of the airplane as a bicycle with wings (Heppenheimer, 2003, p. 89). This was an example of transfer based on a regional analogy, from a land-based vehicle to one meant for the air. Other researchers conceived of an airplane as a boat in the air (another regional analogy), which, however, is controlled very differently. Langley, for example, designed his aerodromes with a rudder at the rear, like that of a boat, to control turns. When one thinks of turning in a rowboat, say, there are few control problems, since a

rowboat presents little in the way of instability and potential danger when it turns. Thinking of an airplane as a bicycle, in contrast, makes one very sensitive to potential dangers in control in general and in turning in particular, which makes one concerned about control.

Thus, Langley also used analogical thinking in his creative process, but, because his background was different from that of the Wrights, his base information was different, and it turned out not to be as useful as that of the Wrights. This example is relevant to the discussion in Chapter 2 of the question of value in the definition of *creative*. It was surmised in Chapter 2 that there might not be any critical differences between intentional novel products of value and those that turn out not to have value (Watson and Crick's double and triple helices were discussed there). Comparing the Wrights' thought process with that of Langley, one sees no obvious difference between them, which supports the conclusion that value is unnecessary in the definition of creativity.

It is interesting to note that some who preceded the Wrights in speculating about the possibility of human-powered flight had also considered bicycles as a possible source of important information. Several years earlier, James Means, a commentator on the flight scene, predicted—in a book that was on the Smithsonian list sent to Wilbur Wright and probably read by the Wright brothers—that the airplane would be perfected by “bicycle men,” because flying is like “wheeling” (Heppenheimer, 2003). Lilienthal had written to Means in praise of his analysis of the relationship between riding a bicycle and flying.

Wing Warping

The Wrights relatively quickly developed an idea for a control system, based on observations they had made of birds in flight. This was an example of analogical transfer based on a regional analogy—from a natural “flight system” to an artificial one. One sees no extraordinary remote-associative “leap” here. The Wrights had read about bird flight, and they reported that they had observed birds gliding on wind currents, with their wings essentially motionless, in a dihedral or V shape (Heppenheimer, 2003). They sometimes saw the birds being tilted to one side or the other by changing winds and air currents (at which point the V would no longer be vertical) and somehow making adjustments that allowed them to return to level flight. Close observation indicated to the Wrights that the birds responded to changes from level flight by altering the orientations of their wing tips. By moving the tips of their wings in opposite directions, one up and one down, they were able to return to level flight as wind currents shifted direction. The

birds essentially turned themselves into windmills, and were turned by the wind back toward level flight.

Here too there were precedents for this observation in the community of researchers. J.-P. Mouillard had written a book in which he discussed bird flight and urged others to observe birds gliding effortlessly on air currents (Heppenheimer, 2003), and Lilienthal had been fascinated by bird flight as a teenager and had continued his observations of birds as an adult. In the article on Lilienthal that had first appeared in the United States, the author noted that Lilienthal's observations of birds in flight had led him to conclusions about the optimal shape of the wings for his gliders. Those precedents are further evidence for the ordinary or common nature of the thought processes involved, since they occurred in multiple people at about the same time.

The discovery of the birds' use of their wing tips to control their orientation led the Wrights to develop a mechanical system whereby the pilot could control movable surfaces, corresponding to the birds' wing tips, through metal rods and gears (Heppenheimer, 2003). This system allowed the pilot to move the trailing edges of the wing tips up and down in opposite directions and thereby cause the machine to tilt when necessary, either to maintain equilibrium in the face of wind gusts or to disturb equilibrium intentionally in order to bank into a turn. This was an example of mapping, in which the solution from the base is applied to the target (see Chapter 4). Since the Wright brothers' glider was a mechanical device, the birds' "solution" had to be modified to fit it. The rod-and-gear system turned out to be too heavy to be useful, however. They then developed a system wherein the pilot, lying prone on the lower wing of a two-winged glider (a biplane), controlled the orientation of the wing tips through wires that he could pull in one direction or another by swinging his hips in a cradle to which the wires were attached. The pilot's movement caused the wires to pull one set of wing tips up and the other down, which was called *wing warping*. The wing-warping system, as we see, developed in response to a problem with the rod-and-gear system.

Using an empty cardboard box from an inner tube that he had sold in the bicycle shop, Wilbur Wright demonstrated to his brother that one could achieve the desired orientations of the wing tips in opposition to each other (Heppenheimer, 2003). The elongated oblong shape of the box was analogous to the shape of the biplane glider's wings. If one squeezed the ends of the box gently in opposite directions, the "wing tips" at each end twisted in opposite ways. This resulted in the "wings" being "warped," in the way that they believed was needed for control in flight. Discussing this

incident almost 30 years later, Orville Wright reported that the twisted-box example simply provided a better implementation of the principle that they had already decided on—that is, that the wings had to be controlled so that the tips on either end worked in opposite directions.

An early version of a wing-warping system was developed by the Wrights at their home in Dayton, Ohio, during the summer of 1899, the very first year they contemplated trying to invent a flying machine, and months before they even thought of going to Kitty Hawk. They tested it on a 5-foot-wingspan biplane kite model that they built. The person flying the kite was able to warp the wings by pulling on two sets of strings, one of which controlled each set of wing tips. They found that the system worked as they hoped. When the pilot's hip cradle was incorporated in their first glider in 1900, it added little or no weight to the machine, and it worked well enough that it was used to control all their gliders (1900–1902) and the first powered flying machine (1903).

We can discern three stages in the Wrights' development of a control system for their aircraft: (1) deciding that there was a need for a control system, (2) using birds' control of their wing tips as an example of a control system, (3) implementing a wing-tip control system for their glider. These stages were outgrowths of different aspects of ordinary thinking. The first two stages, which were dependent on the bicycle and on bird flight, respectively, as antecedents, were the results of domain-specific expertise. The final stage, implementation of a method for controlling the wing tips of their aircraft, was independent of domain-specific expertise, since they did not have any experience constructing a flight-control system analogous to that of birds. That is, the final wing-warping system was based on the Wrights' general expertise as mechanics and carpenters, arising out of years of construction projects as well as their experiences as manufacturers of bicycles. In addition, general reasoning and planning abilities probably also played roles.

It is interesting to note that, although the wing-warping system was in place on the Wrights' earliest glider, the one they flew on their first trip to Kitty Hawk in 1901, it was not until December 1903, more than 2 years later, that the first successful powered flight took place. One of the reasons for this gap was that the Wrights had to learn to fly; that is, they had to learn to use their system to control their aircraft. This can be looked upon as a classic example of the development of expertise, although of a different sort from that involved in the use of the bicycle as the basis for their understanding of the control problems concerning the airplane. In the case of the skill of flying, the Wrights were acquiring a behavioral system capable of adjustments, and it took them years to do so. The acquisition of that system was comparable to learning to ride a bicycle well enough to perform stunts on

it. Further development of expertise is seen once they began to fly their powered craft. The first powered flights of December 17, 1903, were just barely under control, since that day was their first experience flying a powered machine, and it turned out to be much more difficult to control than they had expected. It was not until the latter half of 1905 that they were able to fly a significant number of times without accidents. So one reason it took the Wrights so long to invent the airplane is not because it was particularly difficult for them to conceive of the design for their aircraft. Rather, one could say that the main problems were of a psychological nature: learning to use the system that they had invented.

The accomplishments of the Wright brothers provide further evidence that ordinary thinking plays a role in major creative advances. In this case study, we saw the use of domain-specific expertise (i.e., the bicycle as the basis for the need for a control system in the airplane, a regional analogy, and the bird as an example of a control system to be modeled, also a regional analogy) as well as more general expertise (in the Wrights' use of their skill as mechanics and machinists to design the wing-warping system). We also saw evidence of development of expertise in their learning to pilot their aircraft. We will see further evidence of creative advances based on ordinary thinking in the next group of case studies, which examine several inventions produced by Thomas Edison, one of the most prolific inventors who ever lived.

Thomas Edison as a Creative Thinker: Themes and Variations Based on Analogy

Thomas Edison (1847–1931) held more than 1,000 patents, among which were truly revolutionary devices: the phonograph, the kinetoscope (a device for presentation of motion pictures), the electric light bulb, and the system for distributing electricity to power those bulbs once installed in people's houses (Israel, 1998). Edison was homeschooled, mainly by his mother, and she introduced him to science and experimentation through books that described experiments that could be carried out at home, which Edison did. At age 12, he started selling newspapers and snacks on the railroad, making the daily round-trip run from his home in Port Huron, Michigan, to Detroit. He used the 5-hour layover in Detroit to continue his scientific experimenting, moving his laboratory from his home to the train's baggage car.

Before going to work on the railroad, he had begun to learn telegraphy, practicing on a telegraph line that he and a friend had strung between their houses. He practiced his skill in the offices of telegraph operators along the rail line. He was given lessons in telegraphy as a reward when he rescued an

operator's child from the path of an oncoming railway car. He soon got his first job as a telegraph operator, and his experience with the telegraph played a critical role in many of his inventions. Edison soon became one of a loose community of young itinerant telegraph operators who moved from job to job, always in demand because of their highly valued skill. Many of those operators were interested in bettering their positions with the telegraph companies by suggesting improvements in the technology of telegraphy, which was encouraged by the companies. This route, which came to him relatively naturally given his early experiences with scientific experimentation and general tinkering, was the one that Edison chose (Israel, 1998, p. 24).

One of Edison's first inventions was a device that would slow down a telegraph message that came through at too fast a speed for him to decode it. This training device allowed Edison to practice decoding messages that he would otherwise have been unable to deal with. The decoding device was made up of two "Morse registers," which indented the dots and dashes of the Morse code into paper tape. The paper tape could then be fed through another register, which would send electrical pulses in response to the indentations on the tape. This device had been used earlier to record and preserve messages, which then had to be decoded into ordinary language before the customer could understand them. At that time, the Morse decoders were no longer widely used; the practice was for the operator to directly translate Morse code's electromechanical clicks into language, thereby bypassing the need for the register. Edison used the tape from one register to feed a second one, which was set to respond at about half speed. That allowed Edison to process the message. As we shall see, this double Morse register played a critical role in several other Edison inventions, including those that made him world-famous, to which we now turn.

Edison's Phonograph

Of all of Edison's inventions, perhaps the one that had the strongest effect on the public was the phonograph (Israel, 1998). When Edison demonstrated in 1877 that he could record and reproduce sounds, including, most impressively, the human voice, people were astounded. Even though Edison said that the principles involved were very simple and could be understood by anyone, the nickname "the wizard of Menlo Park" was bestowed upon him in response to his invention of the phonograph. The development of that invention followed a path that will not be surprising, based on our experiences with other creative advances: It was solidly based on Edison's expertise, and in a case of transfer based on a regional analogy it was developed almost directly out of another Edison device.

A sketch of the phonograph is shown in Figure 5.13A. A cylinder wrapped

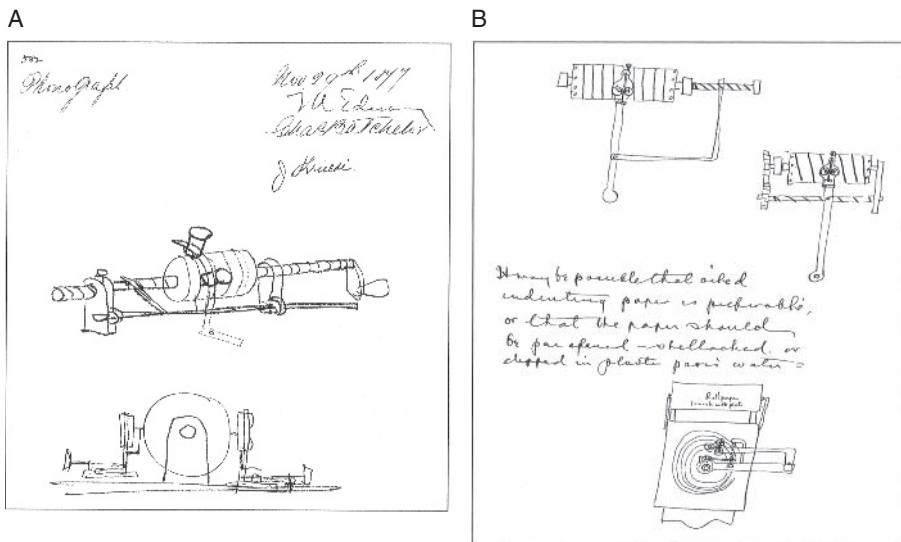


Figure 5.13 Edison's inventions: A, Phonograph; B, Telegraph repeater-recorder

in foil spins on its axis as a result of the crank's being turned, while a person talks into the cone-shaped receiver. At the bottom of the receiver, near the foil, is a diaphragm, which is set into vibration by the sound waves produced by the person speaking into the cone. Attached to the bottom of the diaphragm is a stylus, which is pressed into the foil by the vibrating diaphragm, thereby leaving a track of indentations or embossing around the cylinder rotating under it. This embossed track is a record of the speaker's voice. Once that track is laid down, one has a record of a message that can be used to transmit a new message, simply by running the process in reverse. One can set the embossed cylinder into rotation using the crank, and then set a stylus into the track. The stylus is attached to a diaphragm, which in turn is stretched across the narrow end of a broadcasting cone. As the stylus tracks the embossed groove, sound is heard from the broadcasting cone.

This device, surprisingly simple when it is analyzed after the fact, served to establish Edison's reputation as a man who could work miracles. Let us now examine the nature of the thought processes through which those miracles were worked, by considering the origins of the phonograph.

The Telegraph Repeater-Recorder: The Antecedent to the Phonograph

In the summer of 1877, Edison was a telegraph engineer for Western Union. One project he was engaged in at the time centered on the telegraph repeater-recorder, a device for reproducing telegraph messages (Israel, 1998). Due to the relatively inefficient technology of the day, when the electrical

pulses of the coded message were sent over long distances, the electrical signal gradually grew weaker, so there were limitations to how far a message could travel before becoming so weak that the electrical pulses would not be strong enough to activate the receiving mechanism. A telegraph company such as Western Union needed a repeating device of some sort that would allow a message, once transmitted by an operator, to be automatically repeated over a series of stations not too far apart from each other. A message could thereby ultimately be sent over long distances without the necessity of involving multiple highly-paid operators.

Edison's repeater-recorder used a stylus or point attached to a telegraph key to produce an indentation in a heavy piece of paper under it. As the operator tapped out the dots and dashes of the Morse-coded message, a corresponding track of short and long indentations was embossed into the paper. To reproduce the original message, the embossed track was traced by a stylus attached to a spring-loaded electrical switch. When the stylus was tracking an indentation, the spring made contact and the circuit was closed, thereby sending a short or long pulse to the receiving station, exactly as if it had been done by an operator's hand on the key. This device thus allowed the preservation of a telegraphic message, which could then be transmitted down the line automatically. The similarity of this device to the double Morse register, designed by Edison to help him practice decoding messages, is noteworthy, most particularly the use of embossed paper tape to store the information.

At the same time that he was working on the repeater-recorder, Edison was also working with Western Union on a design for a telephone that would be significantly different from the one recently patented by Alexander Graham Bell (1847–1922), which would allow Western Union to market a telephone in competition with Bell's (Israel, 1998). In contemplating the broader aspects of the telephone, Edison assumed that, as with the telegraph, telephone messages would have to be preserved for further transmission. His work on the telegraph repeater-recorder, combined with that on the telephone, served to set the stage for the invention of the phonograph. Edison reasoned that if one could set the embossing process into motion using the human voice instead of the telegraph key, one would then be able to produce a record of the spoken message. A critical component of the telephone as conceived by Edison was a diaphragm set into motion by the speaker's voice. In devising the phonograph, Edison attached a stylus to that diaphragm, and the vibrations from the voice then served to produce embossed marks in a strip of paper tape, which could be used to store the message for later reproduction. The paper tape was not a very good storage mechanism, however, because its requisite stiffness made it difficult to

emboss, so Edison also experimented with different types of storage devices, including paper discs and tinfoil-wrapped cylinders.

It is interesting to note that Bell, the inventor of the first practical telephone, expressed dismay on learning of Edison's phonograph and its design that he had not invented the phonograph, because he had earlier developed a device for representing sound waves graphically (the *phonautograph*), and he had also remarked in public lectures that if one could take those written waves and reproduce them mechanically, one would be able to reproduce sound. So the question arises as to why Bell was not able to take the final steps, as Edison did. One critical piece of expertise Edison possessed that Bell did not was familiarity with telegraphy, which, as we have seen, provided Edison with a means for reproducing sound waves mechanically: the Morse register. Thus, when Edison got to the point of realizing that it would be important to translate the human voice into electromechanical pulses, he had available a device that could supply the principle for accomplishing that task. Since Bell did not possess Edison's telegraphic expertise, it is from our perspective not surprising that Bell was not able to take the steps that Edison did (Israel, 1998, p. 144).

This example is further evidence of the specific differences between those who make creative advances and those who do not. In the case of Franklin and the Watson-Crick duo, we saw differences in general attitude toward modeling; in this case, we see differences between Edison and Bell in problem-specific expertise. Once again, it seems that one can understand who makes advances, versus who gets close but does not, on the basis of what each person is able to bring to the problem at hand. One may not have to look beyond the knowledge that each person brings to the specific context in which he or she is working.

Considered as an outgrowth of Edison's earlier thinking, the phonograph can be looked upon as a repeater-recorder for the human voice (with the recording not necessary). Edison's process of invention in this case was based on a regional analogy: One mechanism for preservation of a message transmitted through an electromechanical device served as the basis for another one. We do not need to go beyond analogical thinking in understanding Edison's advance. A similar process can be seen in Edison's invention of the kinetoscope, a device for presenting moving pictures.

Edison's Motion Picture Device: The Kinetoscope

Besides establishing Edison's reputation as an out-of-this-world inventor, the phonograph also served as the basis for another Edison invention: the kinetoscope, a device that presented moving pictures (Buonanno & Weisberg, 2005; Carlson & Gorman, 1990; Israel, 1998). Figure 5.14A shows

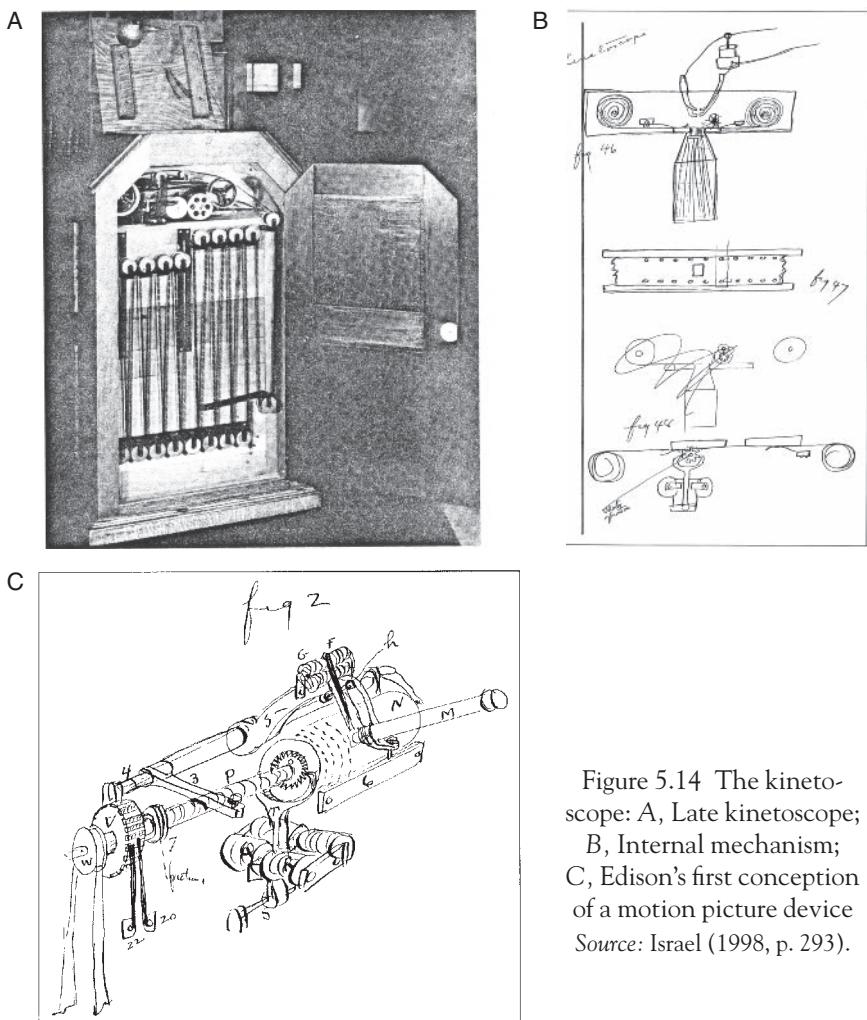


Figure 5.14 The kinetoscope: A, Late kinetoscope; B, Internal mechanism; C, Edison's first conception of a motion picture device
Source: Israel (1998, p. 293).

In Edison's first conception of a motion picture device from October 1888 the pictures were to be photographed "in a continuous spiral on a cylinder or plate in the same manner as sound is recorded on the phonograph" and viewed with a microscope.

a picture of a kinetoscope with its cabinet open, so that one can see the film on which the record of the moving object is stored. With the doors of the cabinet closed, the device works much like a modern motion-picture projector: The film is drawn under an eyepiece, and a person looking into the eyepiece sees a small moving image (see Figure 5.14B). The device in Figure 5.14A looks nothing like the device in Figure 5.13A, but the latter was derived by Edison from the former. Again we have an example of a regional analogy: A device for recording speech (information strung out

over time) is used to record motion (information strung out over time). As Edison says in the patent application for the kinetoscope, the device “does for the eye what the phonograph does for the ear” (Israel, 1998, p. 292).

If one examines an early sketch for the kinetoscope, that which accompanied that early patent application, one sees clearly the analogy between that invention and the phonograph (see Figure 5.14C). In that early kinetoscope, a cylinder rotates as the result of the user’s turning a crank. On the cylinder is a sequence of pictures representing the to-be-viewed moving object. As the cylinder turns, the sequence of pictures is drawn one by one under an eyepiece, and a person looking into the eyepiece sees a moving picture. The similarities between the phonograph and the early version of the kinetoscope are manifold: the cylinder on which is stored the information representing the message to be retrieved; the hand crank; and the input-output device (the stylus/eyepiece). Once Edison had invented the phonograph, the analogy between speech (a stimulus—a series of waves—extended over time) and a motion picture (also a stimulus—a sequence of pictures—extended over time) provided a link to another invention.

In developing the kinetoscope, Edison may also have been stimulated by his contact with Eadweard Muybridge (1830–1904), a pioneer in photography who produced stop-action photographs of people and animals (Israel, 1998; see Figure 5.15), although there is some question about Muybridge’s influence (Carlson & Gorman, 1990). In February 1888 Muybridge had lectured in East Orange, New Jersey, near Edison’s laboratory, at which time he demonstrated a device called a zoopraxiscope that could use his photos as the basis for producing moving images. The earliest version of this device was a disc on which a sequence of drawings of some object, based on his photographs, were placed around the periphery. When the disc was set in spinning motion, one would see a single picture of the object moving. In a more complex version, the one he demonstrated in his lecture, the drawings could be projected in sequence one at a time by means of a light, and one would see a moving image of the object. Edison thus saw that a string of stop-action photos contained within it the information needed to produce motion. Muybridge visited Edison’s laboratory, and the two discussed the possibility of combining a moving image with Edison’s phonograph in order to produce a talking image of a person. In addition, Muybridge sent Edison a set of photos. This set of experiences would have made more obvious to Edison the connection between visual images and speech as sets of information distributed over time.

It should also be noted that the Muybridge zoopraxiscope was not the only device then in existence that could produce moving images (Wexman, 2006). There were others, ranging from the very simple—decks of cards

CREATIVITY: UNDERSTANDING INNOVATION

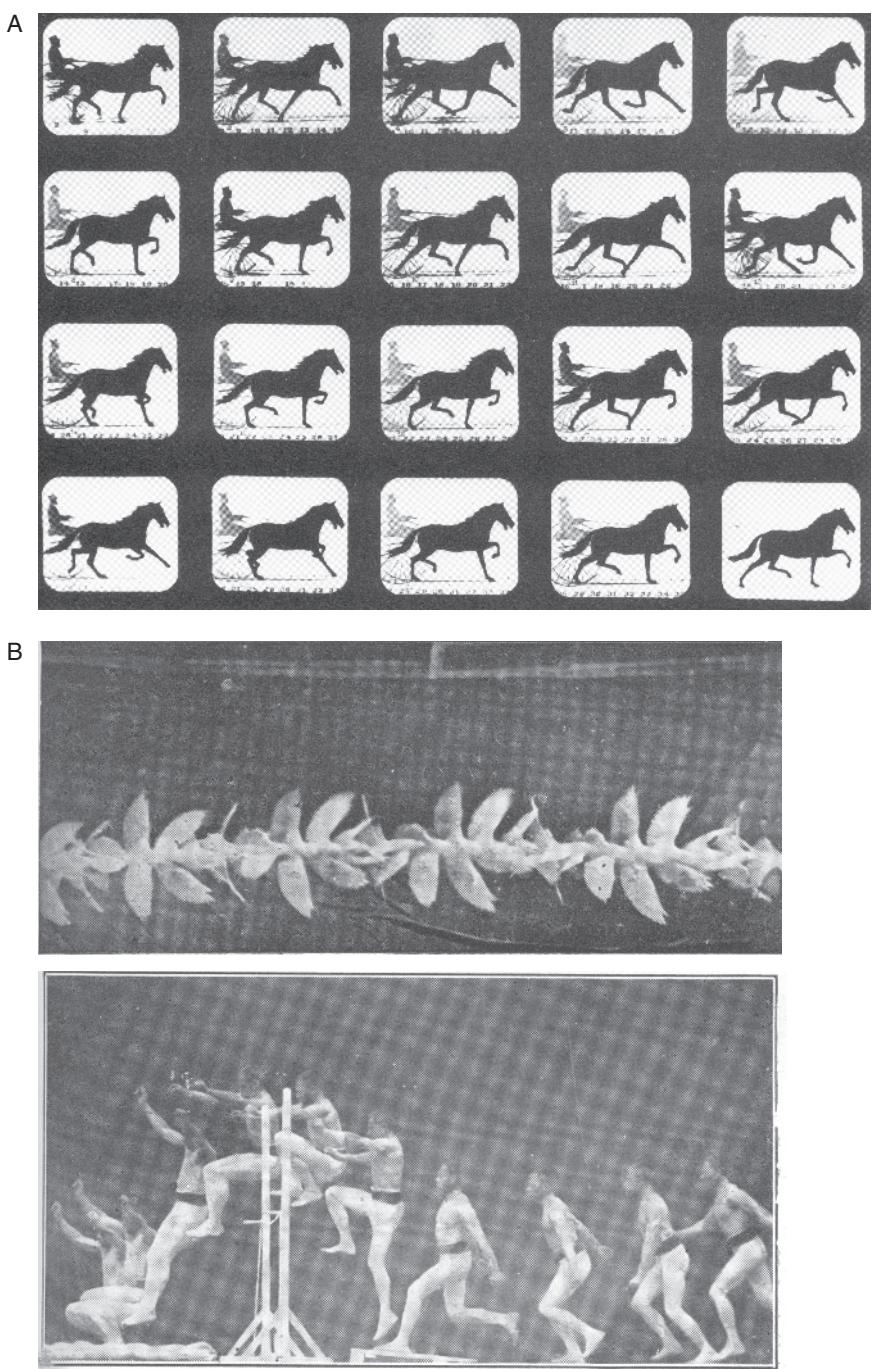


Figure 5.15 Early stop-action photos: A, Muybridge photos; B, Marey photos

that showed an object in motion when one flipped through them—to other mechanical devices that also used a sequence of closely related images to show an object in motion. So Edison was familiar with the possibility of displaying moving images. Edison's kinetoscope could be looked upon as the high point in this development, but it was not the first successful motion-picture device.

In developing his early kinetoscope, Edison focused on photographing a series of small photographs—microphotographs—on a cylinder, to create a string of images directly analogous to the embossed acoustic phonograph track that was left behind by the spoken message. This was a further direct analogy to the phonograph, in which the recording and playback of the sound were accomplished by the same device (Carlson & Gorman, 1990). Edison and his staff initially attempted to photograph objects directly on the cylinder of the kinetoscope, using a light-sensitive chemical emulsion applied to the metal; they also experimented with wrapping the cylinder with photosensitive film, analogous to the tinfoil used for the cylinder phonograph.

In 1889, Edison visited Paris to attend a universal exposition (a world's fair), and there he came into contact with Étienne-Jules Marey (1830–1904), who had extended Muybridge's work in the photographing of animals in motion (Israel, 1998). He had developed a camera that could take 60 photos per second on a roll of light-sensitive paper film (see Figure 5.15B). Marey and Edison discussed that technique, and Marey gave Edison a copy of his book, which described his work in detail. When Edison returned to his laboratory he began to work on a kinetoscope in which film was drawn under a viewer, as in the version shown in Figure 5.14A and B. Here we see another example of a creative thinker adopting an idea from an external source. This invention, then, was an amalgam: a core idea from one of Edison's earlier inventions, modified as a result of his contact with others' ideas.

Let us now examine an additional set of Edison's inventions—the light bulb and the electrical lighting system—to further demonstrate the role of ordinary thinking in Edison's creative process. There is one important difference between the latter inventions and those that we have already reviewed: For the lighting inventions, Edison did not build on his own previous work.

Edison's Invention of the Light Bulb

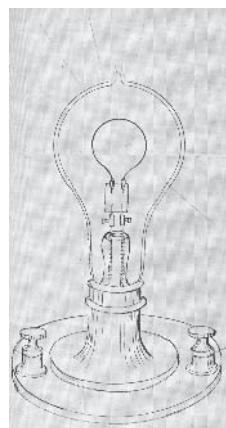
On New Year's Eve of 1879, Edison opened his Menlo Park laboratory to the public so that they could see and marvel at the electric lighting system that had been installed there, which demonstrated to all that a useful electric light had been achieved. This demonstration culminated several years'

work in Edison's laboratory. In Edison's light bulb (see Figure 5.16), electric current passed through a thin filament of carbon (the burner), which was enclosed inside a glass bulb, in a vacuum. The current flowing through the carbon caused it to heat to the point of glowing or incandescence, thereby producing light.

The invention of the light bulb is a story that many of us think we know. Edison, who is famous for saying that genius is 1 percent inspiration and 99 percent perspiration (Friedel, 1986), is legendary for working through innumerable possibilities before finding just the right material for the burner in his bulb. If all Edison did was try one material after another until he stumbled on one that worked, however, we would have little reason to look more deeply into his accomplishment. In reality, however, the story is different (Friedel & Israel, 1986; Friedel, 1986; see also Jehl, 1937; Weisberg, Buonanno, & Israel, 2006), and examination of Edison's accomplishment will enable us to consider in still another context the role of ordinary thinking in creativity.

Antecedents to Edison

Edison is usually referred to as *the* inventor of the light bulb, as if no one preceded him. However, there had been numerous attempts to produce a working incandescent electric light bulb before Edison began to work on the problem, and he was aware of what had been done (see Table 5.1; Friedel & Israel, 1986). Almost all of those earlier attempts used either carbon or platinum as the burner in the bulb. Each of those elements presented difficulties, but earlier investigators had been unable to overcome them. When carbon was heated by the flowing electric current to a temperature sufficient to produce light, it would quickly oxidize (burn up), rendering the bulb useless. In order to eliminate oxidation, it was necessary to remove the carbon burner from the presence of oxygen. Most of the earlier workers had attempted to place the carbon in a vacuum, which required a vacuum pump that could draw the air out of the bulb. The vacuum pumps available when Edison began his work could not produce anything near a complete vacuum, so the burner could not be protected and the bulbs quickly failed. Platinum burners presented a different problem: Their temperature had to be controlled very carefully, because if the burner got too hot (just a few degrees above the temperature at which it glowed and gave off light) it would melt and crack, thereby rendering the bulb useless.



5.16. Edison's light bulb

Case Studies of Creativity

Table 5.1 Who invented the incandescent lamp?
Antecedents to Edison's light bulb

Date	Inventor	Nationality	Element	Atmosphere
1838	Jobard	Belgian	Carbon	Vacuum
1840	Grove	English	Platinum	Air
1841	De Moleyns	English	Carbon	Vacuum
1845	Starr	American	Platinum	Air
			Carbon	Vacuum
1848	Staite	English	Platinum/iridium	Air
1849	Petrie	American	Carbon	Vacuum
1850	Shepard	American	Iridium	Air
1852	Roberts	English	Carbon	Vacuum
1856	de Changy	French	Platinum	Air
			Carbon	Vacuum
1858	Gardiner & Blossom	American	Platinum	Vacuum
1859	Farmer	American	Platinum	Air
1860	Swan	English	Carbon	Vacuum
1865	Adams	American	Carbon	Vacuum
1872	Lodyguine	Russian	Carbon	Vacuum
			Carbon	Nitrogen
1875	Kosloff	Russian	Carbon	Nitrogen
1876	Bouliguine	Russian	Carbon	Vacuum
1878	Fontaine	French	Carbon	Vacuum
1878	Lane-Fox	English	Platinum/iridium	Nitrogen
			Platinum/iridium	Air
			Asbestos/carbon	Nitrogen
1878	Sawyer	American	Carbon	Nitrogen
1878	Maxim	American	Carbon	Hydrocarbon
1878	Farmer	American	Carbon	Nitrogen
1879	Farmer	American	Carbon	Vacuum
1879	Swan	English	Carbon	Vacuum
1879	Edison	American	Carbon	Vacuum

Source: Adapted from Friedel and Israel (1986).

Thus, when Edison began his work, there had been earlier attempts to invent an electric light, and those attempts had shown that it was possible to produce light using electricity. The problem with the earlier attempts was that the lights functioned only very briefly before they failed. It was well known that improvements in the vacuum were crucial to the carbon-burner light bulb and that control of the temperature was crucial in utilizing platinum. Like the Wrights, Edison began his work relatively knowledgeable

about what had been done before, and most of that knowledge consisted of information about other researchers' failures (Friedel & Israel, 1986).

Edison's Early Work: Beginning with the Past

Edison started his electric-light work in 1877, with a bulb containing a carbon burner in a vacuum. This work, which built directly on the past, was not successful: Since Edison could not produce a complete vacuum with the then-available vacuum pumps, the burner oxidized. Since he knew of no way to improve the vacuum, Edison abandoned work on the carbon burner. About a year later, he carried out a second phase of work on the light bulb, in which he used platinum as the burner. Here too his work built directly on what had been done in the past. In order to prevent the platinum from melting, Edison's platinum bulbs contained "regulators," devices like thermostats in modern heating systems, which were designed to regulate the temperature of the platinum and thereby keep it from melting (Friedel & Israel, 1986). Edison had seen regulators incorporated into electric-lighting circuits designed by others. However, it proved impossible at that time to control the temperature of the platinum burner.

Edison's response to his failure with platinum burners was to attempt to determine exactly why they failed. He observed the broken burners under a microscope, and he and his staff thought they found evidence that the melting and cracking was caused by escaping hydrogen gas, which platinum under normal conditions absorbed from the atmosphere. The hydrogen escaped when the platinum was heated, causing holes to form, which facilitated melting and cracking of the burner. Edison reasoned that the platinum might be stopped from cracking if the hydrogen could be removed slowly. He reasoned further that if the platinum were heated slowly in a vacuum, that would allow the hydrogen to escape without destruction of the platinum. Based on those new conclusions, Edison's subsequent work involved a platinum burner that was heated slowly in a vacuum and then sealed in the bulb. The removal of the hydrogen from the platinum burner did indeed make it last longer and burn brighter, but the burners still overheated and melted (Friedel & Israel, 1986, pp. 56–57 and 78).

Improved Vacuum Pumps and Return to Carbon

In the summer of 1879, Edison and his staff attempted to develop more efficient vacuum pumps for the platinum-burner bulb. They eventually produced an efficient vacuum pump that was a combination of two types of advanced vacuum pumps, a Geissler pump and a Sprengel pump, products of different manufacturers. The idea of combining two vacuum pumps was first presented in an article by de la Rue and Muller (Friedel & Israel, 1986,

pp. 61–62). Using this new combined pump, Edison was able to reduce the pressure inside the bulb to one one-hundred-thousandth of normal atmospheric pressure, which was the most nearly complete vacuum then in existence (Friedel & Israel, 1986, pp. 62, 82). Further work in autumn 1879 produced pumps that were even more efficient. However, this advance did not solve the basic problems with platinum: Even after being heated in the vacuum, the filaments would last for only a few hours and would tolerate only a minimal amount of electrical current before cracking, making it very difficult to generate light of useful brightness.

In early October 1879, Edison began to experiment once again with carbon as an incandescent substance. The return to carbon follows directly from Edison's situation at that time: (1) The platinum bulb was still not successful, (2) an improved vacuum pump was available, and (3) Edison's earlier attempts with carbon had failed due to incomplete vacuums. On October 19, Edison's assistant Francis Upton experimented with raising a stick of carbon to incandescence in a vacuum, with encouraging results. On October 21, Upton recorded that he had raised a .5-inch stick of carbon that had a diameter of .020 inches to "very good light" (Friedel & Israel, 1986, p. 100). On October 22, another assistant, Charles Batchelor, conducted experiments using a carbonized piece of cotton thread placed inside an evacuated bulb. The thread had been baked in an oven until it turned into pure carbon. Batchelor continued to experiment with a variety of carbon materials throughout that day, and at 1:30 the next morning he attempted once again to raise a carbonized cotton thread to incandescence (Friedel & Israel, 1986, p. 104). This light burned for more than 14 hours, with an intensity of 30 candles, more than enough illumination to be useful. By early November 1879, Edison felt sufficiently confident in the success of the carbon lamp that he filed for an electric light patent with the U.S. patent office. The light was given its public debut on New Year's Eve.

Edison's Light Bulb: Summary

Edison's development of the light bulb is an example of a situation in which the creative thinker began by trying to build on the past but was forced to go beyond it. The methods that had been developed by earlier workers were no more successful in Edison's lab than they had been elsewhere. His analysis of the problems with the platinum burners led him to the need for a strong vacuum. This need in turn led to the development of an efficient vacuum pump, based on an idea available in the literature. When platinum was still not viable, the availability of the improved vacuum may have stimulated a return to carbon and ultimate success. The core of Edison's achievement, his triumph over the problem with carbon that had defeated earlier workers,

was the result of his analysis of the reason for the platinum burners' failure and his attempt to correct it by building a new vacuum pump.

In examining the thought processes underlying Edison's invention of the light bulb, we can see, in a parallel to the Wright brothers, that a broad range of Edison's expertise played a role. Edison began by trying to build on the past, so his initial work depended on his domain-specific expertise. His impasse with platinum, however, led him to examine carefully the failed burners. There was no direct precedent for this, but it is a response to an impasse that seems not untypical, based on people's general knowledge: If something is not working as you expect it to, examine it carefully to try to determine why. This is a weak method of problem solving that we all use. On the basis of his analysis of the problems with platinum burners and how they might be overcome, through the process of logical reasoning Edison turned to the development of an efficient vacuum pump. Edison's new pump came from an idea available in the literature, so domain-specific expertise played a role here. When platinum was still not viable, Edison returned to carbon and ultimate success; the return to carbon was related to the fact that the new, highly efficient vacuum pump provided the solution to the problem plaguing the earlier carbon-burner bulbs. In this account we see that Edison's thinking exhibited several characteristics of ordinary thinking as outlined at the beginning of the chapter.

Edison's Electrical Lighting System

Edison's success in inventing the light bulb was only one component of the development of an electrical lighting system (Israel, 1998, Chaps. 10–12). Edison had been working on a viable electrical light because he hoped to use it as part of a lighting system that would replace the gas systems then in near-universal domestic use. Gas was relatively inexpensive as a source of lighting, and it was convenient in that it allowed the user to control each burner separately. However, gas lighting was dangerous, and the threat of fire was always of great concern. In addition, the gas flame could be dirty and emit an unpleasant odor. To persuade people to change to electric lighting, Edison and the people who had invested in his research had to demonstrate that electricity could provide lighting that was superior to gas. In order to do so, Edison set up a system that would deliver electric lighting to part of lower Manhattan. This system involved a power-generating station, which provided electricity that could be sent through wires to the houses using electric lighting. Thus, the invention of the electrical lighting system is another of Edison's inventions, one of very large scale.

Not surprisingly, Edison used his expertise in designing his electrical lighting system: He based his system on the gas lighting system that was

already in place. This was transfer based on a regional analogy, from a lighting system based on gas to one based on electricity. There were numerous similarities between the two systems, ranging from superficial ones to deeper relationships. One superficial similarity was that the electric light was called the “burner” in Edison’s system, although nothing actually burned; this was an obvious transfer from the gas system. Similarly, the amount of light output from each bulb was designed to be the same as that from the typical gas burner. In addition, the electrical system was designed so that each bulb could be controlled independently of the others, like the gas burners, and the metering system used to determine the monthly charge for electricity was similar to that used in the gas system. Most of those correspondences are not particularly significant and may have resulted from Edison’s desire to mimic the features of the gas system that were useful. However, one other aspect of the gas system that Edison incorporated was to run the electric wires underground like gas mains, which by necessity were underground. Here is a parallel between the gas and electrical systems that indicates that Edison was basing his system on the extant lighting system. Other systems using wires, such as the telegraph and telephone systems, strung their wires on poles.

Edison’s Inventions: Summary

Edison’s inventions—the phonograph, the kinetoscope, the electric light, and the lighting system—radically altered the world. As far as the public was concerned, those inventions represented sharp breaks from the current situation. However, those inventions were all based on ordinary thinking as it has been described in this book. Edison’s thinking was firmly top-down in nature: His knowledge played a critical role in directing his activities. In addition, the knowledge that served as the basis for the inventions we have discussed so far was transferred from past situations as the result of analogical thinking, and those analogies were local or regional in nature. We did not see examples of far-ranging unstructured leaps of thought in Edison’s advances.

I will now turn to two additional case studies of creative thinking in invention, James Watt’s invention of the steam engine and Eli Whitney’s invention of the cotton gin. These two inventions had wide-ranging economic effects in Europe and the American South, so once again we can examine the role of ordinary thinking in their development.

James Watt’s Invention of the Steam Engine

The steam engine played a critical role in the industrial revolution, which paved the way for the modern world as we know it. Watt (1736–1819) is

often described in history books as the inventor of the steam engine, a statement that has two important implications: first, that nothing in the way of steam engines existed before Watt carried out his creative work, and second, that only he played a significant role in that invention. Both of those implications are incorrect (Basalla, 1988; Weisberg, 1993).

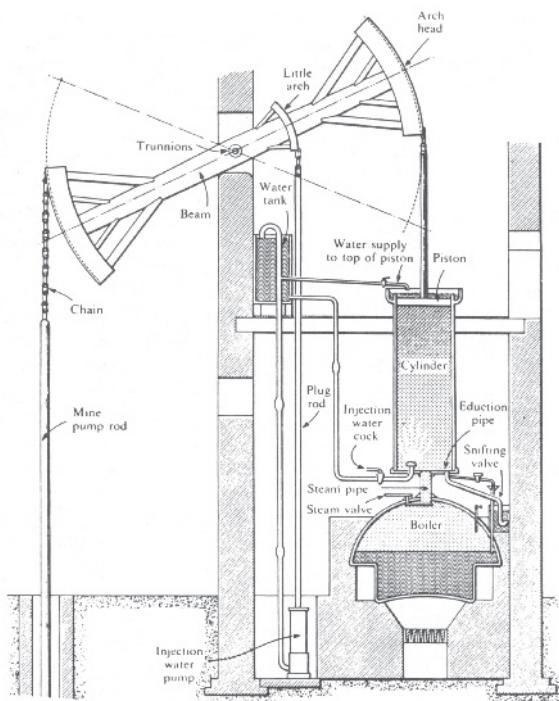
Watt's purported invention of the steam engine in 1763 came about as part of his employment. He was a scientific-instrument maker at the University of Glasgow, where, in addition to other tasks, he maintained the equipment used in scientific demonstrations in class. One demonstration involved a Newcomen engine, a steam engine that had been invented more than 50 years earlier by Thomas Newcomen (1663–1729; see Figure 5.17A). Newcomen's engine was initially used to pump water from mines, which made accessible the coal and other minerals that played a critical role in the industrialization first of England and then of other European countries. Thousands of those Newcomen engines were in use in Europe at that time, and some remained in use into the twentieth century.

Newcomen's engine was built around a piston that was enclosed in a cylinder with an opening at the top to the outside atmosphere. When the piston was at the top of the cylinder, steam from an attached boiler was introduced into the cylinder. The cylinder was then cooled with a burst of water, which resulted in the steam contracting, which left a vacuum in the cylinder. Atmospheric pressure then served to push the piston down to the bottom of the cylinder, resulting in the ability to carry out work. The piston then returned to the top of the cylinder, and the cycle was carried out again: The cylinder was heated so that the steam could be introduced, and then the cooling occurred again, and so forth. Technically, Newcomen's engine was an atmospheric engine rather than a steam engine, since the atmosphere, rather than high-pressure steam, was supplying the motive force. Steam pressure could not be used because of the technological limitations of the era.

Watt's task in 1763 was to prepare a model Newcomen engine for a demonstration, but he found that he had difficulty keeping it running; it would go through a small number of cycles and then stop working. Watt found that the problem was that the Newcomen engine was very inefficient, because the cylinder had to be heated and then cooled for each cycle, and coal had to be replenished almost continuously. Watt developed several improvements to Newcomen's engine, the most important of which was the introduction of a second cylinder, in which the steam was condensed. (See Figure 5.17B.) With this alteration, one cylinder could be kept hot while the other was cooled, which meant that introduction of steam could be almost continuous. This resulted in a more powerful and efficient engine,

Case Studies of Creativity

A



B

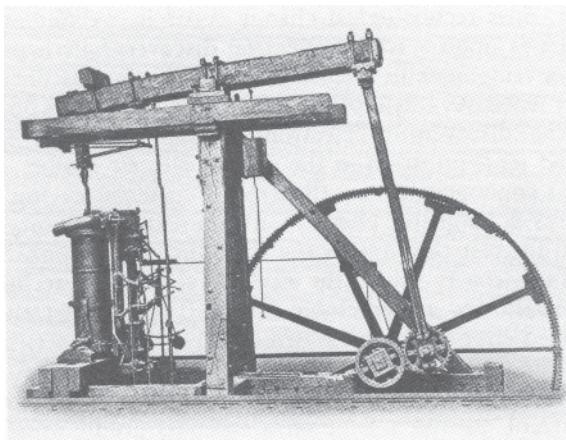


Figure 5.17 Steam engines:

A, Newcomen;

B, Watt

Source: Basalla (1988).

but it was not the first steam engine (technically, it too was an atmospheric engine): It was simply an improvement on an earlier device. So once again we see a historically important invention being brought about through ordinary thought processes. Most critically, Watt's expertise played two roles in this invention. First, his specific knowledge and experience with Newcomen engines were critical in his decision to attempt to improve their

operation. In addition, Watt's general experience as a machinist served as background for his analysis of the drawbacks of the Newcomen engine and for his attempts to overcome them.

Eli Whitney's Cotton Gin

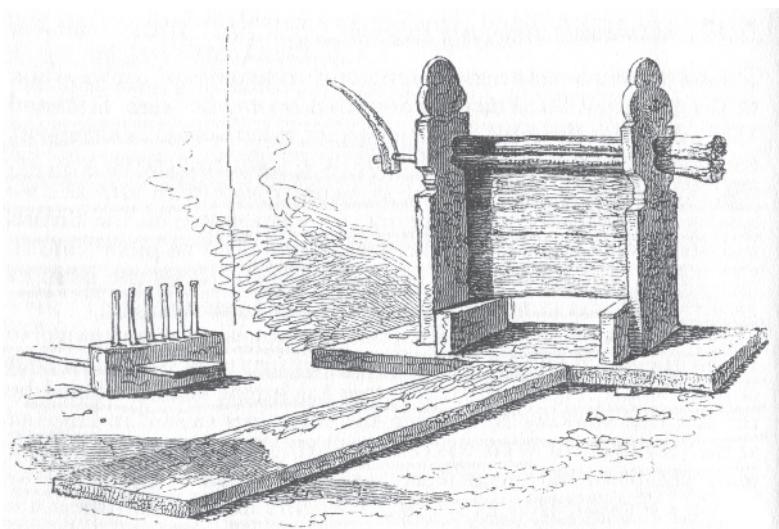
Eli Whitney (1765–1825) was a New Englander who invented a machine—the cotton gin—that saved the economy of the antebellum South. However, once again we must examine carefully just what it was that Whitney's creativity accomplished.

In order to process cotton so that it can be made into cloth, it is necessary first to remove the seeds from the cotton bolls; this process is also called *cleaning the cotton*. Some cotton—black or long-staple cotton—contains seeds that are relatively easy to remove, and a machine (the charka) had existed for millennia that served to clean it. Those machines, which originated in India, feed the raw cotton through two rotating rollers that essentially squeeze the seeds out of the cotton (see Figure 5.18A). Long-staple or long-fiber cotton produces cloth of high quality, but it could only be grown near the seacoast in the American South. Farther inland, short-staple or green cotton would grow, but that cotton had “fuzzy” seeds: The fibers were attached to the seed surface, which meant that one had to separate the seed from the fibers in order to use the cotton. In the American South that very labor-intensive process was carried out by hand by slaves, and it was so slow that cotton farming in inland areas was not a viable industry.

Whitney graduated from Yale college in 1792 and accepted a position as a teacher in South Carolina. En route, he met a plantation owner, Katherine Greene, who invited him to stay at her plantation when his teaching job did not materialize. In discussions with Greene and other plantation owners, Whitney became aware of the difficulties of processing cotton, and he soon developed a prototype of a machine that could clean short-staple cotton mechanically much faster than people could (Invention Dimension, Lemelson-MIT Program, Inventor of the Week Archive, Eli Whitney Cotton Gin [<http://web.mit.edu/invent/iow/whitney.html>]; retrieved January 25, 2006). Whitney's gin (the term *gin* in this context has nothing to do with alcoholic beverages; it is short for *engine*), shown in Figure 5.18B, was built around a pair of rollers, through which the raw cotton was fed. Wire teeth on one of the rollers caught the cotton fibers and drew them through a breastwork with slits cut in it. The teeth and the fibers could pass through the slits, but the seeds were left behind.

Two points about Whitney's device are noteworthy. First, the gin shown in the figure is not the first design that Whitney developed; his first model

A



B

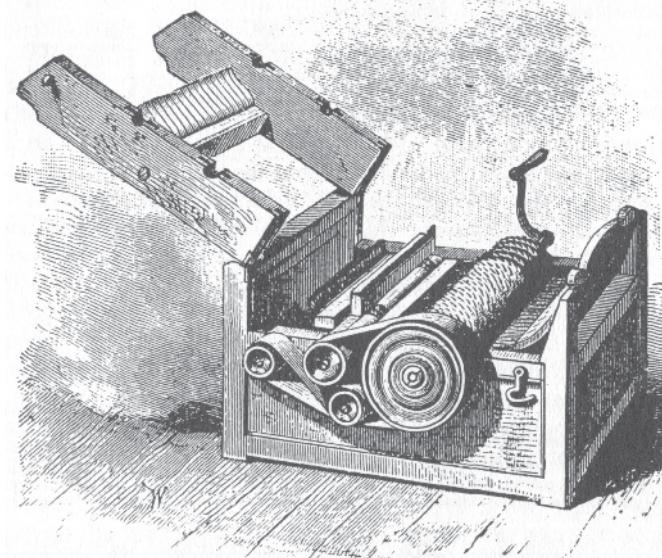


Figure 5.18 The cotton gin: A, Charka; B, Whitney cotton gin

Source: Basalla (1988).

had a screen through which the cotton was forced while the seeds were left behind. This device did not perform well enough to be useful. The design shown in the figure is the second design. Also, even Whitney's successful gin was from the beginning in need of improvement, because it damaged much of the fiber.

It seems that Whitney's purported invention of the cotton gin was another example of a creator's building on expertise, of both a general and a specific nature. Whitney seems to have based his gin at least in part on the design of the gin to clean long-staple cotton (see Figure 5.18A and 5.18B). In addition, Whitney's experience with manufacturing in New England provided the foundation on which his specific inventive activity was carried out. This invention is an example of analogical transfer based on a near analogy: A device for cleaning one type of cotton was adapted to clean another.

Ordinary Thinking in Invention: Summary

In each of the case studies of invention, we can see the role played by ordinary thinking and by domain-specific and general expertise. The Wrights and Edison accomplished their great innovations in different ways. Edison stayed within established knowledge and perfected methods that were already known to researchers in the field; this allowed him to overcome difficulties that other researchers had also come up against. The Wrights, in contrast, went farther away from what had been done before. No one had even begun to address the problem of control when the Wrights came on the scene, so, by necessity, they went off on their own path. Watt and Whitney also built on established knowledge, in each case making an advance by modifying an already-extant device. In all those cases, we have seen evidence for structure in creative thinking, as exemplified by analogical thinking based on local or regional analogies, as well as the use of logical reasoning and evidence of the importance of antecedents even in radical breakthroughs. In no case was it necessary to postulate any sort of nonordinary thought processes in order to understand the creative advance.

Case Studies of Creativity: Conclusions

This chapter has provided support from varying sources for the premise that ordinary thinking underlies creativity and that ordinary thinking is the basis for even radical creative advances. We first reviewed evidence that the 10-Year Rule is relevant to the development of even the most renowned creative individuals, such as Mozart and Picasso (Hayes, 1989; Weisberg, 2003). Significant creative achievement comes about after the acquisition of deep knowledge or expertise in a domain, acquired through years of immersion, sometimes as the result of deliberate practice. Examination of several case studies, including some that were groundbreaking, has also provided evidence of the presence of the components of ordinary thinking outlined at the beginning of the chapter. Antecedents were seen for many

Case Studies of Creativity

of those advances, and domain-specific expertise also played a critical role in many of them. In addition, analogical thinking—specifically, the use of regional analogies—was important in several of the advances. In short, the discussion in this chapter has supported the conclusions from the case studies presented in Chapter 1, and it supports the conclusion that, at the very least, ordinary thinking has been the foundation for a wide range of creative advances, including some radically new advances, produced by individuals of the highest levels of renown.

CHAPTER

6

The Question of Insight in Problem Solving

The cognitive perspective on problem solving, as we now know well, is built on the notion of search through a problem space (see Chapters 3 and 4). The methods that are applied to problems vary according to degree of specificity (*strong* versus *weak* methods), depending on the amount of problem-specific knowledge the individual possesses. The model summarizing the cognitive-analytic view of problem solving, presented at the end of Chapter 4, is presented again as Table 6.1. The model assumes that the first step in dealing with any problem is attempting to match the situation with the person's knowledge; that is, the model is based on the top-down conception of human cognition, discussed earlier. The person analyzes the problem on the basis of his or her knowledge about the situation. If the person possesses expertise in the area, there will be a relatively precise match between the problem and the individual's knowledge, which will result in the person's retrieving a solution method that fits the problem reasonably closely. This outcome is shown in Stage 1B, and it results in a solution attempt based on analogical transfer or on expertise. If the solution transfers successfully, then the problem is solved. If there is no success, then the person would attempt in Stage 2 to apply weak heuristic methods to the problem. If this is successful, then the problem also would be solved. If no weak methods are successful, then the person would fail to solve the problem and would give up.

As noted in Chapter 4, we can categorize the various modes of solving problems that are based on degrees of specificity of knowledge about a problem

The Question of Insight in Problem Solving

Table 6.1 Cognitive-analysis perspective: Stages
in solving a problem through analysis

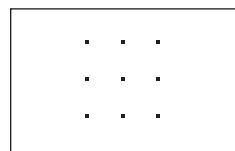
Stage 1: Solution through application of strong methods
1. Problem presented \Rightarrow attempt to match with knowledge <ul style="list-style-type: none">A. No solution available \Rightarrow Stage 2B. Successful match with knowledge \Rightarrow transfer solution based on expertise or analogyC. If solution transfers successfully \Rightarrow problem solvedD. If solution fails \Rightarrow Stage 2
<i>Comment:</i> If no match is made with memory, person goes to Stage 2; if match is made, solution is attempted. Can result in solution of the problem.
Stage 2: Solution through direct application of weak methods
2. Failure at Stage 1A \Rightarrow analysis based on weak methods <ul style="list-style-type: none">A. Analysis successful \Rightarrow solutionB. No solution \Rightarrow impasse; problem not solvable
<i>Comment:</i> Person works through problem using weak heuristic methods, trying to develop solution; if successful, problem is solved.

as *analytic* methods. In using any of these methods, one applies knowledge and reasoning skills, to the degree that one is able, to analyze the problem and determine what to do. When using analytic methods, even weak methods, you have at least a general idea as to how you are going to proceed, and any specific solution method that develops can be seen as growing out of that idea. The method that one attempts to apply to a problem is the result of the match between the problem and one's knowledge. The solution process usually proceeds gradually, in what can be called a step-by-step manner, and you usually have a feeling as to whether you are making progress. Problems that are solved through the application of analytical methods can be called *analytic* problems. Examples would be the Towers of Hanoi and Missionaries and Cannibals problems (see Tables 3.3A and 3.3B, p. 120).

There also seems to be a second kind of problem solving, however, which occurs in a manner very different from problem solving based on any of the analytic methods just discussed. You may be working on a problem and achieving little success when the solution suddenly flashes into consciousness—out of the blue—in what can be called an *Aha!* experience: The proverbial light bulb goes on. When such *leaps of insight* occur, they are accompanied by feelings that are very different from those that arise when problems are solved using analytic methods. Leaps of insight involve upsetting the applecart, as you suddenly discover a new direction of approaching the problem. Figure 6.1 presents several *insight problems* that psychologists

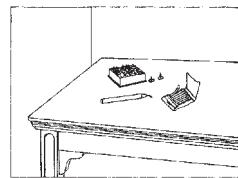
A. Nine-Dot

Connect 9 dots in a 3x3 matrix with 4 connected straight lines. for solution, see Fig. 6.2A.

**B. Candle**

With the objects available in the picture, how can you attach the candle to the wall so that it will burn properly?

For solution, see Fig. 6.2B.

**C. Antique Coin**

A museum curator is approached by man offering to sell him an ancient coin. The coin had an authentic appearance and was marked with the date 544 B.C. The curator had had dealings with this man before, but this time he called the police. Why?

Solution: The coin must have been fake. It was dated 544 B.C. How could anyone know when Christ would be born?

D. Lilies

Water lilies double in area each day. On the first day of summer, there is one lily on the lake. Sixty days later, the entire lake is covered. On which day is the lake half covered?

Solution: Day 59

E. Socks

You wake up early to go to work. It is still dark, and you do not want to disturb your partner by turning on the light. You know that you have five pairs of blue and four pairs of black socks in your drawer, but the socks are not separated into pairs. What is the fewest socks you have to take out of the drawer in the dark so that you will be certain of having a matching pair?

Solution: Three socks.

F. Trees

How can you arrange 10 trees in five rows with four trees in each row?

Solution: Make 5-Pointed star, with several trees in more than one row:

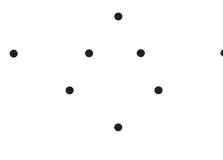
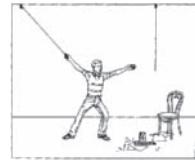


Figure 6.1 Insight problems

The Question of Insight in Problem Solving

G. Two-String

How can you tie together the two strings? You cannot reach the second while holding the first. *Initial solution:* Try to reach the second string while holding the first.



Insight solution: Set the second string swinging like a pendulum, catch it when it swings close. Among the items in the room are pliers, which can be used as the pendulum weight.

H. Triangle

The triangle below points to the bottom of the page. By moving only three dots, make the triangle point to the top of the page.

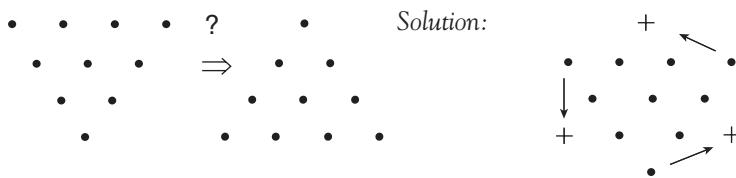
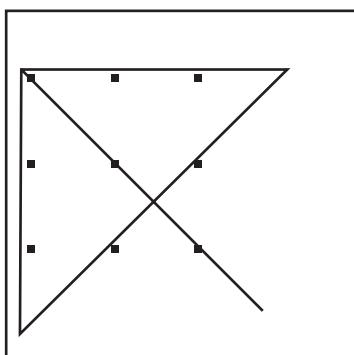


Figure 6.1 (continued)

A. Nine-Dot



B. Candle

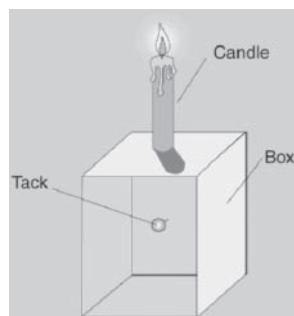


Figure 6.2 Solutions to insight problems

have used in attempts to study leaps of insight in the laboratory. Figure 6.2 presents solutions to some of those problems.

The concept of insight in problem solving has a long history in psychology, beginning with the Gestalt psychologists early in the twentieth century (Weisberg, 1980, 1995), and in the last 25 years there has been a renewal of interest in the topic among cognitive psychologists (e.g., Fleck & Weisberg, 2004; Jung-Beeman et al., 2004; MacGregor, Ormerod, & Chronicle,

2001; Perkins, 1981; Sternberg & Davidson, 1995; Weisberg, 1980, 1995; Weisberg & Alba, 1981). From the time of its introduction into psychology, the notion of insight has been the center of debate. In recent years, that debate has focused on the question of whether different mechanisms are involved in solving a problem through insight versus analysis. The present chapter examines this question.

Outline of the Chapter

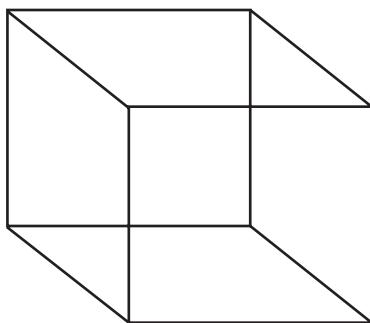
The chapter begins with an overview of the development of the Gestalt notion of insight as a process different from analysis, followed by a review of the research support for that view. Included in that review is a discussion of a recent elaboration of the Gestalt view, which I call the *neo-Gestalt view*, which proposes that insight is the result of a heuristic-based search in response to an impasse during problem solving (Kaplan & Simon, 1990; Ohlsson, 1992). I will then review several critical findings that in my opinion raise significant challenges to the Gestalt view. Given the shortcomings of the Gestalt view, an alternative theoretical account of insight will be presented, based on the cognitive-analytic perspective on problem solving presented in Table 6.1. That cognitive-analytic account proposes that insight and analysis are not two different ways of solving problems. Rather, the processes underlying all problem solving are the same—analytic processes of varying degrees of specificity, as we have already discussed. Depending on the circumstances, there can be large differences in the subjective experiences that accompany solution of a problem. Sometimes one can solve a problem gradually, in what seems like a routine activity, while other times one can solve a problem suddenly, in a leap of insight. However, I will propose that both types of subjective experiences are the result of the operation of the same set of underlying processes. I will then present research to support this unified cognitive-analytic view of insight in problem solving.

The Gestalt Analysis of Insight: Problem Solving and Perception

Solving a problem through insight is characterized by three criteria (Ohlsson, 1992; Simon, 1986; Weisberg, 1995):

- The problem is solved *suddenly* (in an *Aha!* experience).
- It is solved after an *impasse* (a period of no progress).
- It is solved as a result of a *new way of approaching the problem* (a *restructuring* of the problem).

A. Reversible figure



B. Gestalt theory of insight: Analogy between perception and problem solving

Perception:

$$\begin{array}{ccc} \text{Cube}_1 \Rightarrow \text{time} & & \Rightarrow \text{Cube}_2 \\ (\text{Structure}_1) \Rightarrow \text{time (restructuring)} & \Rightarrow & (\text{Structure}_2) \end{array}$$

Problem solving:

$$\begin{array}{ccc} \text{Solution method}_1 \text{ [Failure]} \Rightarrow \text{impasse} & & \Rightarrow \text{Solution method}_2 \text{ [success]} \\ (\text{Structure}_1) \Rightarrow \text{time (restructuring)} & \Rightarrow & (\text{Structure}_2) \end{array}$$

Figure 6.3 Problem solving and perception

As is well known, the Gestalt psychologists began their work in psychology with the analysis of perceptual phenomena, and they applied perception-based concepts to problem solving and creative thinking in general and to insight in particular. In the Gestalt view, a problem situation is like the stimulus presented in Figure 6.3A: More than one interpretation is possible—that is, the situation can be *structured* in more than one way. If one studies the stimulus in Figure 6.3A for a period of time, one will see it reverse; that is, a new interpretation of the figure will suddenly emerge, based on a *new structuring*, or a *restructuring*, of the situation. The restructuring of Figure 6.3A is *spontaneous*: It seems to *happen to you*, and sometimes that reorganization can surprise an unsuspecting observer. The reason for the restructuring of Figure 6.3A, according to Gestalt theory, is that the stimulus figure sets up an unstable pattern of activity or “forces” in the viewer’s nervous system (Humphrey, 1963, Chap. 6). This unstable pattern will tend to spontaneously reorganize itself into another pattern, the one corresponding to the second interpretation of the stimulus. However, this organization is also unstable, so it will sooner or later reorganize into the first pattern, and

so forth. In this way, the figure will appear to be spontaneously reversing, which is the result of the way the nervous system functions and is out of the viewer's conscious control.

In the Gestalt view, a problem is also a state of instability or tension, because the goal cannot be immediately attained from the problem state. In order for the solution to be produced, one must develop the correct or insightful structuring of the problem, which will allow the instability to be resolved. Insight problems (Figure 6.1) are typically designed so that the first method one thinks of will not work. In order for solution to occur, there must be a switch in the way the problem is analyzed, corresponding to the restructuring that occurs in viewing the reversible cube in Figure 6.3A.

The Socks problem (Figure 6.1E), for example, tends at first to generate an (incorrect) approach that uses probability. ("Is this a problem about permutations or combinations? Do I multiply 5 by 4? What do I divide by?") This approach must be abandoned before solution can occur. One must consider the situation from the perspective of the person taking the socks out of the drawer and think about what he or she has in hand. So imagine taking the socks out of the drawer one at a time. After the first two socks, you may have a pair of the same color, in which case you have solved the problem. However, you cannot be *sure* that the two socks will be of the same color, so you must go further: On the chance that the two socks will not match, you must take out at least a third sock. On contemplating that third sock, you may suddenly realize that it must solve the problem (and that realization may be accompanied by an *Aha!*). Since there are only two colors of socks in the drawer, if the first two that you take out are mismatched, the third sock must match one of them. Thus, three socks is the solution to the problem. We see here how the initial direction from which people typically approach the problem—calculating probabilities—must be abandoned before the problem can be solved. If we call that initial direction the original *structure* that is applied to the problem, we can say that in order to solve the problem one has to *restructure* it.

Similarly, most people first approach the Lilies problem (Figure 6.1D) using simple arithmetic, saying something like this: "Thirty days to be completely covered; zero coverage on the first day; then the pool is half covered in half of 30 days, or 15 days." That answer, however, is incorrect. Solving the problem requires first of all that that arithmetic method be abandoned. The Lilies problem is solved easily, without any calculation at all, if you start with the last day and work backward. If the pond is fully covered on day 30, and lilies double in area each day, then the pond must have been half covered on the day before it was fully covered—that is, on day 29. You can

solve the problem by simply analyzing the concepts involved and reasoning from them, but in order to do so, you must first restructure it.

In the Nine-Dot problem (Figure 6.1A), everyone begins by drawing lines within the square or box formed by the dots, but in order to solve the problem, lines must be drawn (literally) outside the box. (See Figure 6.2A.) In the Candle problem (Figure 6.1B), most people begin by trying to attach the candle directly to the wall, either using melted wax as glue or using the tacks. In this problem, the solution of interest involves emptying the tack box and using it as a shelf or holder for the candle (the “box solution”; see Figure 6.2B). In the Two-String problem (Figure 6.1G) the individual tries to reach the second string while holding the first one but soon realizes that that is impossible. If one thinks of getting the second string to swing like a pendulum, using the pliers lying on the table as the weight for the pendulum, one can hold the first string and wait for the second to swing within reach. So in all those problems a restructuring can occur that will bring the solution, and perhaps an Aha! experience, with it.

In problem solving, restructuring can occur as the result of the individual’s reaching an impasse. Like a reversible figure that seems to spontaneously reverse as you look at it, a problem can suddenly become restructured as you contemplate it, bringing with it new possibilities for solution. Depending on the complexity of the problem, restructuring can bring about *complete* or *partial* insight (e.g., Koffka, 1935). If a problem situation is relatively simple, restructuring may result in the complete solution becoming immediately available. An example would be the Lilies problem, where restructuring brings the complete solution. Such occurrences would be analogous to the complete reversal of the cube in Figure 6.3A. On the other hand, if a problem situation is relatively complex, then a restructuring may only result in the thinker’s seeing a new solution path, not the complete solution. The new direction only provides the setting in which the solution can occur.

These examples show that the Gestalt view assumes that restructuring in problem solving is analogous to restructuring in perception, as summarized in Figure 6.3B (Ellen, 1982; Ohlsson, 1984a). This view believes the perception-like processes underlying restructuring and insight to be basically different from the processes underlying analytic problem solving.

Insight versus Experience: Fixation in Problem Solving

The Gestalt psychologists assumed that under ordinary circumstances no specialized knowledge is needed to achieve insight into a problem situation, as exemplified by solving insight problems (Wertheimer, 1982). This is analogous to the assumption that no specific experience is needed to

perceive both orientations of the reversible cube in Figure 6.3A. In order to solve the Antique Coin problem (Figure 6.1C), for example, all one needs to know is that one cannot predict when a specific person will be born several centuries hence, and we all know that. Solving the Nine-Dot problem (see Figure 6.2A) requires only that we draw four connected straight lines; and we can all put a tack through a cardboard box, as the Candle problem requires (see Figure 6.2B). Similarly, as we saw earlier, the solutions to the Lilies and Socks problems, once restructuring occurs, require only one or two steps, and no specialized knowledge is needed for either problem. The Two-String problem (Figure 6.1G) requires little more than that one set a string to swinging.

However, people sometimes have difficulty solving insight problems (e.g., Fleck & Weisberg, 2004, 2006; Weisberg and Alba, 1981; Sternberg & Davidson, 1995), which means, according to the Gestalt view, that restructuring a problem can sometimes be difficult. In order to explain why restructuring might not occur when a person tries to solve a problem that requires reorganization and insight, the Gestalt psychologists proposed that there are factors that can interfere with restructuring. One of those factors can be a person's attempting to apply his or her knowledge to an insight problem to which that knowledge does not apply. Whereas experience and expertise have positive effects in the solution of many analytic problems (see the discussion of heuristics and expertise in Chapters 3 and 4 and in Table 6.1), applying one's experience to an insight problem may result in an inability to restructure the situation in the way that is necessary for solution. The person in this situation is said to be *fixated* on past experience (Scheerer, 1963). This notion is reminiscent of the *tension view* of the negative relationship between expertise and creativity discussed in Chapter 4.

We can better understand the Gestalt psychologists' analysis of fixation in problem solving by considering the Nine-Dot problem (see Figure 6.1A and 6.2A), one of the best-known (and most difficult) in all of psychology. As an example of the problem's difficulty, Weisberg and Alba (1981) gave undergraduates 100 chances to solve it, but fewer than 10% succeeded (Weisberg & Alba, 1981; see also Burnham & Davis, 1969; Lung & Domi-nowski, 1985; MacGregor et al., 2001). The extreme difficulty of the problem is assumed to be the result of fixation (Scheerer, 1963); solution requires that lines be drawn outside of the shape of the dots, but the presentation of the problem results in the viewer's perceiving the dots as a square. This analysis of the problem causes the person to keep the lines within the square, which makes it impossible to solve. In this case the fixation is brought about by perceptual factors, as well as by our experience solving connect-the-dots puzzles (Scheerer, 1963). In the Antique Coin problem (Figure 6.1C), fixa-

tion occurs if we become locked into our present-day perspective; that is, we “look back in time” from the present at the person making the coin. In order to solve the problem, however, one must switch to the perspective of the coin’s maker: What could he or she have known when making the coin? In these examples, the thinker is fixated on one mode of structuring the problem, which can make an apparently easy problem impossible to solve.

The Gestalt View of Insight: Conclusions

In the Gestalt view, the basic mechanism underlying insightful problem solving is the thinker’s discovering an alternate structure of the problem, one that allows the solution to come to the surface. This discovery can be hindered by a too-heavy and unthinking reliance on the past.

The question of the role of insight in problem solving is important because there is a close connection between insight and creativity. It is assumed by some researchers (e.g., Perkins, 2000; Sternberg & Lubart, 1995) that the mechanisms underlying insight in problem solving play a role in creative thinking in general. Therefore, elucidating those mechanisms may have implications for our understanding of creative thinking. In addition, specification of the mechanisms underlying insight may have practical implications. For example, researchers have developed educational programs based on the Gestalt view of insight that are designed to improve problem-solving performance (e.g., Ansburg & Dominowski, 2000). It may be but a short while before such programs are adopted in schools, if they have not already been adopted. If, as proposed in this chapter, the adequacy of the Gestalt view can be questioned, then the usefulness of those programs must be reexamined as well.

Evidence to Support the Gestalt View

A wide range of research findings have been brought forth over the years to support the Gestalt view. I will review a number of seminal findings, as well as several more recent findings of potential import.

Köhler’s Research on Insight: Problem Solving versus Learning

The classic research on insight in problem solving, which introduced the notion of insight into psychology, focused on animals rather than people. At the turn of the twentieth century there was a thriving interest in the study of psychological processes in animals (Boring, 1950), which arose at least partly because of the emphasis in Darwin’s theory of evolution on the close relationship between humans and animals. At that time, however, little

rigorous experimental research was carried out with animals, so much of the purported evidence concerning animals' capacities and behaviors came from reports of the great feats carried out by pets. One animal learned to open a locked door; another found its way home after being lost far from home (such reports still appear occasionally in the media). The writers of such reports claimed that the animals had exhibited intelligence similar to that of humans, but they offered no concrete evidence to support the claims, just anecdotal reports about the wonderful things that animals could do.

Thorndike's Study of Intelligence in Animals

In response to unsubstantiated claims made about high levels of animal intelligence, Thorndike (1911) undertook a systematic investigation to determine whether animals were capable of exhibiting the sort of intelligence that was claimed in discussions of the behavior of pets. He designed several similar apparatuses, called *puzzle boxes*, each of which was a cage in which a hungry cat could be placed. Food was placed outside the cage, in the animal's sight but out of reach. Typically, the animals would respond to the food by reaching toward it, scratching the cage wall, and so forth. These responses were unsuccessful, so the animal was faced with the challenge of discovering how to get out of the cage. The animals could escape from their cages by operating a mechanism that opened the door, but the operation of this mechanism was not obvious. Straightforward responses like pushing on the door or clawing at it did not cause it to open.

In Thorndike's view, the animal would demonstrate evidence of intelligence or reasoning ability if, once it had discovered the mechanism, it left the cage efficiently thereafter. Judged by this criterion, Thorndike's animals did not exhibit intelligence in his puzzle boxes: They seemed initially to stumble upon the way to open the cage door, and they only slowly became more efficient in leaving their cages. Thorndike concluded that the animals only gradually *learned* to escape from the cages; they were not able to exhibit *insight* into how to escape. If the animals had no experience to fall back on, they were left to random responding; bits and pieces of the solution were gradually glued together into a chain that could be run off efficiently. They were not capable of reasoning out the method of escaping from the cage.

Köhler's Response to Thorndike: Intelligence and Insight in Chimpanzees

Thorndike's conclusion concerning the lack of insight shown by animals was criticized by the Gestalt psychologists, such as Köhler (e.g., 1925) and Wertheimer (e.g., 1982), who were of the belief that animals (including, of course, humans) were capable of exhibiting intelligence and achieving insight into the structure of a problem. As noted earlier, the Gestalt psy-

chologists analyzed problem solving in terms of perception and held that the critical factor in achieving insight was a restructuring of the situation. It follows from such a perceptually based analysis of problem solving that, in order for an organism to exhibit insight in a situation, the *layout of the whole situation* had to be available (Humphrey, 1963), so that the situation could be restructured. From this perspective, Thorndike never gave the animals a chance to exhibit any insight of which they might have been capable, because his puzzle boxes were so constructed that it was impossible for the animal to see, and therefore to understand, how they worked. In one puzzle box, for example, the door opened if the animal pushed against a vertical pole in the middle of the cage, but one could not tell from inside the cage that there was a connection between the pole and the door. It was not surprising that an animal in such a situation would rely on trial-and-error behavior and would show no insight: There was no way for the animal to do anything else but fumble around until it stumbled on the solution.

In response to such limitations in Thorndike's work, Köhler (1925) carried out a now-classic series of investigations of insight in chimps. Köhler's problem situations were designed so that an intelligent animal should be able to solve the problem simply through examination of the situation, thereby demonstrating that it was capable of going beyond simple conditioned responses and of producing novel responses based on thinking and insight. One problem set by Köhler was the Rake problem. The situation was as follows. The chimpanzee-subject would be in its cage, and outside the cage was an attractive piece of banana. One animal reacted to the situation in the following way. The animal reached through the bars of the cage, but the banana was out of reach. The chimp expressed some displeasure and then sat quietly, unhappily contemplating the banana. There was a stick lying on the ground in front of the chimp's cage, extending from the bars to the banana. The animal had previously paid no attention to the stick; now, suddenly, she grasped the stick and used it as a rake to bring in the piece of banana. In this situation we see an animal that reached an impasse in trying to solve a problem and then suddenly saw the solution.

In support of the idea that perceptual processes were important in problem solving, Köhler found that, in order for the animal to use the stick to rake in the banana, it was crucial that the stick be lying *between* the ape and the banana, so that the stick could be perceived as a potential extension of the animal's arm (Köhler, 1925). If the stick was off to the side or behind the animal, so that the banana, stick, and arm could not be seen in one glance, then the stick would not be used. If, however, the situation was structured correctly, then things would fall into place and the solution would be produced as an integrated whole, without the fumbling trial and

error exhibited by Thorndike's animals (Humphrey, 1963, Chap. 6). No specific information or knowledge was needed.

Insight in Humans: Evidence for the Occurrence of Aha! Experiences in the Laboratory

Metcalfe (1987; Metcalfe & Wiebe, 1987) carried out several studies that provided evidence for the occurrence of Aha! experiences when humans solve insight problems under controlled laboratory conditions. Her method involved a variation on the child's game in which a blindfolded person is searching for something and we tell the searcher that he or she is getting *warmer* or *colder* as he or she moves around the environment. Increases in *warmth* ("You're getting warm . . . warmer . . . hot . . . very hot . . . burning") mean that the person is getting closer to the target, and increases in *coldness* ("You're getting cold . . . colder . . . freezing") mean that he or she is moving farther away. Metcalfe used a similar method to assess people's subjective experiences as they were working on insight versus analytic problems: Participants provided ratings of how "warm" they felt—*feeling-of-warmth ratings*—as they worked through a problem. This was done several times a minute, providing an almost continuous record of the participants' beliefs concerning how close they were to solution of the problem. Metcalfe hypothesized that, if insight problems are solved in an Aha! experience, there ought to be a sudden surge in the warmth ratings just before solution, with little or no increase before that point. In contrast, if analytic problems (e.g., long-division problems or the Towers of Hanoi problem [Table 3.3, p. 120]) are solved through a gradual working-out of the solution, then the warmth ratings for such problems should show a gradual increase as the solution is approached.

The warmth ratings obtained by Metcalfe and Wiebe (1987) supported those predictions. For insight problems, there was little increase in warmth until just before solution, which supports the idea that solution occurred suddenly, in a burst of insight. For non-insight-based problems, on the other hand, a gradual increase in warmth was found, indicating that the person was working through the solution, which allowed the accurate prediction of how things were progressing. Metcalfe's findings demonstrated that solutions to insight problems can come about in an Aha! experience, and her method has been used by others to examine subjective experiences during problem solving (e.g., Davidson, 1995; Bowers, Farvolden, & Mermigis, 1995).

Laboratory Evidence for Restructuring in Problem Solving

The demonstration of Aha! experiences by Metcalfe and Wiebe (1987) is support for only one component of insight. The Gestalt view postulates that an Aha! experience during problem solving results from restructuring

A. Problem

A man walks into a bar and asks for a glass of water. The bartender points a shotgun at the man. The man says “Thank you” and walks out. What was going on?

Solution: Man had hiccups; bartender startled him and cured them.

B. Results: Relatedness ratings

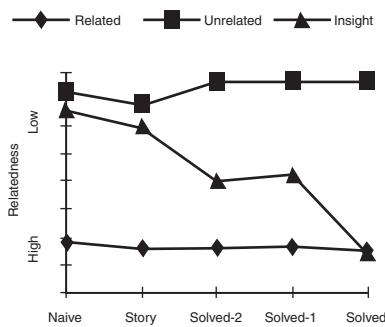


Figure 6.4 Bartender problem

Source: Durso et al. (1994).

of the problem. Metcalfe provided no direct evidence that restructuring had occurred, since she measured only feelings of warmth. Durso and colleagues (Durso, Bea, & Dayton, 1994) used the Bartender problem presented in Figure 6.4A to demonstrate restructuring in problem solving. The Bartender problem seems to require a restructuring before the solution can occur, because, on hearing the story, one thinks that the bartender is pointing the gun at the person in self-defense. The thinker must change that structure in order to solve the problem. To provide a measure of the structure among the elements in the problem, people were asked to judge the relatedness of pairs of words that were connected in various ways to the problem. Some of the pairs of words had been judged by other people as being related in the problem as it was presented (*related pairs*: bartender—bar; gun—loaded). *Unrelated pairs* were not judged as being related, either in the problem as presented or in the problem as solved (e.g., pretzel—shotgun; TV—remedy). Finally, *insight pairs* had been judged as becoming related only after the solution of the problem was discovered (e.g., surprise—remedy; relieved—thank you). Individuals were asked to judge the relatedness of the word pairs at several points: before they heard the problem (when they were *naive*); after they heard the problem (in response to the *story*); every 10 minutes as they worked on the problem; and after they *solved* the problem.

The ratings of relatedness for the various pairs of words are shown in

Figure 6.4B, and several points should be noted. First, the relatedness for the *insight pairs* changed from the *naive* rating to the *solved* rating, providing evidence that the structure of the problem changed as it was solved. In addition, the ratings for the related and unrelated pairs did not change from the *naive* to the *solved* rating, which indicates that there was a specificity to the change in structure: Only those pairs judged to be important to the structure of the problem changed in their relations. However, the results also may have raised a question for the Gestalt view. If one examines the change in the relatedness scores for the insight pairs as the participants worked through the problem, one sees that they did not change suddenly, as one would expect from the Gestalt view (and from Metcalfe's feeling-of-warmth ratings). This discrepancy may be due to the method of data analysis carried out by Durso and colleagues (1994), since they measured the structure of the problem at a few points, and these were relatively widely separated in time. Perhaps if they had measured the possible changes in problem structure relatively frequently, as did Metcalfe and Wiebe (1987) in measuring changes in feelings of warmth, the change in structure might have been found to be sudden.

Although there may be some ambiguity in their interpretation, overall the results of Durso and colleagues (1994) provide evidence that restructuring does occur during the solution of one insight problem. This study is also important because it provides an example of a method that can be used to demonstrate the occurrence of restructuring, which one might have thought was too vague a concept to be captured in the net of experimental methods.

Failure and Fixation in Problem Solving

Several different sorts of investigations have provided evidence that insightful problem solving can be interfered with by fixation—a too-strong reliance on the past. The following sections examine some of these investigations.

Duncker's Study of Functional Fixedness

In a classic study, Duncker (1945) investigated several problems in which seemingly simple solutions were not produced by the participants, presumably because of interference by fixation. The problems all required that a familiar object be used in a novel way. However, if that object was first used in its *usual* way in the problem, solution was interfered with; the typical function of the object blocked the discovery of the new function demanded by the problem. In those problems, one's experience with an object interfered with the ability to use that object in a new way. One problem studied by Duncker

The Question of Insight in Problem Solving

was the Candle problem (Figure 6.1B). The solution to this problem that was of interest to Duncker was the box solution: constructing a shelf or holder for the candle, using the tack box (see Figure 6.2B). The box solution is either not produced at all or is not the first solution that a person proposes (Duncker, 1945; Fleck & Weisberg, 2004). If the box is presented empty of tacks, however, then the box solution is usually the first solution produced, which means that it is within everyone's grasp. Thus, presenting the box in its usual function (as a container for the tacks) interfered with its being used in a novel way. Duncker used the term *functional fixedness* to refer to the interference brought about by an established function of an object.

In explaining the occurrence of functional fixedness, Duncker (1945) relied on perceptual mechanisms. He proposed that presenting the box full of tacks highlighted what he called its *container properties*. Constructing the box solution to the problem, however, required that the box be used as a *platform* or *shelf*, and the properties of the box that are relevant to its use as a shelf (i.e., that it is flat and sturdy) were obscured or made difficult to perceive by the usual presentation of the problem. This component of the initial structure of the problem had to be changed in order for the box solution to be produced, and the restructuring was interfered with by the presentation of the box in its typical function.

Design Fixation in Problem Solving

Jansson and Smith (1991) examined *design fixation* in a situation in which engineers and engineering students were asked to design new versions of everyday objects—for example, a bicycle rack for a car, a measuring cup that could be used by the blind, and a spill-proof cup to hold hot beverages. Jansson and Smith noted that when engineers are given a design problem to solve, they are often given a present-day version of the desired object to improve upon and are informed of its shortcomings. The engineer's task is to design a new object that avoids those shortcomings. However, based on the idea of fixation, concern arose on the part of Jansson and Smith that the presence of the example might result in the designer's incorporating aspects of it into the new design, even the problematic features. Jansson and Smith's study consisted of several experiments, each of which tested groups of engineers or engineering students. In each experiment, two groups were given the same design problem; the only difference was that one group was given a pictorial example, with its problematic aspects pointed out, and was told to *avoid* those components. The control group never saw the example. In all the experiments, the presence of the example resulted in designs that contained the problematic aspects of the example, even when the individuals were told to avoid those aspects in their designs. It seems on the basis

of this study that people have great difficulty approaching a problem on its own terms if they have information that is relevant to it.

Other studies that have been interpreted as demonstrating the interfering effects of past experience on problem solving and creative thinking have been carried out by Frensch and Sternberg (1989) and by Ward (1995), among others. In a study already discussed in the context of expertise in Chapter 4, Frensch and Sternberg showed that expert bridge players were less able to cope with changes in the structure of bridge than were less-experienced players, which seems to indicate that expertise can interfere with adjustment to new problematic situations. Ward found that people who were asked to create entirely new species of organisms (in a test of imaginative ability) seemed to be negatively affected by their knowledge of creatures on Earth: The new creatures were structured in ways similar to creatures on Earth (e.g., symmetrical, with similar sense organs). Thus, there was a lack of novelty in the new creatures. Ward took those results as evidence that, in order to create novel species (such as for science fiction), an individual must have a way of breaking away from his or her knowledge about the creatures we see around us.

Evidence for Nonanalytic Processes in Insight

We have now seen evidence for several critical aspects of the Gestalt view of insight. Metcalfe's (Metcalfe & Wiebe, 1987) research demonstrated that problem solving can occur in an Aha! experience. The research of Durso and colleagues (1994) showed that insightful problem solving involves restructuring, and several studies have demonstrated detrimental effects of experience on insightful problem solving. A further critical issue from the Gestalt perspective is that the restructuring and Aha! reactions during solution of insight problems come about through processes different from those used in solving analytic problems. Several different sorts of evidence have been brought forth to support that claim.

Verbal overshadowing of insight

Schooler and colleagues (Schooler, Ohlsson, & Brooks, 1993) reasoned that if analytic problems are solved through step-by-step methods, people ought to be able to verbalize what they are thinking about at any point during the problem-solving process. If, on the other hand, insight problems are solved through a sudden perception-like restructuring of the situation, then people might not be able to describe what has happened. Therefore, asking them to produce a verbal protocol might actually interfere with the solving of insight problems. Schooler and colleagues accordingly collected verbal protocols while people worked on insight and analytic problems. Results

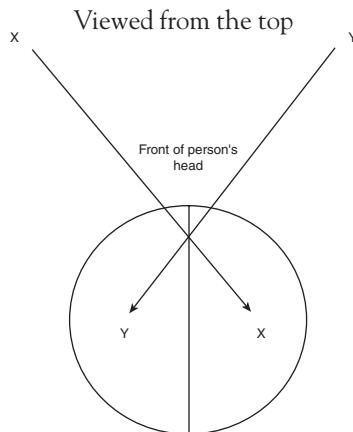
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of the study indicated that asking people to think aloud during problem solving interfered with solution of insight problems but did not interfere with performance on non-insight-based problems. Schooler and colleagues called this result *verbal overshadowing of insight*. They concluded that verbal overshadowing indicates that insight and analytic problems are solved using different methods, and that the methods underlying the solution of insight problems may be nonverbal (i.e., perceptual or nonanalytic) in nature.

Hemispheric Differences in Solving Insight Problems

In order to demonstrate the uniqueness of restructuring as a process, Bowden and Beeman (1998) examined hemispheric differences in solution of insight problems. Evidence indicates that the two cerebral hemispheres process verbal information differently. When a stimulus word is presented to the left hemisphere, which is done by showing the word in the far right-hand part of the visual field, as shown in Figure 6.5A, it activates different asso-

A. Visual fields and hemispheres



B. Example problems

For each set of three words, find one other word that, when paired with each individual word, makes a common phrase in English.

1. high / house / district (answer is school: high school; schoolhouse; school district)
2. palm / shoe / house (answer is tree)
3. pie / luck / belly (answer is pot)
4. pine / crab / sauce (answer is apple)

Figure 6.5 Beeman and Bowden left hemisphere versus right hemisphere study of problem solving

ciates from when it is presented to the right hemisphere. Left-hemisphere processing involves activation of words closely related in meaning to the presented word, while right-hemisphere processing results in activation of more distantly related words. Bowden and Beeman carried out several studies in which college students tried to solve simple verbal insight problems, like those presented in Figure 6.5B. Three cue words are presented, each of which forms a common phrase in English when combined with the same fourth word, and the task is to determine that fourth word. Solution of those problems requires that the person use remote associations to the cue words, because the connections between the solution word and the three cue words are not always direct. When people solve such problems, they sometimes experience an Aha! moment, so Bowden and Beeman classified those types of solutions as resulting from insight.

In one study, Bowden and Beeman (1998, Experiment 2) presented a large set of remote-associate problems to each participant, one problem at a time, with 15 seconds to solve each one. Most of the problems could not be solved within this time period, so the experimenters then presented a possible solution word, and the participant was asked to judge whether that word actually solved the problem. Bowden and Beeman hypothesized that problems would be solved more easily if the possible solution word was presented to the right hemisphere, where any remote and hard-to-find associative connections common to the possible solution word and the cue words would be more likely to be activated. Results of the investigation indicated that presentation of the possible solutions words to the right hemisphere facilitated solution more than left-hemisphere presentation. That is, the participants were faster in recognizing the actual solution word when it was presented to the right hemisphere.

Bowden and Beeman interpreted this result as supporting the premise that insight depends on a unique set of processes, since left- versus right-hemisphere presentation differentially affected solution. However, one must be cautious in drawing that conclusion, because Bowden and Beeman did not examine the effects of left- versus right-hemisphere processing on performance on non-insight-based problems. It is necessary to test both insight-based and non-insight-based problems in this experimental situation before one can conclude that the two types of problems are solved through processing in different parts of the brain. However, those results are consistent with the idea that there are differences between insight and analysis as modes of solving problems. It should also be noted that, since the people in this study had intact brains, presenting the words to one hemisphere did not mean that the other hemisphere did not process them. In the intact brain, information is transmitted from one hemisphere to the

other. So, in this context, when one says that information was presented to hemisphere x , it should be taken to mean that the information went to that hemisphere first before it crossed over to the other. In other words, “presenting information to one hemisphere” means that that hemisphere gets a head start on processing the information, not that it is the only hemisphere that processes it.

Several recent studies have attempted to investigate more directly the brain mechanisms involved in insight versus analysis as modes of solving problems, using electroencephalogram (EEG) measures as well as functional magnetic resonance imagery (fMRI; e.g., Jausovec, 1997; Jung-Beeman et al., 2004). Those studies have just begun to examine possible differences in the brain regions involved in solving problems through insight versus analysis, so few strong conclusions can be drawn at this time. This is an area that will without doubt be the subject of much investigation in the future.

Working Memory and Planning in Insight versus Analysis

Another method that has been used to differentiate insight and analysis as modes of solving problems is examining the role of working memory and planning in the two types of problems. Lavric and colleagues (Lavric, Forstmeier, & Rippon, 2000) assumed that insight comes about without planning, because the restructuring suddenly occurs to the person. Analysis, on the other hand, centers on planning. As noted in Chapter 3, working memory plays a critical role in carrying out planning, so the researchers hypothesized that working memory should be important in analytic processes but not in insight. The importance of working memory is demonstrated in experiments with a dual-task or divided-attention design, in which the individual is asked to do two things at once. If both of the tasks require working memory, then doing both at the same time should be more difficult than doing them separately. On the other hand, if one of the tasks does not require working memory, then carrying out both at once should be no harder than carrying out either alone.

Lavric and colleagues (2000) had people work on either insight problems (the Candle and Two-String problems; see Figures 6.1B and 6.1G) or a logic problem, while at the same time keeping track of the number of tones presented by a computer. Keeping count of the tones was assumed to require working memory, so, according to the logic just outlined, that task should interfere with performance on the analytic (logic) problem. In contrast, if insight does not involve analysis and planning (and therefore does not require working memory), then counting the tones should not interfere with performance on insight problems. Results supported those predictions, which Lavric and colleagues took to mean that when people solve insight problems they do so without planning, which is different from the way they

go about solving analytic problems. Those results therefore provide evidence that the processes underlying insight are different from those underlying analysis, and the former might involve the sudden realization of the solution to a problem, as contrasted with consciously working it out.

Conclusion: Gestalt View of Insight in Problem Solving

We have now examined the development of the notion of insight and have examined research support for it. The basic phenomenon of interest was the sudden solution to a problem that came from a direction different from that which the person had been pursuing. Such a leap of insight was assumed to be the result of a restructuring or reorganization of the problem situation, which was assumed to come about in a manner analogous to the way the perception of the object represented in Figure 6.3A undergoes restructuring. In some cases, people are not able to solve problems that should be within their reach. It is assumed in those circumstances that the restructuring needed for solution is blocked by the incorrect structure. We also reviewed research that provided support for several components of the Gestalt view.

The Gestalt analysis has had an important influence on research on thinking and problem solving, as the notions of restructuring, insight, and fixation have led to the belief that there are two different ways to solve problems. One way is based on analysis and experience, and includes the weak and strong methods discussed in the last three chapters; the other is through insight, as a result of the sudden restructuring of a problem, independent of problem-specific experience. The Gestalt psychologists' emphasis on the potentially negative role of experience—through fixation—has also had a great influence on how modern society in general thinks about problem solving and creative thinking. Familiarity with the Gestalt view has led to a widespread belief that productive problem solving, as well as creative thinking in general, comes about only by breaking away from experience and letting our ideas roam freely. As noted earlier, we have all seen numerous articles and advertisements urging us to *think outside the box* in order to be productive and creative. This is a direct influence of the Gestalt view on popular thinking: The box that we are urged to get out of is usually a metaphorical box, but this directive began as a literal instruction, as directed toward the square formed by the dots in the Nine-Dot problem.

The Neo-Gestalt View: Heuristic-Based Restructuring in Response to Impasse

In the classic Gestalt view, occurrence of an impasse was assumed to set the stage for a spontaneous restructuring of the situation, as happens with

the reversible cube (see Figure 6.3A). Some researchers have questioned whether the reliance on perceptual processes as explanations for problem solving provides a true explanation of the phenomena involved (e.g., Weisberg & Alba, 1982). Notions of perception can be applied to problem solving only by analogy, and one can raise questions about whether anything has been explained through the use of such analogues. There is also a lack of precision in applying perceptual concepts to problem solving. In response to these perceived deficiencies in classic Gestalt theorizing, several modern researchers (Kaplan & Simon, 1990; Ohlsson, 1992) have attempted to explain restructuring and insight in response to impasse by using concepts adapted from the cognitive perspective. This neo-Gestalt view retains the basic structure of the classic Gestalt view, so it is, as we shall see, significantly different from the cognitive-analytic view of insight to be presented later in the chapter.

In extending the cognitive perspective to restructuring and insight, Kaplan and Simon (1990) and Ohlsson (1992) adopt the familiar notion of heuristically guided search, discussed extensively in Chapter 3. In the earlier discussion of heuristics, we were dealing with methods that serve to direct the search for moves within a problem representation. In the neo-Gestalt analysis of insight, it is proposed that heuristics can also serve as the basis for the problem solver's *search for a new problem representation*. That is, heuristics serve as the basis for the person's switching from one representation of the problem to another. We are now talking about heuristics that serve to guide a search in a space of *representations* (the space of *problem spaces*). The attempt to find a new problem representation when one is at impasse could be called a "switch when stuck" (Ohlsson, 1992) or "restructure when stuck" (Kaplan & Simon, 1990) heuristic: One attempts to switch to a new representation (to restructure the problem) when one is making no progress (when one is stuck).

Ohlsson (1992) has emphasized the close relationship between impasses, restructuring, and insight.

Insights occur after the problem-solver has encountered an impasse, i.e., a mental state in which problem-solving has come to a halt; all possibilities seem to have been exhausted and the problem-solver cannot think of any way to proceed. Subjectively, his or her mind is "blank." Behaviorally, impasses are characterized by the cessation of problem-solving activity. . . . Insight, I suggest, is the act of breaking out of an impasse. . . . Without the impasse, there is no insight, only smooth progress. (Ohlsson, 1992, p. 4)

According to Ohlsson (1992), restructuring—changing the problem representation in response to impasse—can take several forms.

1. The individual may try to find a different way to describe an object or objects in the problem, which might be important in opening a new path that leads to solution. This is called *elaboration* of the problem representation.
2. The individual may decide that some previously ignored object should be included among the objects in the problem, which can lead to new solution methods. This is called *re-encoding* of the problem representation, since new information is encoded into the representation.
3. The individual may change the way in which he or she thinks about the goal of the problem, or the method to be used in reaching the goal. This is called *relaxing goal constraints*.

As a concrete example of how these ideas work, Ohlsson (1984b) analyzes behavior in several insight problems, including the Two-String problem (Figure 6.1G) and the Candle problem (Figure 6.1B). In analyzing the Two-String problem, Ohlsson considers the predicament of an individual who is at impasse, holding one string but unable to reach the second. That person may, through *elaboration*, examine the other objects in the problem and note that the pliers are heavy. That realization may lead him or her to contemplate uses for heavy things, which can lead to the possible use of the pliers as a weight for a pendulum. In this situation, elaboration of an object in the problem representation leads to new solution possibilities. In the Candle problem, similarly, Ohlsson assumes that the initial attempts to solve the problem result in an impasse, which forces the individual to attempt to restructure the problem. This may lead to an examination of the features of the box, which, again through Ohlsson's postulated process of elaboration, might lead to the realization that the box is flat and sturdy, which can pave the way to the idea of using it as a shelf. It is also possible that the individual working on the Candle problem might not even have noticed the box initially, so *re-encoding* the problem in response to impasse might reveal the presence of the box, which also could trigger new solution possibilities.

A Bottom-Up Explanation of Restructuring

In the neo-Gestalt view, the original Gestalt notion of perceptually based restructuring is replaced with the idea of heuristic search for an alternative problem representation. Heuristic methods, such as *switch when stuck* or *restructure when stuck* (Kaplan & Simon, 1990; Ohlsson, 1992), are weak methods and are independent of the knowledge of the thinker. One does not have to know much, if anything, about the problem itself to try to change the descriptions of the objects in it or the relations among those objects. One could thus say that, in the neo-Gestalt analysis, restructuring as a re-

sult of heuristically guided search is a *bottom-up* phenomenon; without any overall plan, the person works *up* from the information in the problem in the hope of finding a better way of representing the problem. When trying to restructure the Two-String problem, say, by considering the features of the objects lying on the table, the person would not know which objects to examine or how to rethink the description of each. This conclusion follows logically from the notion of impasse: A person at impasse is at a loss. A similar bottom-up process is seen if one tries to find a way to solve the Candle problem, as the neo-Gestalt view proposes (e.g., Ohlsson, 1992), by examining each object in the problem to see if a possible new solution comes to mind. In these examples, the person is not actively doing much to deal with the problem; he or she is simply looking around with no particular purpose in the hope of finding something that might work—again, as the notion of impasse implies. This bottom-up analysis of insight in problem solving can be contrasted with the emphasis on top-down processing in the cognitive-analytic view summarized in Table 6.1.

Studies of Restructuring in Response to Impasse

Knoblich, Ohlsson, and Raney (2001) and Kaplan and Simon (1990) investigated the responses of individuals to impasses during problem solving, looking for restructuring and insight. Knoblich and colleagues used matchstick-arithmetic problems to test Ohlsson's (1992) analysis of restructuring (see Table 6.2). According to their findings, solution of matchstick-arithmetic problems requires that the person carry out *constraint relaxation* and *chunk decomposition*. These are two examples of Ohlsson's notion of loosening of problem constraints. As noted in Chapter 3, matchstick-arithmetic problems clash with constraints imposed by one's experience with equations in ordinary arithmetic. For example, in ordinary arithmetic, individual numerical values cannot be changed—one can only perform the same operations to both sides of any equation. That is, there is a numerical

Table 6.2 Matchstick-arithmetic problems

Problems A and B: Move only one matchstick to produce a true equation.

A. $IV = III + III$ B. $III = III + III$

Solutions:

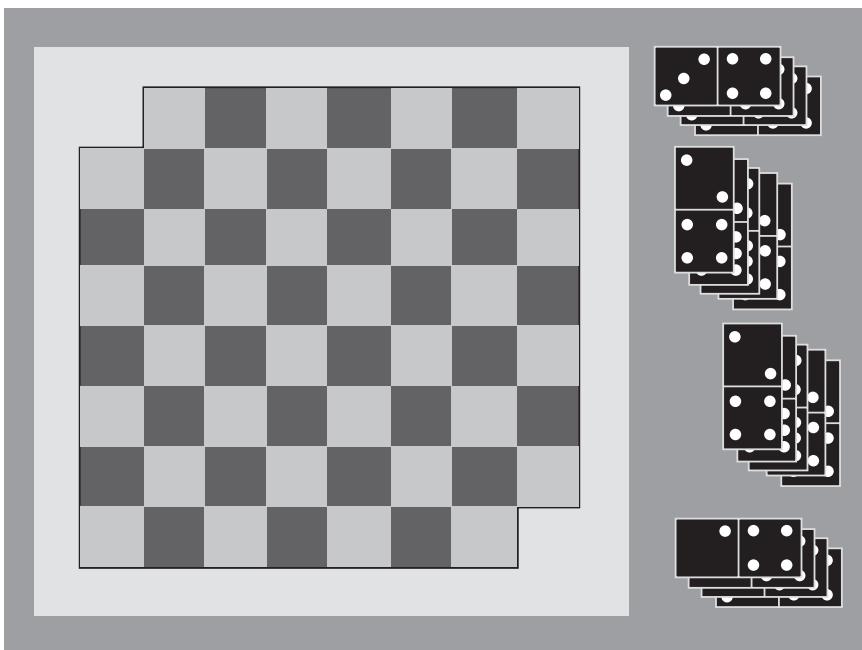
A. Move the “I” on the left to the right side of the “V,” so the equation reads $VI = III + III$.

B. Move one piece from the + sign to make it an = sign, so the equation reads $III = III = III$.

constraint in arithmetic. In matchstick arithmetic, in contrast, one often changes the value of a number on only one side of an equation. Also, in ordinary arithmetic, an operator (e.g., $+$, $-$) cannot be changed arbitrarily (there is an operator constraint), but exactly such a change may be required to solve a matchstick-arithmetic problem.

Knoblich and colleagues (2001) assume that it is harder to relax the operator constraint than the numerical constraint, because the former is wider in its application. Based on that assumption, Knoblich and colleagues made predictions as to the relative difficulty of a set of matchstick-arithmetic problems. When those problems were given to undergraduates, solution rates conformed to predictions, which supports their theory of constraint relaxation and chunk decomposition. This in turn supports the premise that, in response to impasse during a matchstick-arithmetic problem, restructuring occurs along the lines postulated by Ohlsson's (1992) theory. However, it should be noted that Ohlsson's theory predicts that restructuring occurs in response to impasse, but Knoblich and colleagues made no attempt to measure whether impasse actually occurred as their participants tried to solve the matchstick-arithmetic problems. Thus, the results obtained by Knoblich and colleagues actually say nothing about restructuring in response to impasse, and therefore they are only indirectly supportive of Ohlsson's view.

A study by Kaplan and Simon (1990) that used the Mutilated Checkerboard problem (see Figure 6.6) also examined the role of impasse in restructuring. In the Mutilated Checkerboard problem, people initially try to place dominoes in various patterns, but always without success. Thus, the individual will arrive at an impasse, which might lead them to believe that the problem cannot be solved. However, the instructions ask that one *prove* that there is no solution, which mere belief does not accomplish. According to Kaplan and Simon, in order to prove that the problem cannot be solved, one must move away from simply trying to place dominoes in various configurations and restructure the situation in a way that will allow one to move down the path toward the proof. In the Mutilated Checkerboard problem, the piece of information crucial to restructuring the problem involves the notion of *parity*: examining the pairing of the squares to be covered by a domino. When one has a way of pairing the squares (e.g., by coloring them alternately black and white), one sees that removing the two diagonally opposite squares disrupts parity, because both removed squares are of the same color. This leaves 32 black squares and 30 white squares, and, since each domino must cover one square of each color, the problem cannot be solved. Thus, the initial problem representation lacks a crucial piece of information: that pointing to parity.



A standard 8×8 checkerboard has 64 squares. Imagine that you have 32 dominoes; imagine placing them on the board so that one domino covers two horizontally or vertically adjacent squares (not diagonally adjacent squares). It is easy to see that the 32 dominoes will cover all 64 of the squares on the checkerboard. Assume now that two diagonally opposite squares have been removed, leaving 62 squares (see diagram). Now imagine that you have 31 dominoes. Show how those dominoes would cover the remaining 62 squares on the checkerboard, or prove logically that those dominoes cannot cover those remaining squares.

Figure 6.6 Mutilated Checkerboard problem

Kaplan and Simon (1990) collected verbal protocols during their research, which enabled them to determine when their participants reached impasse. They found that people working on the Mutilated Checkerboard problem did not, in response to impasse, discover the importance of parity by themselves. However, when a clue to parity was presented—for example, by directing the participants' attention to the coloring of the squares—it sometimes brought about a restructuring and an Aha! experience. This result supports the idea that consideration of the possible importance of parity in response to impasse might be crucial in developing insight in the Mutilated Checkerboard problem. Once again, however, questions can be raised about the relevance of this result as support of the neo-Gestalt view. Kaplan and Simon postulate that restructuring occurs in response to impasse, but none of their participants restructured the problem until they were given a hint. The overall results therefore do not support the neo-Gestalt view.

of Kaplan and Simon, since a person's reaching impasse did not precipitate bottom-up restructuring.

The Gestalt View: Summary and Conclusions

The research reviewed here in support of the Gestalt view and its neo-Gestalt offspring is summarized in Table 6.3. That support ranged from the classic studies of Köhler (1925) and Duncker (1945) to Scheerer's (1963) influential discussion of the role of fixation in problem solving. Metcalfe (Metcalfe & Wiebe, 1987) has presented evidence that humans can solve laboratory problems in an Aha! experience, and Durso and colleagues (1994) showed that restructuring can occur in problem solving. Evidence of the importance of fixation in problem solving was presented by Jansson and Smith (1991), and support for the idea that insight and analysis are different ways of solving problems was provided by Schooler and colleagues' (1993) demonstration of verbal overshadowing of insight, as well as by the studies of Bowden and Beeman (1998) and of Lavric and colleagues (2000). Finally, studies examining various aspects of the neo-Gestalt view have been carried out by Ormerod and colleagues (2002) and by Kaplan and Simon (1990), and those studies have been only partly supportive of the neo-Gestalt analysis.

Challenges to the Gestalt View

In the years from 1930 to 1980, there was not a great deal of interest in problem solving in mainstream American psychology, which at that time was strongly behavioristic in its orientation. American behaviorism attempted to break down complex situations into their basic stimulus-response (S-R) building blocks, so all complex behavior was analyzed into learning—that is, the establishment of S-R connections. This assumption—that complex behavior was made up of simple building blocks—led many American psychologists away from the study of complex human activities, including problem solving. One exception to this trend was Newell and Simon's (1972) contribution to the development of the cognitive perspective in psychology, which, as was discussed in Chapter 3, began with a focus on problem solving. However, that view had not yet become dominant in the study of cognition. Therefore, essentially by default, the Gestalt view of insight and fixation in problem solving, based on nonanalytic processes analogous to those underlying restructuring in perception, became the dominant perspective. Along with the de facto dominance of Gestalt psychology came the distinction between insight and analysis as separate modes of solving problems. That dichotomy can be seen in present-day discussions of insight, which

Table 6.3 Summary of research supporting the Gestalt theory

Study	Method and results
(A) Köhler (1917)	Insight in animals; based on perception-like processes, not dependent on experience.
(B) Metcalfe (1987); Metcalfe & Weibe (1987)	Feeling-of-warmth judgments showed sudden increase for insight problems versus gradual increase for analytic problems; insight problems solved suddenly.
(C) Durso et al. (1994)	Restructuring in Bartender problem measured by relatedness responses to pairs of words.
(D) Scheerer (1963)	Discussion of fixation in Nine-Dot problem based on square configuration of dots (no experimental results presented).
(E) Duncker (1945)	Functional fixedness: Usual use of object interferes with using it in novel way.
(F) Jansson & Smith (1991)	Design fixation: Presence of example with to-be-avoided features results in those features being included in designs.
(G) Schooler et al. (1993)	Verbal overshadowing of insight: Talking aloud during problem solving interfered with solution of insight problems compared with analytic problems.
(H) Bowden & Beeman (1998)	Hemispheric differences in solving insight problems: Right-hemisphere presentation of cues is better than left-hemisphere presentation.
(I) Lavric et al. (2000)	Working memory and planning in solving insight versus analytic problems. Dual-task design interfered with solution of analytic problems, but not insight. Planning not important in insight.
(J) Ormerod et al. (2002)	Ease of solution of matchstick-arithmetic problems predicted on the basis of breadth of constraint that had to be relaxed.
(K) Kaplan & Simon (1990)	Solution of Mutilated Checkerboard problem was facilitated by pointing out parity cue.

sometimes make a distinction between analytic and creative modes of solving problems (e.g., Ansburg, 2000). Solving a problem through analytic means is assumed to be without creativity, and solving a problem through insight is equated with creative solution. The Gestalt view has thus convinced many people that the only way to think creatively is through the restructuring of a problem, which is independent of logical analysis and experience.

However, during that time of default dominance of the Gestalt view, several findings were published that, from my perspective, raised serious challenges to the Gestalt analysis of restructuring and insight in problem solving (e.g., Fleck & Weisberg, 2004; Harlow, 1949; Perkins, 1981; Weisberg & Alba, 1981; Weisberg & Suls, 1973). Overall, those findings did not have a major effect on theorizing concerning insight, as can be seen by the enduring influence of the Gestalt view and the neo-Gestalt view, which, as we have seen, is the classic Gestalt view in a somewhat different guise. I propose to reconsider those neglected findings and to examine the consequences they hold for our understanding of insight. I will demonstrate that serious questions can be raised about the basic foundations of the Gestalt view. This will lead to the conclusion that an alternative should be considered to the Gestalt and neo-Gestalt views of restructuring and insight.

The remainder of this chapter will then present such an alternative view of insight in problem solving, one that builds on the cognitive-analytic perspective as developed in Chapters 3 and 4, which was summarized in Table 6.1. This view assumes that analytic methods—weak heuristic methods, analogical transfer, and strong methods based on expertise—are critical in solving all problems, and that the application of those methods to a problem can in certain circumstances result in restructuring and an Aha! experience. That is, contrary to the usual assumption that problem solving comes about *either* through analysis *or* through restructuring and insight, I will show that in a number of cases insight and restructuring come about as a result of analysis.

Insight and Experience: Knowledge and Insight in Köhler's Chimps

Köhler (1925) concluded from his classic studies that restructuring and insight were brought about by perception-like processes and that those processes did not depend on the organism's experience. The initial perception of the cube in Figure 6.3A, and its subsequent reversal, do not depend on experience; likewise, the perception of the solution to the Rake problem, for example, where an animal uses a stick to rake in an inaccessible piece of banana, is based on processes that do not depend on experience. In contrast, based on the cognitive-analytic perspective on problem solving, as outlined in Table 6.1, one might expect to see experience playing a critical role in

situations in which animals and people exhibit insight. It is impossible to determine the role of experience in the insight displayed by Köhler's animals, because most of his subjects were not raised from birth in the colony; they had been captured at various ages and brought to the colony. Therefore, there was no information available concerning the experiences they might have had before Köhler began working with them. A set of findings reported by Birch (1945) indicated that those experiences in the wild were critical in the "insightful" performances of Köhler's animals.

Birch (1945) carried out an investigation of problem solving very similar to that of Köhler (1925), except that Birch's animals were raised from birth in captivity, so he was able to control their experiences, especially their experiences handling sticks. Birch's animals that had had no experience with sticks of any sort were not able to solve seemingly simple stick-use problems, even when the objects in the problem were organized in the optimal way. Birch examined Köhler's Rake problem in one of his studies and confirmed that he had all the required elements organized correctly: The animal reaching for the food was able to see the stick extending outside the cage toward the desired food. However, even with that optimum setup of the problem, the animals did not achieve insight; that is, they did not use the stick to rake in the food. Birch tested five animals on the Rake problem. One animal, which had had some experience with sticks, immediately used the stick as a rake. However, three of Birch's four naive animals never thought of using the stick to rake in the fruit. One naive animal did use the stick, but he first by accident pushed the stick while trying to reach the food, causing the stick to move the banana. This accidental discovery stimulated him to attempt to move the banana with the stick, and so he was eventually successful, but it came about by accident. Birch's other naive animals could see no connection between the stick and getting the food.

After those failures on the Rake problem, Birch's animals were returned to their home compound, and sticks were left in the compound by the experimenters. As the animals came across those new objects, they picked them up and began manipulating them, eventually using them as extensions of their arms to poke things. After several days of free play with the sticks, the Rake problem was presented again, and now all the animals quickly solved it. It thus seems that experience using sticks is necessary before an animal will have the insight of using a stick as a rake. Even so seemingly simple a problem as the Rake problem requires analysis that is beyond the capacities of a truly naive animal. The reason that the solution to the Rake problem seems so obvious to us (and to Köhler's apes) may be because we have had extensive experience using sticks as an extension of our arms. That is, one could say that we have expertise here. These results raise questions about the

broadly negative conclusions drawn by the Gestalt psychologists concerning the role of experience in insight in problem solving. A classic study by Harlow (1949), which we will examine next, provides further evidence of the need for problem-specific experience in order to perform with insight even in seemingly simple situations.

Learning Sets and Insight: Positive Effects of Experience on Insight

Harlow's (1949) research examined the ability of monkeys to solve discrimination problems, as shown in Figure 6.7. The problems are extremely simple: One of the two objects always covers a piece of food, and the animal must learn that it will be rewarded when it picks up that object. This situation is called *discrimination learning*, because the animal must learn to discriminate between the two objects when making its choice. Monkeys only gradually learn to pick only the object that covers the food.

The innovative aspect of Harlow's study was to give the animal a series of several hundred discrimination problems. After the animal had learned to pick one object consistently to get a reward, a new problem was presented with a different randomly chosen pair of objects. The underlying solution principle was always the same, however: Food was always under only one of the objects. By the end of that long series of problems, the animals' behavior toward each problem had changed significantly; they now needed only one choice to learn what to do. When a new problem was presented, the animals picked one stimulus; if the food was under it, they picked it consistently from then on. If the food was not under that stimulus, then the animals switched to the other from then on.

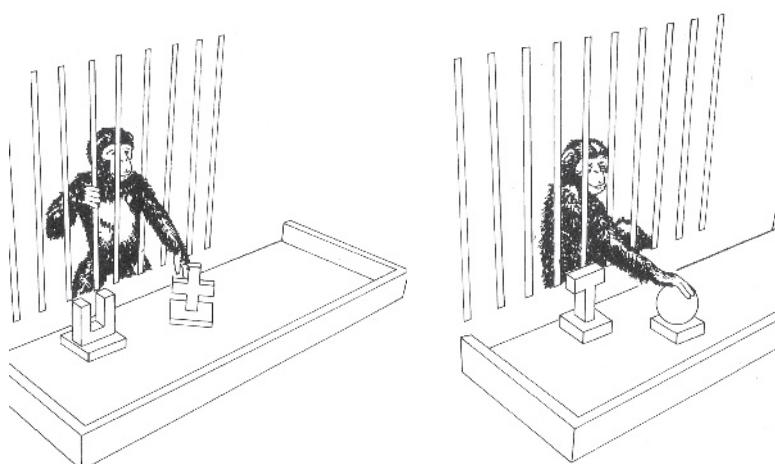


Figure 6.7 Examples of Harlow's discrimination problems

Source: Weisberg (1993).

If you had seen one of those animals at the beginning of the experiment, when it was fumbling its way through a problem, you would have said that it was a "Thorndike animal," behaving on the basis of blind trial and error, with only a gradual strengthening of the correct response. By the end of the experiment, however, one could describe the animals' behavior in Gestalt terms, by saying that they were showing insight into the structure of the problems. Thus, in the same situation, the same animal can behave by trial and error and can also show insight; the crucial element is the large amount of experience needed before insight develops. Once again we see that insight into the structure of even seemingly simple problems may require much knowledge about those problems.

The Role of Analysis and Experience in Failure to Solve the Nine-Dot Problem

As discussed earlier, the concept of fixation was brought forth to explain people's striking inability to solve the Nine-Dot problem (e.g., Burnham & Davis, 1969; Lung & Dominowski, 1985; Weisberg & Alba, 1981). The Gestalt psychologists proposed that fixation on the shape of the square makes the problem impossible to solve (Scheerer, 1963). Solution would be within our grasp if only we could structure the situation in the correct way, by breaking away from the fixation brought about by the shape of the set of dots. In an early test of the Gestalt view of fixation in the Nine-Dot problem, Weisberg and Alba (1981) gave college students the Nine-Dot problem with a hint: In order to solve the problem, they had to draw lines beyond the boundaries of the square. The students were instructed that if the lines were kept within the shape of the square, solution was impossible (see also Burnham & Davis, 1969). Weisberg and Alba assumed, on the basis of the Gestalt view, that if the hint made people think about going beyond the square's boundaries, then restructuring should occur, fixation should be eliminated, and solution should become relatively frequent. In addition, the solution should be produced as an integrated whole, rather than in bits and pieces, as happens when a solution comes about through trial and error.

The go outside hint was not very effective in producing solutions, however (Weisberg & Alba, 1981): Only about 25 percent solved the problem. The hint did result in most people drawing lines beyond the boundaries of the square, so it seemed to have broken the fixation on the square. Furthermore, those people who solved the problem after the hint took an average of more than 11 additional solution attempts to do so, indicating that the solution was not suddenly seen as an integrated whole, as the Gestalt view of restructuring and insight might lead one to expect. In another experi-

ment, Weisberg and Alba (1981) gave undergraduates some practice solving simple connect-the-dots problems, in which they had to draw lines outside the shape defined by the dots (Figure 6.8A). This practice facilitated performance on the Nine-Dot problem, although still only a minority of the participants (46 percent) solved it.

Those results were extended by research carried out by Lung and Dominowski (1985), who also studied the effects of practice and instructions on performance on the Nine-Dot problem. Lung and Dominowski gave participants six practice problems before the Nine-Dot problem, two of which are shown in Figure 6.8B. They also provided what they called *strategy instructions*, shown in Figure 6.8C, which provided information about the logic of constructing a solution. The effects of all this information on performance on the Nine-Dot problem are shown in Figure 6.8D, and here too we find support for the idea that insight depends on more than a simple restructuring of the situation. Both the practice and the strategy instructions were effective in facilitating solution to the target problem, but even with both strategy instructions and six practice problems, only about 60 percent of the participants solved the Nine-Dot problem, and those people still took an average of more than *eight* attempts to do so.

The results of Weisberg and Alba (1981) and Lung and Dominowski (1985) indicate that, for most people, solving the Nine-Dot problem may require a large amount of relevant information. Even with a large amount of relevant information, however, not nearly everyone solves the problem. And when we examine the performance of those who solve the problem, we do not see anything like a sudden Aha! experience, where the solution simply falls into place. Even a relatively knowledgeable person has much difficulty solving the Nine-Dot problem. It seems that in this problem fixation is not simply blocking the solution from occurring.

A recent set of studies on the Nine-Dot problem provides additional information on why it usually is so difficult to solve and points further toward the importance of analytical processes in solving it. MacGregor, Ormerod, and Chronicle (2001) analyzed the problem from a cognitive perspective, looking at heuristic methods that might be applied to it and the planning capacities that are needed to carry out such methods. They assumed that people begin by trying to formulate a solution plan, based on a heuristic whereby each line that one draws should cover as many as possible of the remaining dots. That means that the first line will cover three dots, and the next three lines will cover two. After drawing four lines, one finds that there are still dots left to be covered, and so one fails. In order to solve the problem, one must be able to plan far enough ahead to realize that simply using the *maximum-coverage* strategy is doomed to failure.

A. Weisberg and Alba practice problems



B. Lung and Dominowski practice problems



C. Lung and Dominowski strategy instructions

In order to solve each of these problems, you must extend some of the solution lines beyond the dots; that is, you should not always regard a dot as the place where you stop a line just drawn and where you start a new line. On the contrary, sometimes it is necessary to extend a line beyond the last dot on the line, to a point where you can start a new line connecting other dots. At least one line must end beyond the last dot on the line, and the next line will start beyond the dots on that line.

D. Lung and Dominowski results: Performance on the Nine-Dot problem

Group	Solvers (%)	Mean trials
Strategy + practice	59	8.5
Practice	22	13.4
Strategy	34	18.9
Control	9	19.7

E. MacGregor and colleagues problems

In each problem, connect all the dots with four straight lines (leftmost problem is the Nine-Dot problem).

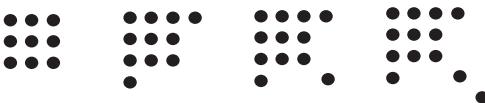


Figure 6.8 Studies of Nine-Dot problem

Source: A, Weisberg and Alba (1981); B, Lung and Dominowski (1985); E, MacGregor, et al. (2001).

MacGregor and colleagues (2001) assume that most people cannot go beyond the maximum-coverage strategy, because doing so would require an ability to imagine the consequences of drawing four lines (which they refer to as a “look-ahead” of four moves). Most people do not have a large enough working-memory capacity to look ahead that far. That is, most people are not able to imagine in advance the consequences of carrying out their chosen strategy, and so they must actually carry it out before they can see that it will not work. MacGregor and colleagues provided support for their view by designing new versions of the Nine-Dot problem, which were structured so that the participant did not have to imagine as many lines in advance (see Figure 6.8E), and under those circumstances solution was much more frequent, a finding that supports their analysis.

The analysis of the Nine-Dot problem by MacGregor and colleagues (2001), if it was pointed in the correct direction, also raises problems for the conclusion drawn by Lavric and colleagues (2000) that planning is not important in solution of insight problems. A recent study by Murray and Byrne (2005) also provided evidence that planning is important in insight: They found that people who performed best on a set of insight problems also performed well on a test of working-memory capacity. Although that study was correlational in design and therefore did not test for the causal influence of working memory on problem solution, the fact that a correlation was found between the two types of performances supports the hypothesis that planning is important in achieving insight.

One potentially interesting piece of information that MacGregor and colleagues (2001) did not obtain was an actual measure of the visual working memory capacities of their participants. People with larger visual working-memory capacities ought to be more likely to solve the Nine-Dot problem in its usual form. A related prediction is that if one could teach people strategies for visualizing, and in so doing increase their visual working-memory capacities, one would expect an increase in solutions of the Nine-Dot problem. Neither of these sorts of studies has been carried out as yet, so for the present the analysis of the Nine-Dot problem proposed by MacGregor and colleagues has received only indirect support, although it may be a promising way to analyze the problem. It is also of note that the analysis of MacGregor and colleagues does not assume that fixation plays a role in making the Nine-Dot problem difficult. Rather, in their view, what makes that problem difficult is that it puts heavy demands on the cognitive capacities of the would-be solver, and most people cannot meet those demands.

The results reviewed so far raise several problems for the Gestalt analysis of insight in problem solving. First, Birch (1945) and Harlow (1949) demonstrated that, even in simple problems, behaving with insight may

be a function of detailed problem-specific knowledge. Performance on the Nine-Dot problem is also greatly affected when individuals are provided with problem-specific information, in the form of practice in solving problems similar to the Nine-Dot problem, or through instructions that provide information relevant to construction of the solution. In addition, the Nine-Dot problem may be difficult not because people are fixated on the square of the dots but because most of us are not capable on our own of carrying out the complex planning that the problem demands.

Analysis as the Basis for Aha! Experiences

Several other studies have presented evidence that analytic processes are involved in production of Aha! experiences and also in bringing about restructuring in problem solving. We now turn to those studies.

Perkins's Studies of Insight

Perkins (1981) showed that one can have an Aha! experience during problem solving as the result of analysis of the problem. He presented the Antique Coin problem (see Figure 6.1C) to individuals, and when someone solved it, Perkins asked him or her to provide what could be called an *immediate retrospective protocol*: The solver was to report immediately after solution on the thought processes that had led up to it. I noted in Chapter 2 that one must be cautious about self-reports as the basis for theorizing about the creative thought process, which raises the question of how Perkins ensured that he could rely on such reports in analyzing insight in problem solving. First, the reports were obtained immediately after problem solution, which means that the probability of error was minimized. Second, the participants were asked to *report* on the thoughts that led up to the solution; they were not asked to *interpret* or *make judgments* about what had happened. As noted in Chapter 3, careful use of such reports does not seem to change the thought processes in any significant way (Ericsson & Simon, 1996). In addition, Perkins gave his participants practice in making those reports, which also helps make them reliable.

As noted earlier, Schoeler and colleagues (1993) have demonstrated *verbal overshadowing of insight*: That is, they found that producing verbal protocols interferes with solution of insight problems. That result would seem to preclude the use of verbal protocols in the study of processes underlying restructuring and insight. Without getting ahead of the logic of the argument, I can point out that the verbal overshadowing effect has been difficult to replicate (Fleck & Weisberg, 2004, 2006), so, for the time being, I will assume that verbal protocols are useful in the study of insight.

Two of Perkins's retrospective reports are presented in Table 6.4. The two

Table 6.4 Perkins's two protocols on Antique Coin problem (Perkins, 1981)

Abbott
1. Couldn't figure out what was wrong after reading through once.
2. Decided to read problem over again
3. Asked himself, do architects dig up coins? Decided yes.
4. Asked himself, could the problem have something to do with bronze? Decided no.
5. Saw the word <i>marked</i> . This was suspicious. <i>Marked</i> could mean many different things.
6. Decided to see what followed in the text.
7. Saw 544 B.C. (Imagined grungy coin in the dirt; had an impression of ancient times.)
8. Immediately realized—"it snapped"—that B.C. was the flaw.
Binet
1. Thought perhaps they didn't mark coins with the date then.
2. Thought they didn't date at all—too early for calendar. (Image of backward man hammering 544 on each little bronze coin.)
3. Focused on 544 B.C.
4. Looked at B.C.
5. Realized "B.C.—that means Before Christ."
6. Rationalized that it couldn't be before Christ since Christ wasn't born yet.
7. Saw no possible way to anticipate when Christ was going to be born.
8. Concluded "Fake!"

people solved the problem differently, with one (whom Perkins called Abbott) reporting that the solution "just snapped" together in a small Aha! or leap of insight; the other (Binet) worked out the solution through analysis, in a series of steps. In other words, Binet solved the problem through the weak method of reasoning through the information and what it implied—an analytic process. When Perkins examined the reports further, however, he concluded that the thought processes carried out by Abbott and Binet were in actuality very similar, which raised the possibility that Abbott's leap of insight was also the result of an analytic thinking process. First, both Abbott and Binet focused on, or *recognized*, the date as the crucial piece of information. Second, Abbott's "leap" turns out to have required only a couple of steps of reasoning on Binet's part; that is, the insight process turns out not to have done much cognitive work. What was required was that the thinker *realize* the contradiction in the coin maker's knowing that Christ would be born at some later date. Perkins pointed out that we often experience such realizations in our ordinary cognitive activities. For example, when you discuss politics with a friend with whom you differ, you and your

friend may occasionally catch each other in contradictions as each tries to explain the policies of a favored candidate. One of you may ask, “How will your candidate be able to carry out all those new policies and still reduce taxes? Isn’t there a contradiction there?”

Thus, one can understand Abbott’s ostensible leap of insight as an example of the analytic process of realizing that something is impossible; the suddenness of that realization brought with it an Aha! experience. Perkins concluded that it was not necessary to assume that leaps of insight are brought about by anything beyond what we can call ordinary analytic thought processes. Sometimes we use *reasoning* in order to work out the consequences of some state of affairs, and other times we can *realize* the consequences directly, without reasoning anything out. As a parallel situation, Perkins points to our understanding of jokes: Sometimes we get a joke directly, as we hear the punch line, whereas other times we have to have the logic of the joke explained to us. Getting a joke as we hear it involves realization of the same sort that plays a role in leaps of insight. Perkins’s findings and theorizing present a challenge for the Gestalt view that solutions to insight problems are brought about through a mechanism that is basically different from that involved in more ordinary analytical thinking, because he demonstrated that the insights involved in problem solving might be the result of small analytic steps rather than large perceptually based leaps.

More recently, Perkins (e.g., 2000) seems to have changed his perspective on the thinking processes involved in achieving insight as indexed by solution of insight problems. He has proposed that analytic problems are “reasonable” problems, since they can be solved through reasoning and other analytic methods. Insight problems, in contrast, are “unreasonable,” because they cannot be solved using conventional reasoning. One must, in Perkins’s view, approach such problems (and, presumably, real-world situations that demand insight) using “breakthrough” thought processes, those that can deal with the unique structure of insight problems. Details of Perkins’s analysis are presented in Perkins (2000).

It is also noteworthy that the participants who provided the protocols in Table 6.4 were able to solve the Antique Coin problem without reaching an impasse and without restructuring the problem. This result can make us sensitive to the need for detailed analysis of a problem situation before we draw firm conclusions about the underlying cognitive processes. If a researcher had based an analysis of the Antique Coin problem on the presence or absence of an Aha! experience (using Metcalfe’s [1987] feeling-of-warmth ratings, say), he or she would have concluded, ipso facto, that Abbott solved the problem through restructuring and that analysis was not involved. However, more detailed examination of the information avail-

able in the protocols indicates that such a conclusion would be mistaken. Thus, any inferences that one draws concerning processes underlying the solution of problems depend critically on the sensitivity of the measures one has used to assess performance. In order to conclude, for example, that restructuring has occurred during solution of a problem, it is necessary to go beyond simply measuring time to solve the problem and even, as we have just seen, measuring the presence or absence of an Aha! experience. Weisberg (1995) has discussed in more detail the difficulty of determining the processes involved in solving a given problem, as well as the related difficulty of determining whether a given problem is solved through insight or analysis.

Further Evidence for Analytic-Based Solution of Insight Problems

In support of Perkins (1981), Fleck and Weisberg (2006) provided additional evidence that insight problems—specifically, the Triangle problem (Figure 6.1D)—can be solved through application of weak methods, without restructuring. A large majority of participants tested by Fleck and Weisberg solved the problem, often through one of two types of heuristically based analysis. Some solved it through *numerical analysis*, saying something like this: “The rows now have four, three, two, and one coins. How can I change it so that they will have one, two, three, and four? I can’t move three coins from the top row, because that will not produce what I need. Maybe I can move two coins from the top, but where should they go? The row with two coins could take two more. . . .” This line of reasoning resulted in several solutions. These people were using logical analysis to try to deduce the solution from the information given in the problem, combined with a hill-climbing strategy, in which they tried to change the current problem state into one that was closer in appearance to the goal.

Other people solved the Triangle problem through what one could call *perceptual analysis*. They moved one or two coins, considering carefully the results of each move (see Figure 6.9), also in a hill-climbing strategy, but not one based on counting. Moving the end coins from the top row down to the third row, for example, results in most of the triangle being pointed up, with a single coin under the base of the new triangle, and the solution was then easily seen. These people did not talk in the same way about what they were doing; they seemed to be *looking* at the outcomes of the moves they made, trying to see what could be done next. They were using what one could call a *visual* hill-climbing heuristic (see Chapter 3): They made a move that seemed to transform the situation closer to the goal, and they then looked at the new situation carefully to determine whether it opened any further opportunities. The numerical-analysis people, in contrast, were

The Question of Insight in Problem Solving

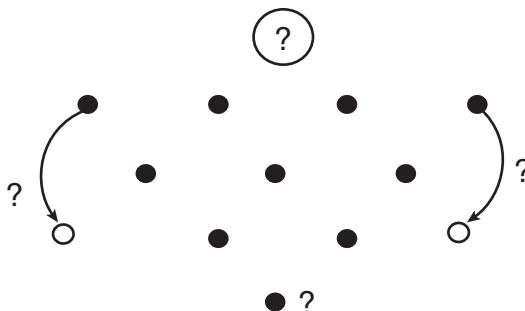


Figure 6.9 Perceptual analysis of Triangle problem (see text for explanation)

counting and using logical analysis based on the results of that counting to determine what the next move should be.

Fleck and Weisberg (2006) thus provided additional evidence that problems usually considered insight problems can be solved on the basis of heuristic methods. In addition, those solutions can come about without restructuring of the problem, as was also found by Perkins (1981). Fleck and Weisberg found that more than one type of heuristic was used in solving the Triangle problem. It is also interesting to note that none of the people who solved the Triangle problem had an Aha! experience in doing so. This may be because they were working gradually toward the solution, using analytic methods, so when the solution came about there was no surprise, and therefore no Aha! occurred.

Analytic Methods in Solving Insight Problems without Restructuring: Conclusions

We have seen support for the theory that the solution of insight problems can come about without restructuring, through the use of weak heuristic methods. Sometimes, even though no restructuring occurs, weak heuristic methods may produce surprising solutions, which are accompanied by Aha! experiences (Perkins, 1981). Thus, the occurrence of an Aha! experience is not conclusive evidence that a problem was solved through a nonanalytic process that brought about restructuring and insight.

Restructuring and Insight Based on Analysis

Perkins (1981) and Fleck and Weisberg (2006), by studying the Antique Coin and Triangles problems, respectively, found that solution and Aha! experiences could be brought about through analytic processes—that is, weak methods. A supporter of the Gestalt view might object that those findings are not relevant to the issue of insight in problem solving. That is,

if weak methods were used to solve those problems without restructuring, then the problems are not true insight problems and are not of interest in the present context, Aha! experiences or not. Therefore, in order to draw strong firm conclusions about the role of analytic processes in insight, we must turn to problems that are solved as the result of restructuring (Weisberg, 1995). One such problem is the Candle problem (Figure 6.1B; Weisberg, 1980, 1995): In attempting to solve this problem in response to the instructions, almost everyone begins by contemplating or actually trying to glue the candle to the wall using melted wax as an *adhesive*, or trying to attach the candle directly to the wall using the tacks. They may then switch to using the tack box as a *shelf* for the candle. Such a switch in method is an example of restructuring (see Ohlsson, 1992; Weisberg, 1995).

Similarly, in the Trees problem (see Figure 6.1E), a person reading the problem sees “10 trees in *five rows with 4 trees in each*” and immediately thinks of a 5×4 matrix. On trying to carry out that solution, one sees that such a configuration must be incorrect, because there are only 10 trees, so restructuring occurs: The person begins to consider other possible configurations for the trees. Thus, examination of the details of the solution process in the Candle problem and the Trees problem should provide evidence concerning the relevance of analytic methods in restructuring in problem solving. Contrary to the Gestalt view, research has shown that restructuring in both the Candle and Triangle problems can occur as a result of analytic processes (Fleck & Weisberg, 2004, 2006).

Analytic Processes in Restructuring in the Candle Problem

The cognitive-analytic perspective assumes that all problem solving begins with an attempt to match the problem as it is presented with information in memory (see Table 6.1; Fleck & Weisberg, 2004, 2006; Weisberg, 1980; Weisberg & Suls, 1973). The instructions in the Candle problem ask that the person attach the candle to the wall. As a first step in solving the problem, therefore, people will search their knowledge about attaching things to walls in order to determine what to do to meet the demands of the problem. Thus, the box is not used in people’s initial solutions because the instructions ask for types of solutions that do not involve it. One does not have to invoke additional theoretical concepts, such as fixation in the form of functional fixedness, to explain why the box is not used initially to solve the problem; one simply has to consider how a rational person facing the Candle problem would try to solve it, based on what the problem asks for.

Turning to the factors that bring about restructuring and box use, we find that several studies (Fleck & Weisberg, 2004; Weisberg & Suls, 1973) have provided evidence that use of the box occurs in response to difficulties that

arise when people attempt to carry out the initial attaching solutions in response to the demands of the problem. For example, the candle may be too heavy for wax-glue to hold up, or the tacks may be too short to penetrate the candle completely and thus unable to hold it up. The person must then either try to fix the solution or look for another way to hold up the candle. At this point, he or she may contemplate ways to hold objects in general, or candles in particular, on a wall, which may lead the person to think about making a shelf or candleholder of some sort, which can lead to use of the box. This is an example of *restructuring* (Ohlsson, 1992)—the goal is changed—resulting from *analytic* processes: The person is trying to deal with inadequacies in a solution, and information from those inadequacies stimulates further analysis of the problem, which in turn leads to another way of looking at the problem.

One interesting finding emanating from the study of the Candle problem is that use of the box as a shelf or holder for the candle is inversely related to the size of the fasteners presented in the box (Weisberg & Suls, 1973). If the box is presented with small tacks in it, it is emptied and used to hold up the candle more frequently than when it is presented holding long tacks. Based on Duncker's (1945) functional-fixedness explanation of failure to use the box, such a result is hard to understand. Since the box is being used as a container in both conditions, functional fixedness should occur equally in both, and the box should not be used more frequently in one case than the other. According to the cognitive-analytic view, on the other hand, the use of the box as a holder or shelf for the candle comes about because an initial attaching solution is found to be inadequate. When the tacks are small relative to the candle, people's knowledge about the way in which tacks are used should result in a higher chance of rejection of the tack solution. This should increase the chances that the box will be called upon as a shelf or holder for the candle. Thus, the relationship between box use and size of fasteners can be understood in a straightforward way from the cognitive-analytic perspective.

We have just reviewed several findings that support the idea that restructuring in the Candle problem comes about through analytic processes, which are set in motion in order to deal with inadequacies in solutions arising in response to the demands of the problem. Similar results have arisen from study of the Trees problem (Figure 6.1E), which is also solved through restructuring, as we see in the next section.

Restructuring Based on Analysis in the Trees Problem

Fleck and Weisberg (2006) found that only a small minority of their participants solved the Trees problem; however, all did so through analy-

sis. They restructured the situation through logical reasoning: Either they deduced that the solution could not be a rectangular 5×4 matrix (only 10 trees are available), or they tried to form such a matrix and then realized that they did not have enough trees. They then deduced that trees must be counted more than once, and from that they deduced that the lines in the solution configuration could not be parallel. They then tried different shapes that fit those criteria (e.g., a triangle, a trapezoid, etc.), determining for each whether the configuration of trees was correct, until they constructed a five-pointed star and solved the problem. In solving the problem, those people used a very simple heuristic: trial and error (Newell & Simon, 1972). They went through shapes more or less randomly until, essentially by accident and without any anticipation of success, they tried to construct a star, which brought solution. Those people thus solved an insight problem by first restructuring the problem, but the solution was ultimately produced through the weakest of the weak methods, trial and error.

In addition, when participants solved the Trees problem as the result of their more or less laborious trial and error, they did not have an Aha! experience, probably because the solution brought with it little surprise or excitement. Since they knew the general method they were working on, and since the solution came out of one variant on that method, there was no reason for an Aha! reaction. It is interesting to note that most of those who did not solve the Trees problem made partial progress toward the solution, based on the same processes. Those individuals too realized that the solution could not be a rectangular matrix and that trees had to be counted in more than one line, and they also constructed patterns with lines that were not parallel. However, the difference between them and the people who solved the problem was that the nonsolvers did not hit upon the correct shape. An example of a partial solution is shown in Figure 6.10.

Fleck and Weisberg's (2006) examination of the Trees problem demonstrates that weak analytic methods can result in the restructuring of a prob-

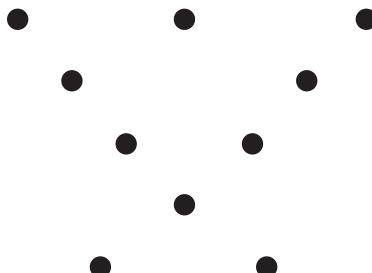


Figure 6.10 Partial solution to Trees problem

lem. In the Trees problem, furthermore, restructuring simply set the stage for solution by the weak method of trial and error, and no Aha! experiences were observed. Therefore, the lack of an Aha! experience during problem solving does not mean that restructuring has not occurred. Examination of the Trees problem also indicates that, as in the Candle problem, solving an insight problem through restructuring does not mean that solution has come about through nonanalytic processes.

Top-Down Processes in Restructuring Based on Analysis

We have concluded that the use of restructuring in solving a problem can be brought about as a result of the person's attempting to repair difficulties that have arisen in a proposed solution. Such a conclusion is another way of saying that the person is using his or her knowledge to deal with a newly discovered problem or difficulty: that is, with the weakness in the proposed solution. This behavior is an example of the top-down control of problem solving by the person's knowledge. As discussed in earlier chapters, top-down processing is seen when one's concepts direct one's activities, and that is what we have seen in the examples of analytic-based restructuring discussed in this section. The problem solvers used what they knew about the objects in the problems in order to make judgments about the adequacy of solutions that they thought of, as well as to determine how inadequacies in those solutions might be dealt with.

An Elaboration of the Cognitive-Analytic Model to Deal with Restructuring and Insight

There is no question that solving a problem in a leap of insight is subjectively very different from solving one through analysis, such as one does when working through the Towers of Hanoi or Missionaries and Cannibals problem (see, e.g., Metcalfe & Wiebe, 1987). Those differences in subjective experiences are part of the reason that many psychologists believe that distinctly different processes play a role in solving a problem through insight versus analysis. However, different subjective experiences do not necessarily imply different underlying cognitive processes. To counter the assumption that insight and analysis are two distinct modes of solving problems, I have proposed that the restructuring of a problem and the subjective experience of insight that may accompany it (the Aha! experience) are the outcome of the same analytic processes (i.e., weak heuristic methods, analogical transfer, application of expertise) that we have already extensively discussed in examining the cognitive perspective on problem solving in Chapters 3 and 4.

Table 6.5 Cognitive-analysis perspective: Stages in solving a problem through analysis, including restructuring arising from analysis

<p>Stage 1: Solution through application of strong methods</p> <ol style="list-style-type: none"> 1. Problem presented \Rightarrow attempt to match with knowledge <ol style="list-style-type: none"> A. No solution available \Rightarrow Stage 2 B. Successful match with knowledge \Rightarrow transfer solution based on analogy or expertise C. If solution transfers successfully \Rightarrow problem solved (problem is familiar \Rightarrow no Aha!) D. If solution fails, but new information arises \Rightarrow Stage 3 E. If solution fails and no new information arises \Rightarrow Stage 2 <p><i>Comment:</i> If no match is made with memory, person goes to Stage 2; if match is made, solution is attempted. Can result in direct solution of the problem; no restructuring. New information arising from unsuccessful solution leads to Stage 3.</p>
<p>Stage 2: Solution through application of weak methods</p> <ol style="list-style-type: none"> 2. Failure at Stage 1A \Rightarrow analysis based on weak methods <ol style="list-style-type: none"> A. Analysis successful \Rightarrow solution B. No solution \Rightarrow impasse; problem not solvable <p><i>Comment:</i> Person works through problem using weak heuristic methods, trying to develop solution; if successful, problem solved without restructuring; however, Aha! is possible.</p>
<p>Stage 3: Restructuring based on analysis—repairing a failed solution</p> <ol style="list-style-type: none"> 3. Attempt to match with knowledge any new information from failure at Stage 1C <ol style="list-style-type: none"> A. New match with knowledge \Rightarrow new method (restructuring). If new method leads to solution \Rightarrow problem solved B. If new method leads to failure, but more new information arises from the failure \Rightarrow Stage 3A. C. If new method fails and no new information arises \Rightarrow impasse; problem not solvable <p><i>Comment:</i> Restructuring based on feedback from problem; Aha! possible.</p>

The cognitive-analytic perspective on problem solving outlined in Table 6.1 can be directly extended to deal with the findings on restructuring and insight that we have discussed in the last few sections; those are findings that, as we have seen, raise problems for the Gestalt view. An expanded version of the model is presented in Table 6.5; additions to the model that deal with the findings concerning restructuring and insight are presented

in **boldface**. The additions to the model are straightforward: If in Stage 1 an unsuccessful solution results in the acquisition of some new information by the individual (Stage 1D), he or she then uses that information as the basis for a new attempt to solve the problem, in Stage 3. The process begins again: A new memory search is carried out, with the difficulty from the unsuccessful solution having become a new problem to solve. This new information can lead to top-down restructuring of the problem and to its solution from a new perspective, so once again the person can stop. If no new information arises from the failed solution (Stage 1E), then the person would try to solve the problem through the application of weak methods (Stage 2). Again, if Stage 2 fails, the model as outlined in Table 6.5 assumes that person is at an impasse and has failed to solve the problem. In this way, the cognitive-analytic perspective on insight, as outlined in Table 6.5, enables us to understand the major findings on problem solving that we have discussed in this chapter and in the previous two, including restructuring and insight.

The discussion of Stage 3 in Table 6.5 makes explicit the important role that *evaluative processes* play in problem solving. That is, the restructuring that comes about at that stage is set in motion by the person's realization that a solution attempt is not working. Evaluative processes are also seen in Stages 1 and 2 of the model. The role of evaluation in problem solving has been studied in larger-scale problem-solving environments by Mumford and colleagues (see, e.g., Lonergan, Scott, & Mumford, 2004; Mumford, Baughman, & Sager, 2003).

Bottom-Up Restructuring in Response to Impasse

There is one further situation that is potentially important enough to bear discussion: the possibility of heuristic-based bottom-up restructuring in response to impasse, as proposed in the neo-Gestalt view by Kaplan and Simon (1990) and by Ohlsson (1992). It was just noted in the discussion of the elaborated cognitive-analytical model in Table 6.5 that situations will arise in which a person reaches an impasse (Stage 2B and Stage 3C). As discussed earlier, the neo-Gestalt view places much emphasis on the role of impasse as a stimulus to bottom-up restructuring. We examined earlier research support for the neo-Gestalt view and saw that that support was not very strong. Additional evidence supports that skepticism toward the neo-Gestalt bottom-up analysis of restructuring. In their study of the details of the solution process in the Candle problem, Fleck and Weisberg (2004) were able to examine directly the role of impasse in restructuring and production of the box solution. They first determined whether each person working on the problem reached impasse, by analyzing the comments that

he or she produced. Comments such as “I haven’t got the slightest idea of what to do” and “I am at a complete loss,” as well as repetitions of the same unsuccessful solution attempt several times, were taken as evidence of impasse. Fleck and Weisberg found that most of the people who restructured the problem and solved it using the box had not reached impasse first. As already discussed, those individuals restructured the problem in a top-down manner, as a result of attempts to repair inadequacies found in their initial attaching solutions. The box solution resulted from a restructuring of the problem, but no impasse had occurred; those box solvers never stopped working on the problem. In addition, the few people who did reach impasse on the problem were less likely to restructure the problem than were people who did not reach impasse.

However, Fleck and Weisberg (2004) found that a small number of people working on the Candle problem did, in response to reaching impasse, carry out bottom-up restructuring that led to solution of the problem. For example, one person first tried to attach the candle to the wall using tacks, and succeeded in doing so after using the tacks in combination with wax-glue obtained by melting the candle. She was then asked if she could produce another solution, but she was unable to think of anything else, meaning that she had reached impasse. In response to a further request by the experimenter that she try to think of something else, she said, “Okay, what objects have I not yet used? Can I use the box from the tacks? Maybe I can.” Thus, she restructured the problem from the bottom up, in the neo-Gestalt manner, by examining objects she had not thought about earlier in an attempt to find something new that she could do.

In examining research relevant to impasse-driven heuristic-based restructuring, it is notable that impasse seems to be much less important to insight than the Gestalt psychologists and the neo-Gestaltists (Kaplan & Simon, 1990; Ohlsson, 1992) assumed it to be. Several studies have shown that impasse is neither a necessary nor a sufficient condition for the occurrence of restructuring in problem solving. However, Fleck and Weisberg (2004) have shown that restructuring can occur in the Candle problem in response to impasse. Since we therefore have some evidence that impasse can stimulate bottom-up restructuring and insight, for the sake of completeness, a further elaboration on the cognitive-analytic model is necessary. The final model is presented in Table 6.6, with bottom-up heuristic-based restructuring in response to impasse added as Stage 4. New components are in **bold**. It should be relatively easy to work through the implications of the model. With this model, we can understand all the major phenomena associated with insight in problem solving, and we can do so with a set of assumptions that is consistent with the cognitive-analytic perspective developed in Chapters

The Question of Insight in Problem Solving

Table 6.6 Cognitive-analysis perspective: Stages in solving a problem through analysis including bottom-up restructuring in response to impasse

<p>Stage 1: Solution through application of strong methods</p> <ol style="list-style-type: none">1. Problem presented \Rightarrow attempt to match with knowledge<ol style="list-style-type: none">A. No solution available \Rightarrow Stage 2B. Successful match with knowledge \Rightarrow transfer solution based on analogy or expertiseC. If solution transfers successfully \Rightarrow problem solved (problem is familiar \Rightarrow no Aha!)D. If solution fails, but new information arises \Rightarrow Stage 3E. If solution fails and no new information arises \Rightarrow Stage 2
<p><i>Comment:</i> If no match is made with memory, person goes to Stage 2; if match is made, solution is attempted. Can result in direct solution of the problem; no restructuring.</p>
<p>Stage 2: Solution through application of weak methods</p> <ol style="list-style-type: none">2. Failure at Stage 1A \Rightarrow analysis based on weak methods<ol style="list-style-type: none">A. Analysis successful \Rightarrow solutionB. No solution \Rightarrow impasse \Rightarrow Stage 4
<p><i>Comment:</i> Person works through problem using weak heuristic methods, trying to develop solution; if successful, problem solved without restructuring; however, Aha! is possible.</p>
<p>Stage 3: Top-down restructuring based on analysis—repairing a failed solution</p> <ol style="list-style-type: none">3. Attempt to match with knowledge any new information from failure at Stage 1C<ol style="list-style-type: none">A. New match with knowledge \Rightarrow new method (restructuring). If new method leads to solution \Rightarrow problem solved.B. If new method leads to failure, but more new information arises from the failure \Rightarrow Stage 3AC. If new method fails and no new information arises \Rightarrow impasse \Rightarrow Stage 4
<p><i>Comment:</i> Restructuring based on feedback from problem; Aha! possible.</p>
<p>Stage 4: Bottom-up restructuring in response to impasse</p> <ol style="list-style-type: none">4. Impasse \Rightarrow “switch when stuck?”<ol style="list-style-type: none">A. If bottom-up restructuring leads to new information \Rightarrow Stage 3B. If no new information \Rightarrow stop
<p><i>Comment:</i> Attempt to acquire new information from bottom up, through re-encoding, elaboration, and constraint relaxation; may result in restructuring; and perhaps Aha!</p>

2–4 to deal with research on problem solving and creativity. Furthermore, we can incorporate the cognitive-analytic and the neo-Gestalt views into one single overarching model, which indicates that the two views are not antagonistic but, in some ways at least, complementary.

A Critical Reexamination of Evidence in Support of the Gestalt View

We have seen that several critical findings (e.g., Birch, 1945; Fleck & Weisberg, 2004, 2006; Harlow, 1949; Perkins, 1981) challenge the Gestalt view. Furthermore, there is positive support for the cognitive-analytic alternative to the Gestalt view, as presented in Table 6.6. Therefore, it will be useful at this point to explicitly reexamine all the research that was presented earlier in support of the Gestalt view, some of which has already been brought into question. There are findings presented earlier that not only seem to support the Gestalt view but also seem to conflict with the cognitive-analytic perspective. The final task of this chapter is to reexamine those findings to demonstrate that they do not unequivocally support the Gestalt view and do not conflict with the cognitive-analytic view. Table 6.7 summarizes the research presented earlier as support for the Gestalt view. In the last column are comments summarizing the challenges that have already been raised (see rows A, D, and E in Table 6.7). Now I turn to a critical review of the remaining research presented in support of the Gestalt view.

Restructuring During Problem Solving

Durso and colleagues (1994; Table 6.7C) studied restructuring in the Bartender problem by using people's ratings of the relatedness of pairs of words that played different roles in the problem (Figure 6.4). Some pairs ("insight pairs") changed significantly in their relatedness as the problem was solved, which indicated that the structure of the problem had changed. Those results are potentially important, and they point the way to the study of restructuring in other problems. However, those results do not conflict with the cognitive-analytic view, because Durso and colleagues did not collect verbal protocols in order to analyze the details of the solution process. Therefore, we do not know how the restructuring was brought about: It could have been the result of analytic processes. As we have discussed in detail, weak and strong analytic processes can produce restructuring. The results of Durso and colleagues are thus interesting as a demonstration of restructuring, but they tell us nothing about the processes through which restructuring comes about.

Table 6.7 Critical review of research supporting Gestalt theory

Study	Method and results	Critique
(A) Köhler (1917)	Insight in animals; based on perception-like processes, not dependent on experience.	Studies have demonstrated that insight, including insight demonstrated by Köhler's animals, depends on problem-specific experience (Birch, 1945; Harlow, 1949).
(B) Metcalfe (1987); Metcalfe & Weibe (1987)	Feeling-of-warmth judgments showed sudden increase for insight problems versus gradual increase for analytic problems; insight problems solved suddenly.	Metcalfe never measured whether restructuring occurred. Aha! can occur without restructuring (Fleck & Weisberg, 2004, 2005; Perkins, 1981); therefore, feelings of warmth do not necessarily support Gestalt view.
(C) Durso et al. (1994)	Restructuring in Bartender problem measured by relatedness responses to pairs of words.	No analytic problems were studied; so it is not clear that effect is limited to insight. Restructuring occurred gradually. No fine-grain analysis of solution processes was carried out, so we do not know how restructuring came about; it might have come about through analysis.
(D) Scheerer (1963)	Discussion of fixation in Nine-Dot problem based on square configuration of dots (no experimental results presented).	Studies have demonstrated that performance on problem can be facilitated by experience solving connect-the-dot problems (Lung & Dominowski, 1985; Weisberg & Alba, 1981). Difficulty may be due to loads that the problem places on planning capacity (Ormerod et al., 2002).
(E) Duncker (1945)	Functional fixedness: Usual use of object interferes with using it in novel way.	Studies of the Candle problem indicate that restructuring leading to box use comes about through analytic processes.
(F) Jansson & Smith (1991)	Design fixation: Presence of example with to-be-avoided features results in those features being included in designs.	Chrysikou & Weisberg (2005): "Defixation" instructions eliminated design-fixation effects. People were able to ignore presented example. No fixation was found.

(continued)

Table 6.7 (continued)

Study	Method and results	Critique
(G) Schooler et al. (1993)	Verbal overshadowing of insight: Talking aloud during problem solving interfered with solution of insight problems compared with analytic problems.	Fleck & Weisberg (2004, 2005) did not find verbal overshadowing in two attempts to replicate the study of Schooler et al.
(H) Bowden & Beeman (1998)	Hemispheric differences in solving insight problems: Right-hemisphere presentation of cues is better than left-hemisphere presentation.	No analytic problems were studied; not clear that the effect is limited to insight. No fine-grain analysis of solution processes carried out; solution might have come about through analysis.
(I) Lavric et al. (2000)	Working memory and planning in solving insight versus analytic problems. Dual-task design interfered with solution of analytic problems, but not insight. Planning not important in insight.	Insight problems were visual in nature, analytic problem was verbal: Differential interference might have been due to verbal nature of secondary task. Other studies (e.g., Fleck & Weisberg, 2004, 2006) indicate that planning is important in restructuring and insight.
(J) Ormerod et al. (2002)	Ease of solution of matchstick-arithmetic problems predicted on the basis of breadth of constraint that had to be relaxed.	No evidence that participants reached impasse; only solution/non-solution was measured. Therefore, results do not necessarily support neo-Gestalt view.
(K) Kaplan & Simon (1990)	Solution of Mutilated Checkerboard problem was facilitated by pointing out parity cue.	Participants did not discover importance of parity on their own, so, without hints, no restructuring occurred. Therefore, results support the importance of parity in solution of Mutilated Checkerboard problem, but they do not support neo-Gestalt prediction that restructuring occurs in response to impasse.

Design Fixation

The design fixation results of Jansson and Smith (1991; Table 6.7F) were intriguing because people who had been told to avoid negative aspects of examples nonetheless included those aspects in their supposedly improved designs. That seems to be as strong an example of fixation as one could imagine. However, Chrysikou and Weisberg (2005) found that design fixation could be wiped out if the participants were given “defixation” instructions, which were formulated to make explicit to the participants that they were to avoid incorporating in their designs the problematic aspects of the example designs. Once that was made clear, we found that people did not exhibit any fixation on the examples. We concluded that one reason Jansson and Smith found fixation on the examples was because they tested their participants in groups, which made it difficult for the experimenters to ensure that the participants completely understood the task and what they were being asked to do. We tested people individually, which made it easier to ensure that they knew exactly what we meant when we described certain aspects of the examples as problematic and to be avoided. Thus, we found no support for the pervasive fixation effects reported by Jansson and Smith (1991).

Verbal Overshadowing of Insight: Failure to Replicate

Verbal overshadowing of insight—the interference with insight that occurs when people produce verbal protocols—reported by Schoeler and colleagues (1993; Table 6.7G) has been taken as support for the theory that different thinking processes are at work in insight versus analytic problems. Presumably, that interference occurs because insight is brought about through processes whose outcomes are not amenable to verbalization. However, recent research has not been successful in replicating the verbal overshadowing results. The studies by Fleck and Weisberg (2004, 2006) already mentioned also examined the possible occurrence of verbal overshadowing of insight. Fleck and Weisberg tested 110 undergraduates on a randomly ordered set of insight problems: the Candle, Lilies, Necklace, Socks, Trees, and Triangle problems (Figure 6.1). Participants were randomly assigned to a verbalization condition or nonverbalization control condition; all sessions were videotaped to provide a record for later analysis. No significant support was found for verbal overshadowing of insight; for no problem did we find significantly fewer solutions in the verbalization condition. We carried out several additional analyses on each problem to see if there might have been more subtle differences between verbalization and nonverbalization conditions: We analyzed time taken to solve the problem, total number of solutions produced, total number of different solutions produced, and so

Table 6.8 Fleck and Weisberg verbal overshadowing results: Proportion of participants solving each condition

Problem	Proportion solving nonverbalization condition	Proportion solving verbalization condition
Analytic problems		
Balance	.50	.48
Crime	.77	.71
Cards	.64	.67
Mean proportion: analytic	.64	.62
Insight problems		
Triangle	.68	.67
Antique Coin	.36	.29
Prisoner	.41	.57
Mean proportion: insight	.48	.51

Source: Fleck and Weisberg (2006).

forth, and in no case did we find any differences between the verbalization and nonverbalization conditions. (See Table 6.8.) Those negative results raise questions about the occurrence of verbal overshadowing, and ipso facto they raise questions about whether insight-based and non-insight-based problems are solved through different thought processes.

Hemispheric Differences in Insight

Bowden and Beeman (1998; Table 6.7H) found that verbal insight problems were solved more efficiently when the cues were presented to the right hemisphere of the brain rather than the left. They interpreted that finding as evidence for insight as a distinct process. Here too questions can be raised about such a conclusion. First of all, the researchers examined only insight problems; no analytic problems were tested, so one cannot conclude that the hemispheric difference they found is unique to insight problems. In addition, Bowden and Beeman did not carry out a detailed analysis of solution processes, so we do not know how those solutions were brought about. It is entirely possible that the right-hemisphere facilitation was brought about through analysis.

No Planning in Insight

Lavric and colleagues (2000; Table 6.7I) studied the role of working memory in problem solving and demonstrated that attempting to carry out a second task interferes with solution of analytic problems but not insight

problems. They took that result as evidence that planning plays no role in insight. There are a number of reasons to question that conclusion. First of all, we have seen from the discussion of research relevant to the cognitive-analytic view that much planning occurs when people try to solve insight problems. For example, in attempting to solve the Candle problem, people first consider whether they can attach the candle to the wall using the tacks or wax-glue. That is, they plan that solution, which may lead them to question whether it will work. Similarly, in the Triangle problem, we have seen that people who use what Fleck and Weisberg (2006) called the strategy of *perceptual analysis* made a move and then chose the next one based on whether it resulted in further progress. In both those problems, it seems that planning was taking place, which goes against the general philosophy that motivated Lavric and colleagues. In addition, we noted earlier that performance on insight problems has been found to be related to working-memory performance (Murray & Byrne, 2005): People who scored better on measures of working memory also perform better on insight problems. This goes against the conclusion of Lavric and colleagues that working memory and planning play no role in insight.

If we conclude that planning does occur in the solving of insight problems, that leaves us with the question of how to explain the interference results reported by Lavric and colleagues (2000). One possible explanation arises from examination of the materials they used. The interfering task was a verbal task—counting tones generated by a computer. The analytic task, as a logic problem, would seem to demand a verbal strategy. In contrast, the two insight problems that they used, the Candle problem (Figure 6.1B) and the Two-String problem (Figure 6.1G), seem to be problems that would be solved using visual processing. Therefore, perhaps the secondary verbal task interfered with the analytic task and not the insight tasks because of the overlap in modality and processing strategy, not because of the analytic-insight difference. On the basis of this reasoning, we could predict that using a visual interfering task—say, keeping track of a spot of light moving on a computer screen—would interfere with the two insight problems but not with the analytic problem. So the working-memory results do not point clearly to a difference between analysis and insight as modes of solving problems.

Heuristic-Based Restructuring in Response to Impasse

We have seen that the neo-Gestalt view has been proposed independently by Kaplan and Simon (1990) and Ohlsson (1992). These researchers have carried out research that we presented as supporting that view. There are, however, several questions that can be raised about the results of the studies

of Knoblich and colleagues (Knoblich, Ohlsson, Haider, & Rhenius, 1999) on solution rates for different types of matchstick-arithmetic problems and of Kaplan and Simon (1990) on the Mutilated Checkerboard problem. As noted, Ohlsson's (1992) theory of restructuring assumes that the switch-when-stuck heuristic is called into play when the thinker reaches an impasse. However, Knoblich and colleagues provided no evidence that their participants actually experienced impasses while working on the matchstick-arithmetic problems. The only variable that was measured was time to solve each problem, which does not tell us whether the person experienced impasse. In addition, we have no direct evidence that the participants restructured the problems in the way(s) that Ohlsson's view postulates. Again, solution time is too gross a measure for us to draw any conclusions concerning the occurrence versus nonoccurrence of restructuring. Thus, the study of Knoblich and colleagues provides no direct evidence for heuristic-based restructuring in response to impasse.

As discussed earlier, Kaplan and Simon (1990) examined the role of parity in the solution of the Mutilated Checkerboard problem. They found that pointing out a clue to parity (e.g., making the participant aware of the colors on the checkerboard) facilitated solution of the problem. However, that result does not provide direct evidence for the neo-Gestalt idea that an impasse will *lead* to heuristic-based bottom-up restructuring, since no restructuring was seen without hints. It seems that, in the Mutilated Checkerboard problem, at least, impasse does not by itself lead to restructuring, and this conclusion may raise questions about the importance of impasse in insight. As also noted earlier, Fleck and Weisberg (2004) found in studying the Candle problem that impasse did not play a large role in restructuring in that problem either. Thus, although for many years impasse has been discussed as an important factor in restructuring and insight, evidence of restructuring in response to impasse in problem solving is very weak. The only direct evidence that impasse plays a role in restructuring in human problem solving is, to my knowledge, that reported by Fleck and Weisberg. It may be important to remember that the few people in that study who did restructure the problem in response to impasse were driven to that impasse by the experimenter's request that they produce another solution after they had successfully solved the problem. Thus, even here the participants did not respond to impasse on their own by restructuring the problem from the bottom up, as the neo-Gestalt view proposes. Therefore, it seems that a reasonable conclusion is that such restructuring is not a major factor in insightful problem solving. However, as we have seen, the elaborated cognitive-analytic model in Table 6.6 can deal with bottom-up restructuring.

A Reconsideration of Warmth Ratings during Problem Solving

As a final point, let us reexamine Metcalfe's (1987; Metcalfe & Wiebe, 1987; Table 6.7B) groundbreaking research, which employed feeling-of-warmth ratings to support the distinction between insight and analysis. Metcalfe demonstrated that solutions to insight problems come about suddenly, in a burst of activity that is surprising to the thinker. She assumed that the insight pattern of warmth ratings meant two things: that there was no movement toward solution of the problem until the very end, and that the sudden solution came about as the result of perceptual-based restructuring. However, Metcalfe made no attempt to determine the details of processes through which solution came about, so we have no direct evidence that solution did indeed occur as the result of perceptual-based restructuring. We have already seen from Perkins's (1981) results that one can have an Aha! experience as the result of analytic processes (see Abbott's protocol in Table 6.4). Furthermore, that Aha! experience occurred without restructuring, as the result of weak analytic methods, which means that we cannot conclude from Metcalfe's feeling-of-warmth data that nonanalytic processes occurred. Fleck and Weisberg (2006) found similar results.

There is also evidence that raises doubts about the conclusion that no increase in feelings of warmth means no progress toward solution. It has been demonstrated that people can be making gradual progress on a problem even though warmth ratings stay low. Feeling-of-warmth ratings therefore may not directly reflect the cognitive processes involved in solution. Bowers, Farvolden, and Mermigis (1995) discuss a study by Mermigis in which he presented people with problems such as that in Figure 6.11, called the Accumulated Clues Test (ACT). The individual is given a series of words, all of which are clues to a nonpresented stimulus word; the individual's task is to guess the stimulus word. The task is relatively difficult and usually requires presentation of approximately 10 clue words before success occurs. Mermigis also had participants rate their feelings of warmth as they worked through ACT problems.

For some problems, the warmth ratings stayed at zero until the person guessed the correct word, just like the pattern found by Metcalfe (Metcalfe & Wiebe, 1987) with her insight problems. This would indicate that the ACT problem was solved in an Aha! experience. Mermigis then tried to determine if the participants nonetheless had made progress toward solving the problem. He took the *incorrect* solution words, those that had been guessed before the person hit on the correct word, and gave them to a second group of people. This group was asked to rate the "associative closeness" of the incorrect responses to the correct response for that problem. The

Cover all the words with a blank sheet of paper. Then expose the words one at a time, working down the column. After each word, try to think of another word that is related to all the words that you have seen so far. Write that word down on your blank sheet. You do not have to change the written word as you work your way down if you think that it is still correct.

Times
Inch
Deal
Corner
Peg
Head
Foot
Dance
Person
Town
Math
Four
Block
Table
Box

Answer is “square”

Figure 6.11 Accumulated Clues Test

associative-closeness-rating group rated the last incorrect guess (the one given just before the solution) as closer to the correct response than the first incorrect guess (the one given in response to the first clue word). Thus, even though the warmth ratings did not change, the participants had been making progress toward solution of the problem. Bowers, Farvolden, and Mermigis (1995) obtained similar results from a different type of problem.

As these findings show, interpreting Metcalfe's feeling-of-warmth results is more complicated than it might seem at first glance. Although the results provide support for the idea that Aha! experiences accompany the solution of some problems, feeling-of-warmth ratings do not, by themselves, provide unequivocal support for the Gestalt view of restructuring and insight. One needs to carry out a detailed analysis of the thought processes—using protocols, for example—before one can draw strong conclusions concerning solution processes. Metcalfe measured only whether the problem was solved, and such a measure does not permit us to determine whether restructuring was the basis for the Aha! patterns of warmth that she obtained.

Conclusion: Empirical Challenges to the Gestalt Analysis of Insight

This critical review of research has raised doubts about the Gestalt view of insight and the related notion that fixation on experience interferes with creative thinking. We have examined some classic findings, including Köhler's (1925) study of insight and Metcalfe's (1987; Metcalfe & Wiebe, 1987) examination of feelings of warmth during problem solving, and we have found that none of those findings provide unequivocal support for the Gestalt view. Many of the findings, however, can be understood from the cognitive-analytic perspective. One might raise an objection to the literature review just concluded: There was selectivity on my part in choosing the studies to review, so perhaps there are others that provide stronger support for the Gestalt view and that also do not support the cognitive-analytic view. It is obviously true that there are studies that have been interpreted as supporting the Gestalt view that I have not reviewed here (see Ellen, 1982, for discussion). One difficulty is that if I had reviewed all the research from the last 20 years or so, this chapter would have grown to book length itself. Therefore, I can only suggest to interested readers that they review that literature themselves, keeping in mind the basic issue that has been raised in this chapter. That issue concerns the design of the study and the conclusions the researchers wish to draw: Does the design of the study enable one to determine the details of the processes underlying the solution of problems? If not, then the study's claims about restructuring and insight cannot be supported.

Insight in Problem Solving: Conclusions and Implications

This chapter has reviewed from a historical perspective psychological research on insight in problem solving. We have seen that over the course of the last 100 years there has been a cycling of opinion concerning the importance of experience in problem solving. Beginning with Thorndike (1911), one viewpoint has emphasized the importance of knowledge for effective problem solving. A second view, originating with the Gestalt psychologists (Köhler, 1925; Wertheimer, 1982), has proposed that human thinking can function productively in the absence of specific experience, as long as the thinker analyzes the problem he or she faces to determine what it requires and tries to deal with the problem on its own terms. According to this view, human thought can go considerably beyond experience, as long as we do not remain fixated on what we have done before (Duncker, 1945; Wertheimer, 1982). However, the Gestalt view has been called into question by several different sorts of results. First, investigators have found that

relatively specific experience is necessary before animals or humans exhibit insight into a problem (Birch, 1945; Harlow, 1949; Lung & Dominowski, 1985; Weisberg & Alba, 1981). In addition, it has been demonstrated that analytic processes underlie the restructuring in problem solving that the Gestalt view assumes to be the basis of leaps of insight (Fleck & Weisberg, 2004, 2006; Perkins, 1981).

Ultimately, it seems that insight in problem solving is brought about through the same mechanisms that are used in other types of problem solving. Therefore, we do not need a special set of mechanisms to explain how restructuring occurs in problem solving. A model that can explain analysis and insight in problem solving using one set of analytic mechanisms was outlined in Table 6.6. Such a conclusion supports the general perspective motivating this book: that one set of “ordinary” mechanisms underlies all thinking. As far as underlying mechanisms are concerned, there is no need to make a distinction between routine and creative thinking.

CHAPTER

7

Out of One's Mind, Part I

Muses, Primary Process, and Madness

For as long as humans have thought about where new ideas came from, it has been believed that some ideas, those truly novel ideas that produce creative leaps forward, must come from extraordinary sources. Often, the very people who produce those ideas have no awareness of where the ideas came from, so it seems reasonable to assume that something extraordinary must have brought them about. The specific source postulated for novel ideas has changed over the centuries, as our beliefs about human functioning have changed, but the underlying notion—that processes beyond ordinary day-to-day thinking are involved—has remained unchanged. Early in the history of discussions of creative thinking, in ancient Greece, creative ideas were assumed to be gifts from the gods. It was believed that an individual in the throes of creative activity was “out of his or her mind,” in the sense that an outside source was providing the ideas. The person served as the *messenger* or *conduit* through which the ideas were presented from the gods to the rest of us.

In more recent times, beliefs about the sources for creative ideas moved away from the supernatural to internal processes, but those processes were still assumed to be different from ordinary conscious thinking. Extraordinary processes of at least two sorts have been suggested as the possible basis for production of creative ideas. Some believe that *psychopathology*—mental illness—is the basis for creative thinking, a set of beliefs that I will call *genius and madness*. Others believe that *unconscious processes* of one sort or another serve as the basis for production of creative ideas. Each of those theories has a long history in discussions of creative thinking, and each can

be found in current theorizing (e.g., Andreasen, 2005; Csikszentmihalyi, 1996; Jamison, 1993; Kinney et al., 2000–2001; Richards, 2000–2001; Simonton, 1988, 1995), including theorizing outside of psychology (e.g., Kantorovich, 1993; Miller 1996). The current importance of the notions of genius and madness and of unconscious processes in theorizing about creative thinking makes it important that we examine from a historical perspective the evidence supporting the various versions of the view that extraordinary thought processes underlie creative thinking.

Outline of the Chapter

This chapter begins by briefly considering the gods and then turns to psychology. I will begin the discussion of psychological theories of creativity by considering Freud's analysis of creative thinking, which assumes that creative production comes about as a result of *unresolved conflicts* and uses *primary-process thinking*, a primitive emotion- and instinct-based form of thinking, to express its ideas. Use of primary-process thinking is assumed to give the creative person access to mental contents that ordinary thinking cannot reach. Consideration of Freud's view leads to an examination of *genius and madness*, and I will present research and theorizing concerning two variations on genius and madness: that creativity might be linked to manic depression (bipolar disorder) or to schizophrenia.

Messengers of the Gods

The Greeks worshiped the Muses, nine daughters of the god Zeus, each of whom ruled a different area of artistic or scientific activity: poetry, dance, music, history, astronomy, and so forth. During creative production, the creative person was assumed to be possessed by the Muse; the ideas came from her and were simply transmitted through the person (Murray, 1989). Residue of this view appears when we hear someone say "I got an inspiration" to describe the occurrence of a good idea. (*Inspire* literally means "to breathe in"; use of the term *inspiration* to describe the flow of ideas stems from the notion that the Muses gave us ideas by breathing them into us, in a sort of mouth-to-mouth creative resuscitation.) Just last week I read a newspaper interview in which a poet said that "the Muse" provides him with inspiration all the time; he professed to not have the slightest idea about where his poems came from. Plato described the poet in the throes of creation as being *out of his mind*, which meant not that the poet was crazy but that he was *outside of the mind*, receiving ideas from the Muse. The early Greeks talked about possession by the Muses as *madness*, but they did not

mean insanity. However, by the time of the generation following Plato, his student Aristotle talked about creative *frenzy*, which suggested that something not normal was occurring.

In more recent times, the idea that one is out of one's mind during creative work led to the idea that *insanity* might facilitate creative thinking. In order to deal with the notion of genius and madness, it is first necessary to examine the Freudian analysis of creative thinking, because it depends on concepts—most particularly *primary-process thinking*—that will play a significant role in the later discussion.

Primary Process and Creativity

In his theory of psychosexual development, Freud distinguished between two modes of thought (Holt, 1967). First is the ordinary thinking we carry out most of the time every day: We are rational and logical, and our thinking attempts to deal realistically with the world and with the problems we face. Freud called this type of thinking *secondary-process thinking*, because it is the second type of thinking that develops. Based on his extensive clinical work with patients suffering from various neuroses, Freud had come to the conclusion that ordinary conscious thinking is not the only type of thinking we carry out. Ordinary thinking, he felt, is not even the basic type of thinking—that is one reason why he called it secondary-process thinking (Holt, 1967). There is another kind of thinking, more basic than secondary-process thinking, which ignores logic, usually deals with fantasy rather than reality, and pulls together ideas that have nothing to do with the world. Freud called this type of thinking *primary-process thinking*.

According to Freud, primary-process thought is present before secondary-process thinking develops: We bring it with us into the world. It is primitive, irrational, and need-based thinking, intimately tied to our biologically based *id* needs and their associated drives and emotional states. Primary-process thinking operates according to the *pleasure principle*; that is, it is directed toward immediate reduction of tension and satisfaction of needs. It serves as the basis for much of our fantasy life, as exemplified in the fantastic experiences that fill our dreams. Dreams are one product of primary-process thinking with which we all are familiar, and primary-process thinking can also sometimes be seen in states of fever, when one's thoughts may jump from topic to topic, with no logic that the thinker can discern. Reverie and daydreams are other states in which primary-process thought occurs. In all these cases—sleep, fever, reverie—the ordinary secondary-process thought processes are weakened, so primary-process thinking can emerge. Primary-process thought is also seen when people are stressed or

highly aroused emotionally. It can also be seen in children and in so-called primitive peoples; and, most important for the present discussion, primary-process thinking can also be seen in creative artists.

Primary-process thinking differs from secondary-process thinking both in *content* and in *form*. Primary-process *content* is evident if the thought contains libidinal (sexual) or aggressive material. This material can be expressed either at a *blatant* level (that is, expressed directly—"I had a dream about a man stabbing a woman") or at a *symbolic* level (expressed indirectly—"I had a dream about a woman looking for a man but not finding him"). Primary-process *form* can be seen if the response deviates from logical thinking or involves deviant language (Suler, 1980).

As an example of the creative possibilities in primary-process thought, when an infant is hungry, he or she may fantasize an image of the breast. This is an example of primary-process thinking operating in accordance with the pleasure principle, seeking immediate reduction of the tension arising from an unfulfilled need. If no object is available that will satisfy the need, then an object will be imagined. Although this purely psychological action cannot truly satisfy the hunger need, the act of imagining the breast can provide a brief respite. Similarly, in a creative artist, the arousal of a need by some event or experience can result, say, in the individual's painting a portrait with a particular facial expression. Primary-process thinking differs from secondary-process thinking in ways that are potentially useful in creative thinking in general and that also play a role specifically in the creation of works of art. Since primary-process thinking is primitive and present essentially at birth, it does not use language-based logical thinking as its mechanism. Rather, it uses nonverbal imagery as its medium, which allows it freedom from previously established associations. In addition, primary-process thought has a particular looseness or flexibility about it, so that it may facilitate searching among associations to come up with a new idea (Russ, 2000–2001).

Primary-process thinking also uses special mechanisms to establish connections among ideas (Koestler, 1964, p. 179). As one example, primary-process thinking uses *punning*, of two sorts. Through a *verbal pun*, two strings of thought are linked by acoustic overlap: A person might make a humorous response to something said to her by creating a pun based on the *sound* of one of the words, rather than the *meaning*, which would be the focus of secondary-process (i.e., logical, conscious) thinking. An example of a creative product based on primary-process verbal punning can be seen in the use of the nickname "Jack the Dripper," a pun on "Jack the Ripper," to refer to Jackson Pollock's famous technique of dripping paint from the brush onto a canvas lying flat on the floor (see Chapter 5).

Similarly, in the visual mode, primary-process thinking can produce an *optical pun*, which can serve to link ideas; in this case, a common visual form serves to link two streams of thought. You might be imagining some situation when a specific visual form in that situation sets you thinking in a different direction because the new direction contains a similar visual form, even if it does not contain ideas similar in meaning to the original thought. One sees examples of visual puns in art when, for example, a shape present in one part of a painting appears in another unrelated part. The shape of a model's arms and shoulders might be mirrored in the shape of the chair in which she sits, or the stripes in her skirt might be echoed in the wallpaper. I recently read an art historian's description of a painting by Picasso of a young woman seated in a chair with her profiled head tilted back. The historian noted the phallic outline of the shape of the woman's head and neck, and proposed that that shape's presence there symbolized Picasso's sexual feelings toward the woman.

In primary-process thinking, anything can be connected to anything else, even when, from the point of view of secondary-process and reality-based thinking, only the slightest link between those ideas actually exists. So a father can occur as a hockey player in a dream, although the father cannot ice-skate, because of the connection through masculinity between the father and a typically male hockey player.

A second mechanism of primary-process thought is *concretization*, in which abstract and general ideas are represented by particular images: The image of a particular police officer might represent authority, or a particular athletic event might represent the concept of competition. In *condensation*, several ideas are linked together in one symbol, so unpacking the meaning of that symbol can become a complex task. Making things even more complex are *impersonation* and *double identity*, in which an image represents itself and something else at the same time. Finally, in primary-process thought one can have *reversal of causal sequences*, in which one reasons backward, from the effect to the cause.

The original Freudian view assumed that in the ordinary person primary-process thought is superceded by secondary-process thinking as one develops through childhood. Secondary-process thinking becomes more dominant as the ego develops, and ultimately the primitive connections among ideas, and the mechanisms underlying primary-process thought, are suppressed by the ego. This allows the developing child to become a socialized individual. However, as we have already seen, primary-process thinking can still be seen in the adult, in circumstances where the ego defenses are temporarily weakened and the more primitive thinking can thus break out of its bonds. Such weakening of ego defenses occurs during sleep, illness,

intoxication, and the mental state leading to daydreaming. The thinking of the schizophrenic is usually highly saturated with primary-process characteristics (Holt, 1967).

In more recent psychoanalytic formulations, which have moved away from the classical Freudian analysis of primary- versus secondary-process thinking, the two types of thinking are no longer seen as dichotomous categories but rather as the ends of a continuum (Russ, 2000–2001; Suler, 1980). Any one of us can at any time carry out thinking that is situated on the primary-process end of the continuum, as when we ignore the way events occur in time, or think about events that have not occurred and we know cannot occur, or think about people or things in ways that contradict how they are in reality. I might imagine myself becoming president of the United States tomorrow through some strange set of circumstances. Similarly, each one of us carries out thinking that is closer to the secondary-process end of the continuum when we make a decision by weighing the alternatives and choosing on a rational basis the one that best fits what we hope to accomplish.

Primary-Process Thinking and Creativity

It has been proposed by Kris (1952) that the creative artist, unlike the ordinary individual, is able to control primary-process thinking and therefore can use it in the creative process. This phenomenon has been called *regression in service of the ego* (Kris, 1952). The artist is able to regress—that is, to use on a voluntary basis this primitive or early mode of thinking—in order to deal with a situation that requires creative thinking. The artist can use the freedom from reality provided by primary-process thinking to deal with situations in novel ways, because the artist has a strong ego and therefore is not threatened by unconscious wishes. We ordinary folks, who are threatened by our own unconscious desires and therefore locked more strongly into secondary-process thinking, are unable to use primary-process thinking so easily. Thus, one can find primary-process thinking in conscious adults because of *weakness*—as in the feverish person suffering from illness, or the sleepy person, or the schizophrenic—or because of *strength*—as in the artist, who can use primary-process thinking to his or her advantage (Holt, 1967).

According to the Freudian view, creative work arises out of unfulfilled needs, which usually stem from childhood (Freud, 1959). An event in adulthood can arouse a need, and, if the individual has the skills of an artist, a creative product may result. As an example, consider the *Mona Lisa* of Leonardo da Vinci. The most striking aspect of that masterpiece is the emotional expression on the lady's face: a smile that is not warm and welcoming, but somewhat cool and distant. Why did Leonardo paint her looking

like that? Freud proposed that the smile on the subject's face looks the way it does—as if she is emotionally just out of reach—because of Leonardo's feelings toward women. Leonardo lost his mother at an early age, which meant that many of his needs remained unsatisfied; he was forever searching for her, but she would forever be out of reach. Thus, Freud explains the specific form of Leonardo's work—the smile of the *Mona Lisa*—as well as Leonardo's more general interest in that particular subject matter—that woman—on the basis of unfulfilled needs from childhood. The woman who posed for the *Mona Lisa* reminded Leonardo on an unconscious level of his mother—perhaps through her appearance, her smile, or both—and he painted her in that way because of the needs that she aroused in him.

In a Freudian analysis of Picasso's artistic creativity, Gedo (1980) has examined the development of the painting *Guernica*, which was discussed in Chapter 1 (see Figure 1.1B). Gedo uncovered in the painting what she believes are many links to Picasso's childhood, and she proposed that many of the painting's characters, and the way they are presented, stem from childhood experiences of the artist. Most important for Gedo's analysis is that when Picasso was 3 years old he and his family were caught in an earthquake in Málaga, his home city. In Gedo's view, the destruction of the city of Guernica 50 years later brought back to the middle-aged Picasso memories of that childhood trauma, and those memories shaped the content of the painting that he produced in response. One character in the painting that was of particular interest to Gedo is the “fleeing woman,” who enters from the right. In the early sketches in which she appears, she wears a kerchief and holds to her breast a dead baby covered in blood. Gedo found a link between this woman and Picasso's childhood in an account by Picasso of his recollection of the earthquake, in which he noted that his mother had worn a kerchief as the family made their way to a friend's house in a safer location. Picasso commented that he had never seen his mother in a kerchief before. In addition, around the time of the earthquake Picasso's younger sister was born. The blood that covers the baby in the sketches might be based on the appearance of Picasso's sister when she had just been born. Thus, the woman in the kerchief holding the bloody baby is Picasso's mother, giving birth to his sister.

The fact that the baby in the painting is dead is also of interest to Gedo, as it might be related to Picasso's early negative feelings toward the new baby, who removed him from his position as the only child and the center of the family. When he was a child, Picasso could not get rid of his sister, but as an adult he could do it symbolically in his art. Gedo proposes that all the women in *Guernica* may represent different aspects of Picasso's mother; for example, perhaps she carried a lantern as the family made their way through

the earthquake-torn city, which would link her to the light-bearing woman. These linkages go even beyond the women. In one sketch for *Guernica*, the horse is shown giving birth to a Pegasus, so again one can make a connection between Picasso's mother and the painting: This time the horse, through the act of giving birth, is symbolizing the mother. As noted, the blood that covers the baby in the sketches might be based on the appearance of Picasso's sister when she had just been born.

From the Freudian perspective, it is also interesting that Picasso became an artist in the first place. Picasso's father was also an artist, so the son's taking the father's profession has obvious Oedipal overtones, especially since the son outstripped his father even as a young man. One of the father's main painting subjects was pigeons, and it is fascinating to note that many of Picasso's paintings—including *Guernica*—contain pigeons. This too can be seen as having Oedipal overtones, the son taking over the domain of the father. In addition, the young Picasso took his mother's last name when he became an artist (dropping his father's last name, Ruiz), thereby eliminating his father in another way. It is said that when Picasso's father saw the talent in his son, the father put away his paints forever (a true Oedipal event), although that story may not be true (Richardson, 1991). From this example, we can see how one can take Freudian ideas and from them weave a story that interconnects an artist's life and work.

The Freudian view is also seen in analyses of creativity in other domains. For example, Solomon has analyzed the musical creativity of Mozart (Solomon, 1995) and Beethoven (Solomon, 1977) through the lens of Freudian theory. Mozart's father was a reasonably successful musician, so here again we have Oedipal echoes. Solomon argues that Mozart's father tried to dominate him, both as a musician and as his father, and that the son broke away from the father in several ways. The younger Mozart, for example, married a woman of whom his father did not approve. His professional development can also be looked at as a breaking away from his father, since the son played a role in demolishing the musical tradition in which the father had been brought up and to which he had contributed. As far as Beethoven is concerned, his music has been analyzed by scholars as developing through a series of stages. Solomon proposes that these stages can be traced to events in his life that triggered unconscious processes that affected the music he created at various points in his life.

Analyses such as Gedo's and Solomon's are fascinating, although it is difficult to determine their accuracy. Freud's ideas are not currently held in high esteem by most academic psychologists, although the Freudian view is still important in other domains; Gedo is an art historian, and Solomon a

musicologist. Experimentally oriented psychologists see a number of related problems with the Freudian view, the most crucial of which is that it is very difficult to determine whether it is right or wrong. If one presents an analysis of some phenomenon from a Freudian perspective, there is always the question of whether any other equally plausible analysis could be produced, either from the Freudian view or from another perspective. Since Freudians usually do not present such an alternative analysis, accepting the Freudian view comes down to whether one feels comfortable with the story told by Freudians. That does not seem to be a sound basis on which to judge the merits of a supposedly scientific analysis of some phenomenon.

In many cases, moreover, much of the Freudian analysis of a given phenomenon may be impossible to test. Take, for example, Gedo's (1980) suggestion that the woman in *Guernica* holding the light overlooking the scene may be a representation of Picasso's mother. The connection Gedo offers as support for that conclusion is that Picasso may have seen his mother carrying a light as she led the family through earthquake-damaged Málaga. Similarly, Gedo interprets the blood on the baby held by the kerchief-wearing woman in the sketch for *Guernica* as being possibly symbolic of the blood Picasso might have seen on his sister just after she was born. However, there is no evidence to support either of those proposals: Picasso never said anything about his mother using a light, and we have no evidence that he was present at the birth of his sister to see her when she was newly born and still covered in blood. Unless new evidence appears, those claims must remain speculation, and therefore they do not really add to our understanding of Picasso's creative process.

A number of other aspects of Gedo's analysis of the development of *Guernica* can be questioned as well. Central to Gedo's analysis is the assumption that the trauma brought about by the bombing of Guernica aroused in the adult Picasso feelings produced originally by the earthquake he experienced as a child; the trauma is the presumed link between them. However, Picasso reported as an adult that he was excited by the earthquake, not traumatized (Richardson, 1991, p. 28, n. 15); if true, this report means that the bombing and the earthquake are not events of the same sort as far as Picasso was concerned, so the bombing should not have been able to retrieve feelings from Picasso's childhood. The connections seen by Gedo between characters and events depicted in *Guernica* and people and events in Picasso's life may just be coincidental. It is also interesting to note that Picasso's ability to discuss the earthquake indicates that the memories of it were not hidden in his unconscious, which raises questions about the Freudian assumption that unconscious processes were involved at all.

Further doubts arise regarding the connections proposed by Gedo because in other paintings Picasso depicted similar characters in very different situations. For example, a female holding a light to illuminate a scene is seen in *Minotauromacy* (see Figure 1.10), among other works. However, that work was not triggered by a traumatic event comparable to the bombing of Guernica. Therefore, if the light-bearing female in *Minotauromacy* is also symbolic of Picasso's mother, then it becomes difficult to understand why he thought of her at the time he created that painting. Of course, one might argue that the light-bearing woman in *Minotauromacy* is not symbolic of Picasso's mother (and it is true that that woman looks more like a girl), but that raises the question of why a light-bearing female would symbolize Picasso's mother in one work but not in another. Thus, the connections between characters and events in Picasso's life are not nearly as clear as a Freudian analysis of one isolated work of art would lead one to believe. When one looks at works within the context of an artist's career, one finds complexities that seem to raise doubts about the Freudian view. In a similar manner, Freud's original analysis of Leonardo da Vinci's creative process has been called into question. Some of the facts Freud used in his analysis of Leonardo's life seem to have been incorrect, and his interpretation therefore is also incorrect (Stannard, 1980).

In part because of these problems, the Freudian view is not central to modern psychological theories of creative thinking. However, one can see several aspects of the Freudian view in modern views. A number of modern researchers (e.g., Martindale, 1989, 1990; Russ, 2000–2001; see also Suler, 1980) have attempted to demonstrate the importance of something like primary-process thinking in creativity, although the modern emphasis differs somewhat from the classical Freudian view. This research will be examined in the next section. Recently researchers have developed interest in the role of emotions in creativity, in which can be seen echoes of the Freudian emphasis on unresolved conflicts and their emotional concomitants as the basis for creative production. This work will be reviewed in a later section. In addition, even though most modern psychologists reject the view that the specific kinds of primary-process-based unconscious connections postulated by Freud are central to creative thinking, many modern psychologists do believe that unconscious thinking of one sort or another plays a role in creative thinking. It is assumed that unconscious thinking can bring about connections among ideas that could not be produced in ordinary conscious thinking. This belief is a strong residue of the Freudian view. Modern views of the unconscious will be discussed in the next chapter.

Primordial Thinking and Stylistic Change

Martindale (e.g., 1990) has carried out a set of quantitative historical case studies of creative thinking in which he has examined changes over time in the content of creative products. He has developed a theory concerning how creative products change over time as creative movements wax and wane. Martindale's view, which is based on earlier theorizing by Berlyne (1971), assumes that if a creative work is to find an audience it must contain potential for emotional arousal. In order to produce emotional arousal on the part of the audience, the new work must go beyond what has been done before—but not too far beyond: Works that go too far beyond what has been done will violate the audience's expectancies too drastically and will be beyond their comprehension. Thus, there is a conflict between two opposing forces: the need on the part of the creator to go beyond what has been done before and the need to stay reasonably close to the boundaries set by previous work.

In Martindale's analysis (1990), the process that produces novel works is called *primordial thinking*, which is related to, although not identical to, Freud's primary-process thinking. Martindale uses a different term because he does not accept all the assumptions of the Freudian view. Primordial thinking is able to link together ideas that ordinary conscious thinking—*conceptual thinking* in Martindale's terms, secondary-process thinking in Freudian terms—is unable to connect. Since, according to Martindale, producing new ideas means connecting old ideas in new ways, new ideas come about through primordial thinking. Therefore, in order to produce new works that have the capacity to arouse an audience's emotions, the thinker must regress to primordial thinking. The content of primordial thought is based on biological drives, such as hunger, aggression, and sex. In addition, the structure of primordial thinking is different from that of conceptual thinking: Primordial thinking works through chains of association based on primitive connections, such as the sounds (rather than meanings) of words, and the shapes (again, rather than meaning) of visual forms. Once the free-associative primordial mode of thinking has been used, conceptual thinking can serve to edit the product into an acceptable work. Conceptual thinking differs from primordial thinking because it involves making classifications and distinctions among ideas—as seen most clearly in logical thinking—which is opposite to the syntheses, or links among ideas, produced by primordial thought.

Using this sort of reasoning, Martindale developed a hypothesis concerning the pattern of development of creative products over time. Assume that an artist is working within a style—say, Impressionist painting. Since there is a constant pressure for new emotionally arousing works, and since emo-

tional arousal comes about at least in part from the presence of primordial content, it follows that there should be an increasing amount of primordial content in the works that are produced. That is, Impressionist paintings should become more and more involved with biologically based drives, such as hunger, aggression, and sex. However, at some point the Impressionist style will become saturated, and no new developments within it will be possible. At that point, the artists reach a dead end. One response to this is the development of a new style, one that uses much less primordial content. The new style is able to arouse the audience because of its *novelty* rather than its primordial content. This new style will then go through the same sort of evolution, with ever-increasing primordial content, until it too reaches a primordially saturated dead end and tips over into something new. So there should be a cycle within a genre such as French painting, with primordial content increasing, then decreasing as a new style takes over, increasing again, then decreasing, and so forth.

In order to test this hypothesis, one needs a measure of primordial content in a work of art. Martindale developed a measuring instrument for language-based artworks, based on the vocabulary used by the artist. He first developed a set of words that reflected primordial cognition, based on the writings of a number of psychologists: Freud, Heinz Werner, and Carl Jung. The following are examples of such words and the categories into which they fall (1990, p. 92ff):

- Oral*: breast, drink, lip
- Sex*: kiss, naked, caress
- Anal*: sweat, rot, dirty
- Hard*: rock, stone, cold
- Chaos*: wild, crowd, ruin

These words are representative of the 29 categories and approximately 3,000 words Martindale ultimately used. He wrote a computer program that searched poems for primordial content, as defined by the presence of those words. As a test of his hypothesis of artistic change, Martindale investigated the amount of primordial content in French Romantic poetry over the years 1790–1909, and he found the predicted pattern. Primordial content increased until about 1880 and then dropped off at the beginning of the twentieth century, when what Martindale called surrealistic poetry developed as a new style.

Martindale's (1990) analysis of primordial content in creative products and his theory of the mechanisms underlying stylistic change are valuable in several ways. He has shown that it is possible to quantify aspects of

creative products that one might have thought could not be dealt with on any but a completely subjective basis. In addition, his analyses show that one can study large-scale trends in styles in a rigorous manner. Assuming that we accept Martindale's analysis, it raises the question of how we are to explain this movement toward more and more primordial content as a style matures. It is interesting that, although Martindale's theorizing was obviously derived from the Freudian notion of primary-process thinking, one does not have to analyze his results in Freudian terms. In Freudian terms, one might say that the increase of primordial content in creative works is brought about by regression to primary-process thinking by the people working in that area.

However, one can reinterpret Martindale's findings without postulating a direct role for primary-process thinking, in the following manner. Assume that it is true, as Martindale (1990) and Berlyne (1971) propose, that the value of a creative product depends at least in part on its arousal value, and also that audiences require constant novelty in creative products in order for arousal to be maintained. That means that artists face the constant need to produce novel works in order to arouse their audiences. Assume further that whenever an artist begins to work in a genre, he or she will use the content of the works available at that time as the baseline from which to produce novelty. That is, the artist uses what others are producing at that time as the norm from which to begin his or her own work.

On the basis of these assumptions, one will expect that creative products will move farther and farther away from society's norms as time goes on. In the beginning of a stylistic era, creative works will represent the norms, but they will quickly move away from them as the audience becomes inured to "normal" work. The next generation of artists will then have to move farther away from the norms in order to capture the interest of the audience. This movement will be toward what Martindale calls primordial cognition, because the topics dealt with in primordial cognition—sex, aggression, and so on—are precisely those topics that are more or less taboo in ordinary discourse. This movement toward more and more primordial content can occur on a perfectly conscious level; one does not have to assume that there is some underlying primary-process-thought mechanism that allows a privileged few access to those dark nether regions. Rather, if one simply assumes with Martindale that the audience continually demands novelty, and also assumes that society's norms are conservative, then one will predict exactly what Martindale found. Surely all of us know how to produce "primordial content" if we wish to, on a conscious level. We usually do not do so, because most of us have not become members of a field one of the purposes of which is to stretch the norms, as artists have.

As we can see, Martindale's research may provide us with valuable information about how creative processes evolve as a style develops, matures, and dies. However, his results do not force on us the conclusion that unconscious processes based on primary-process thinking are at work.

Primary Process and Affect in Creativity

Russ (e.g., 1993, 2000–2001) has proposed that the affective or emotional components of primary-process thought may be particularly important in creative thinking. Primary-process thinking, as we have seen, is closely tied to affect, especially because much of it involves oral, aggressive, and libidinal (sexual) content, which evokes strong affective responses. Those areas are often accompanied by intense feeling-states in childhood, which might result in much emotional residue later in life. Thus, the child has to learn to deal with the emotion centered on those areas, and that is where there can develop a style of thinking that might play a role in creativity. Russ discusses Holt's (e.g., 1967, 1977) analysis of primary-process thinking as a way of understanding how primary-process thinking plays a role in creative thinking. Holt (1977) developed a scoring system for responses on the Rorschach inkblot test that provided a method for operationalizing primary-process thinking. The scoring system measures the amount of primary-process content and how effectively that content is controlled. As an example, let's say a person interprets one inkblot card as two bugs fighting, which is primary-process content, but then qualifies the response by saying it is a cartoon. That qualification indicates that the person has control over the primary-process content so that he or she can express it appropriately.

Holt's system allows one to derive several scores on the Rorschach related to primary-process thinking, and the system can be used to measure both how easily a person can access primary-process material and how well that material is integrated into ongoing cognition. *Percentage of primary process* is simply the percentage of responses in which primary-process content occurs. *Defense demand* measures the intensity of primary-process thought, based on the total of primary-process content and form seen in the responses—more intense content requires more need for defense against it in order to protect the ego. The *defense effectiveness* score measures a person's control over the primary-process content and form and his or her ability to integrate that content into realistic and appropriate cognition (Suler, 1980). Finally, *adaptive regression* is based on the combination of defense demand and defense effectiveness, and this score measures how well primary-process content and form are expressed in adaptive form. Thus, the various scores in Holt's system allow one to determine how

much access a person has to primary-process material and how he or she expresses that material.

The availability of Holt's (1977) scoring system leads to the expectation that it should be relatively easy to examine the relationship between primary-process thinking and creativity: Have a group of artists, say, take the Rorschach, score the responses according to Holt's system, and then relate the amount and type of primary-process thought to the creativity of the artists. Studies of this sort have been carried out, examining the relationship between primary-process thinking and creativity in adults and children; however, the results do not allow one to draw any simple conclusions. In one type of study, creative people—for example, artists and writers—were given the Rorschach to obtain a measure of primary-process thinking. Cohen (1961, cited by Suler, 1980), for example, examined primary-process thinking in art students rated by professors as being more or less creative. More-creative students produced more primary-process content than the control group, but they also produced more material in general in response to the Rorschach. When overall productivity was taken into account, there was no relationship between primary process and creativity. Other studies reviewed by Suler (1980, pp. 151–152) also did not find a strong relationship between primary process and creativity.

In a second type of study, creativity was determined by the rated quality of the products produced by the participants. Those studies have not found consistent relationships between primary process and creativity: Results vary across studies, and different components of Holt's measures of primary process are related to creativity in different studies. Furthermore, sometimes the results are different across sexes (Suler, 1980, p. 152); that is, sometimes a relationship between primary-process thinking and creativity is found for males but not for females. Such sorts of findings raise questions about underlying relationships. A number of investigations have also examined primary-process thinking and creativity in children, and the results have also not consistently supported the role of primary-process thinking in creativity. Russ carried out a number of studies that examined the relationship between primary-process content in thinking and creativity (summarized in Russ, 2000–2001). In one study of fifth graders, Russ used the Rorschach to measure primary-process thinking, and used performance on the *Alternate Uses Test* (a creativity test; see Chapter 9) as a measure of creativity. She found a significant relationship between the adaptive regression measure of primary-process thinking and performance on the Alternate Uses Test, but only in boys. This is the sort of finding that raises questions about whether we can draw general conclusions about creative thinking based on studies of primary-process thinking.

Primary Process and Creativity: Conclusions

In sum, research on the relationship between primary-process thinking and creativity has not produced compelling findings. Whether one chooses to pursue such studies depends more than anything else on what one believes about the creative process. Since my basic assumption is that all people think alike—females and males, creatives and noncreatives—finding that some relationship is relevant only for boys makes me conclude that we ought to be looking elsewhere in our attempts to understand creative thinking. Put another way, if primary-process thinking were *really* important in creative thinking, then there should be a strong and consistent relationship between that type of thought and creativity, and it should be found for everyone.

Genius and Madness: Bipolarity and Creativity

Interest in extraordinary thought processes in creative thinking has led to a long-standing fascination with the possibility that creativity is linked to psychopathology. The thought processes—and other characteristics—of people who suffer from psychopathology are sometimes seen as providing a possible mechanism whereby production of creative ideas and works might be facilitated. In order to investigate the hypothesis that creative thought processes might be similar to the thinking brought about by mental illness, it is necessary to compare the thought processes of mentally ill people with those of creative individuals who do not exhibit psychopathology.

Different laboratory tasks have been used to tap into the thought processes of those various groups. One such task involves category grouping: The person has to group items that he or she feels belong together (Andreasen & Powers, 1974). For example, let us say that in front of you are the items listed in Table 7.1, and I give you the chocolate cigar. What other items from the whole group should be put with it? Now we put all the items back, and I give you the screwdriver. What other items should be grouped with it?

This sort of test can tell you the categories that a person uses in order to group objects in the world, and one might expect that the creative person's thinking would be influenced in important ways by how he or she categorizes objects. For example, one might expect that a creative thinker would group objects into larger groupings than would a noncreative individual, because large groupings might result in a person's making a creative leap—for example, using an object to create a solution to a problem that no one else might have thought of—because the creative thinker grouped that object in the category needed to solve the problem. If a creative thinker grouped together the candy cigar and the screwdriver in the test in Table 7.1, then he or she might use the cigar to substitute for a screwdriver in a way that

Table 7.1 Scheerer-Goldstein categorization task

Toy spoon
Plate
Pipe
Candy cigar
Screwdriver
Sugar
Large candle
Fork
Knife

I could never think of, since I would not put those two objects together. That creative person might decide to make cookies in the shape of tools as a birthday present for a carpenter, say, because of the link between the candy cigar and the screwdriver.

Results from tests of this sort showed that the object groupings of creative individuals were more similar to those of people with manic depression than to those of people with schizophrenia (Andreasen & Powers, 1974). Therefore, interest in the possible relationship between genius and madness turned to the possible role of manic depression, also known as *bipolar disorder*, in the creative-thinking process, and much research has investigated that possibility. In recent years there has been a return to the notion that schizophrenia might be related to creativity, which I will discuss in a later section.

The Bipolar Spectrum

Bipolar disorder is, in present-day diagnostic terms, actually a whole spectrum of conditions with a broad range of symptoms and severity (Goodwin & Jamison, 1990; Jamison, 1993). The critical component of all of those conditions is the prevalence of changes in *mood* or *affect*—that is, changes in *emotional state*. In Bipolar Disorder I, classic manic depression, the affected individual can alternate between periods of great elation (mania) and depression. Manic episodes frequently occur following psychological or social stressors, such as conflict at work or in one's family. During the manic period, a person can work almost without sleep and may feel that he or she can do anything—overcome any obstacle, accomplish any goal. Unfortunately, a person in the throes of mania also has a tendency to undertake grandiose schemes without planning, such as investing all of her savings in extremely risky business ventures or marrying someone he has just met. One characteristic of the manic person is that he or she feels that ideas flow very easily, and that characteristic has also led some theorists to postulate that

mania may facilitate creative thinking. Until relatively recently, the presence of creative thinking was listed as a criterion for the diagnosis of mania in the American Psychiatric Association's *Diagnostic and Statistical Manual of Mental Disorders* (DSM; the latest version is the fourth edition, revised, or *DSM-IV-R*), which is the standard reference source used by mental health professionals for determining whether a patient suffers from mania.

The other side of the mood-disorder coin is the devastating low of depression. In the typical case of Bipolar I disorder, an individual suffers from major depression in addition to mania. In major depression, the individual experiences a loss of interest or pleasure in life; simply getting out of bed, washing, and dressing in the morning may be too much for the individual to accomplish. There may also be feelings of worthlessness and guilt, decreased energy, and trouble sleeping. There are often thoughts of death and suicide, and many depressed individuals attempt suicide, with a significant proportion (approximately 15 percent; *DSM-IV-R*) succeeding. There may be a genetic component in Bipolar I, because there is strong evidence that it runs in families; it is more common among first-degree biological relatives of bipolar patients than among the general population. Current opinion is that the bipolar spectrum of disorders has a strong genetic component (Jamison, 1993).

Other conditions that fill out the bipolar spectrum differ from Bipolar I in the pattern of symptoms and their severity. A patient suffering from Bipolar II disorder cycles through positive and negative moods, as does the manic-depressive patient, but the positive mood state of the Bipolar II individual is *hypomania*, a state of positive affect that is not as severe as full mania; the negative state is full depression, however. A still less severe condition, *cyclothymia* (literally "cycling mind"), is defined by the individual's cycling through hypomania and negative moods (*dysthymia*) that are less severe than major depression. At the least severe end of the spectrum are conditions in which a person who is normal has a personality marked by typical mood coloring. Examples are the *euthymic personality*, characterized by an overall positive feeling tone (someone who is always "up"), and the *dysthymic personality*, marked by negative feeling tone (someone who is always gloomy). *Cyclothymic personality* is marked by changing moods.

Bipolarity and Creativity

Originally, it was hypothesized that there might be a link between creativity and the full-blown mania of Bipolar I disorder (for review see Jamison, 1993), although it has been suggested that there might be a link between depression and creativity as well (Andreasen, 1987). More recently, focus has shifted to milder forms of mood disorder as possibly being related to

creativity. Different sorts of evidence have been brought forth to support the idea that there is a link between bipolar disorder and creativity. First, researchers have attempted to show that there is a tendency for creative individuals to suffer from bipolar disorder. Approaching the same issue from the other side, researchers have attempted to demonstrate that bipolar individuals are more creative than are other groups. Finally, there have been attempts to show that being in a creative state has the same characteristics as being in a manic state.

Mood Disorders in Creative Individuals

Jamison (e.g., 1993) a leading researcher in this area, has studied the lives of numerous world-famous creative individuals and has concluded that many of them suffered from bipolar disorder. One example is the poet Lord Byron (Jamison, 1993), who led a turbulent life, in which many episodes had the out-of-control, up-and-down aspects of bipolar disorder. Of course, Jamison was not able to diagnose Byron's psychological state directly, since he died before modern methods and criteria were developed, but there is historical evidence (e.g., reports of Byron's contemporaries about his behavior, as well as medical records) that supports her analysis.

Other studies, which have examined individuals presently alive, have also reported a link between bipolar disorder and increased creative activity. Jamison (1989) interviewed a sample of 47 British writers (poets, playwrights, novelists, and biographers) and artists to determine their history of mental illness and to ascertain any pattern in their mood changes and creative productivity. More than 38 percent of the entire sample had been treated for some affective illness, and 30 percent reported relatively severe mood swings, some of which lasted for extended periods of time. (The biographers reported fewer disorders and less severity of symptoms than did the other individuals, whom we might classify as being engaged in more-creative activities than the biographers.) Participants reported that they experienced intense productive and creative episodes, which involved increases in enthusiasm, energy, speed and fluency of thoughts, and elevated mood and sense of well-being. Those reported characteristics corresponded to the diagnostic criteria for hypomanic episodes in *DSM-III* (the third edition of the *DSM*, published in 1980). Almost all the writers stated that those mood and feeling changes were very important in the development of their work. Jamison discussed the possibility that the changes in cognition—speed, fluency, and flexibility of thinking—found during hypomanic states are critical to creativity. In addition, the emotional fluctuations occurring during mood disorders might serve in a positive way to provide creative writers and artists with material for their work.

However, Jamison also noted that it was not clear whether the similar changes during hypomania and creative production are related significantly below the surface or are simply similar on the surface. That is, states of creative production might be psychologically similar to manic states because a common process underlies both, or the similarity might be just a coincidental surface similarity, more apparent than real, without a common underlying process. The latter possibility would be of much less interest to researchers. In addition, the fact that artists and writers report those changes in mood may reflect nothing more than that those people might be more sensitive to their mood changes than is the general population. That is, we might all undergo similar changes in mood as we carry out different activities, but I as a noncreative type might not be sensitive to them, so I would not think about or report them. If that were true, then there might be no specific causal link at all between mood change and creative production. Thus, the purported relationship between creativity and bipolarity has not received unequivocal support from the research just reviewed.

As we have seen, the other side of bipolar disorder is the devastating low of depression, which in its most severe form can lead to suicide. If bipolar disorder is linked to creative thinking, then one might expect to find creative individuals suffering from depression as well. Jamison (1993) has presented evidence that creative individuals, especially poets, suffer from depression to a degree much higher than one finds in the general population. In Table 7.2 are listed the eight poets born in the twentieth century whose works are included in *The Oxford Book of American Verse*, a highly regarded reference work (Matthiessen, 1950). Of those eight poets, five committed suicide, a rate much higher than in the general population, which provides evidence for the prevalence of depression among poets and indirect support for Jamison's proposal that there is a relationship between bipolar mood disorder and creativity. As mentioned earlier, it has also been suggested that the deep negative states of depression might provide creative individuals—especially artists, such as writers, painters, and musicians—with material to use in their work.

Creativity in Mood-Disordered Individuals

The second thrust of research on mood disorder and creativity has attempted to show that being mood disordered raises the likelihood that one will be creative. This hypothesis has been tested by studying whether normal individuals who might carry the genes for mood disorder (we have seen that there may be a genetic component in bipolarity) are more creative than people who do not carry those genes. In an additional investigation

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Table 7.2 Partial listing of major twentieth-century American poets, born between 1895 and 1935, with documented histories of manic-depressive illness

Poet	Pulitzer Prize in poetry	Treated for major depressive illness	Treated for mania	Committed suicide
Hart Crane (1899–1932)		X	X	X
Theodore Roethke (1908–1963)	X	X	X	
Delmore Schwartz (1913–1966)		X	X	
John Berryman (1914–1972)	X	X	X	X
Randall Jarrell (1914–1965)		X	X	X
Robert Lowell (1917–1977)	X	X	X	
Anne Sexton (1928–1974)	X	X	X	X
Sylvia Plath ^a (1932–1963)	X	X		X

Source: Goodwin and Jamison (1990).

^a Plath, although not treated for mania, was probably Bipolar II.

of the possible link between psychopathology and creativity, Andreasen (1987) gave structured diagnostic interviews to 30 creative writers, who were faculty members at the prestigious University of Iowa Writers' Workshop, and 30 control participants, matched to the writers for age, sex, and educational status. The writers showed more affective disorder and more bipolar disorder than the controls. None of the participants, writers or controls, were diagnosed as schizophrenic. These results are comparable to those of Jamison (1993), which we have already discussed. Andreasen also examined the frequency of mental illness and the prevalence of creative achievement in the first-degree relatives of the writers and of the controls; these were assessed by asking the interviewees about the lives of their relatives. The relatives of the writers showed significantly more mood disorder than the relatives of the controls, and they also showed higher levels of creative accomplishment, such as having participated in a major dance

company or having had a solo exhibit of paintings. Andreasen concluded that a tendency toward mood disorder and a tendency toward creativity might be traits that run together in families, and both might be genetically mediated. She also noted that the findings indicated that there might be an advantage for society—increased creative accomplishment—brought about by the prevalence of the genes for psychopathology in the human gene pool. This creative advantage compensates at the societal level for the negative aspects of psychopathology at the level of the affected individuals.

A study by Richards and colleagues (Richards, Kinney, Benet, & Marzel, 1988) further investigated the possibility that there is a compensatory advantage to bipolar illness in the form of increased creativity. The study examined the prevalence of creative accomplishment in bipolar individuals (individuals suffering from either Bipolar I disorder or cyclothymia), their normal relatives, and a control group of individuals who had no personal or familial link to bipolar disorder. Creativity was measured using the Lifetime Creativity Scales, which ask the person about creative accomplishments throughout life, in professional activities as well as in other aspects of life, such as hobbies. This scale examines a broader range of potentially creative activities than do the measures usually used, such as those used by Andreasen (1987). Results indicated that the individuals suffering from cyclothymia and the normal relatives of the Bipolar I individuals had achieved the highest levels of creative accomplishment. The individuals diagnosed as suffering from Bipolar I disorder were no more creative than were the normal controls. Richards and colleagues proposed that the relatives of bipolar individuals carried some of the genes underlying the disorder and that those genes in some way facilitate creative accomplishment.

Richards (2000–2001) also raises the question of why bipolar disorder has remained in our genes throughout the evolutionary history of our species, especially since it has such devastating effects. She speculated that bipolar disorder is still in our inheritance because the positive effect on creative thinking is an advantage provided by the genes, which compensates for the negative aspects of psychopathology. Richards makes an analogy to sickle-cell anemia, another genetically transmitted disorder. That disorder depends on genes from both parents (in other words, only homozygous individuals contract the disease); individuals with only one gene (heterozygous carriers of the disorder) turn out to have an increased resistance to malaria. So the sickle-cell gene produces a competitive advantage in the heterozygous individual. Similarly, the genes for bipolarity might, in some individuals who contain the right subset of them, provide a positive advantage in the form of increased creativity of thinking.

Mood Disorders and Creativity: The Question of Causality

The results discussed in the last two sections, while impressive in showing evidence that bipolarity and creativity may be connected, demonstrate at most only that there is a *correlation* between the bipolar spectrum and creativity; that is, the two go together. The various findings just reviewed do not, however, show a *causal link* between mood and creativity; that is, they do not show, for example, that the occurrence of hypomania *changes a person's thought processes for the better* or that the presence of hypomania *brings about increased creativity in thinking*. Indeed, the results just discussed do not show that hypomania changes a person's thought processes in any way. Furthermore, even if there is a relationship between the presence of bipolar disorder (in some form) and creative accomplishment, that does not mean that the bipolarity is the cause of the creative accomplishment. There are other possible links between bipolarity and creativity. For example, it might be that creativity causes bipolarity. Perhaps being creative, or working in an area that demands creativity, can cause a person to become bipolar (although that might seem an implausible suggestion, there is actually evidence, which will be discussed later, that supports it). So more information has to be gathered before we can conclude that bipolarity in some way causes people to be creative. Jamison (1993) has presented a hypothesis concerning how the thought process might be made more creative by bipolar disorder. Following a suggestion made by Kraepelin (1921), a pioneer in the study of psychopathology, she assumes that thought processes might be made quicker and might be broader during mania. However, she presents no direct evidence that thought processes are actually changed.

Does Mania Increase Creativity?

In order to test the hypothesis that being in a manic state can increase the creativity of the thought processes, I carried out an analysis of the creative productivity of classical composer Robert Schumann (Weisberg, 1994), who is generally believed to have suffered from bipolar disorder. Schumann experienced periods of manic elation followed by bleak periods of depression, in which he tried more than once to kill himself. He spent time in asylums, as did other members of his immediate family, and he died in an asylum of what may have been self-induced starvation. Slater and Meyer (1959) carried out a retrospective psychiatric diagnosis of Schumann's mental condition, based on doctors' records and other historical documents, such as letters written by Schumann and his acquaintances; they concluded that he probably suffered from bipolar disorder. Slater and Meyer presented

evidence that Schumann's disorder affected his work, as shown in Figure 7.1A, which shows the number of compositions Schumann completed in each year of his career and the diagnosis of his prevailing mood state for that year. As is shown in Figure 7.1B, Schumann was approximately 5 times more productive during his manic years. There thus seems to be no doubt that at the very least Schumann's energy and motivation to work increased greatly during the years when he was emotionally "high."

However, once again, the results in Figure 7.1B do not say anything about whether Schumann was producing *better* (or even different) compositions during his manic years; they only show that he was producing *more* of them. In order to go that next step, I examined whether Schumann's changing mood states affected his compositional process (Weisberg, 1994), by measuring whether he produced better compositions during the manic years. In order to carry out such an analysis, one first needs a measure of how good a composition is, and a number of such measures have been used by past researchers. One can ask experts, such as professional musicians and critics, to judge how good each composition is. One can also examine how often a composition has appeared in concert programs. I took a simpler measure, one that had been used by Hayes (1989): the number of recordings available for a musical composition, with more recordings indicating a better work. This measure is based on the opinions of critics, musicians, and the record-buying public. It should also be noted that this measure of quality correlates highly with other measures, such as how often a composition is discussed in critical analyses of music. Thus, the number of recordings is more than simply a measure of the popularity of compositions.

If Schumann's periods of mania improved his thought processes, then compositions produced during his manic years should be recorded more frequently, on average, than compositions produced during the depressive years. The results of this analysis are shown in Figure 7.2, and they do not support the hypothesis that Schumann became more creative during his manic periods; Schumann's compositions from manic years were not, on average, recorded more frequently than those from depressive years. Even though he produced *more* compositions during the manic years, those compositions were not better ones. Thus, we can conclude that in Schumann's case the creative thought process was not changed for the better by bipolar disorder, although his motivation to compose, as measured by the number of compositions produced in a given year, certainly seems to have increased.

Obviously, a single study of one individual cannot settle an issue as complicated as this, but these results, if valid, are potentially important in several ways. First, they tell us something about the creative process: Contrary to

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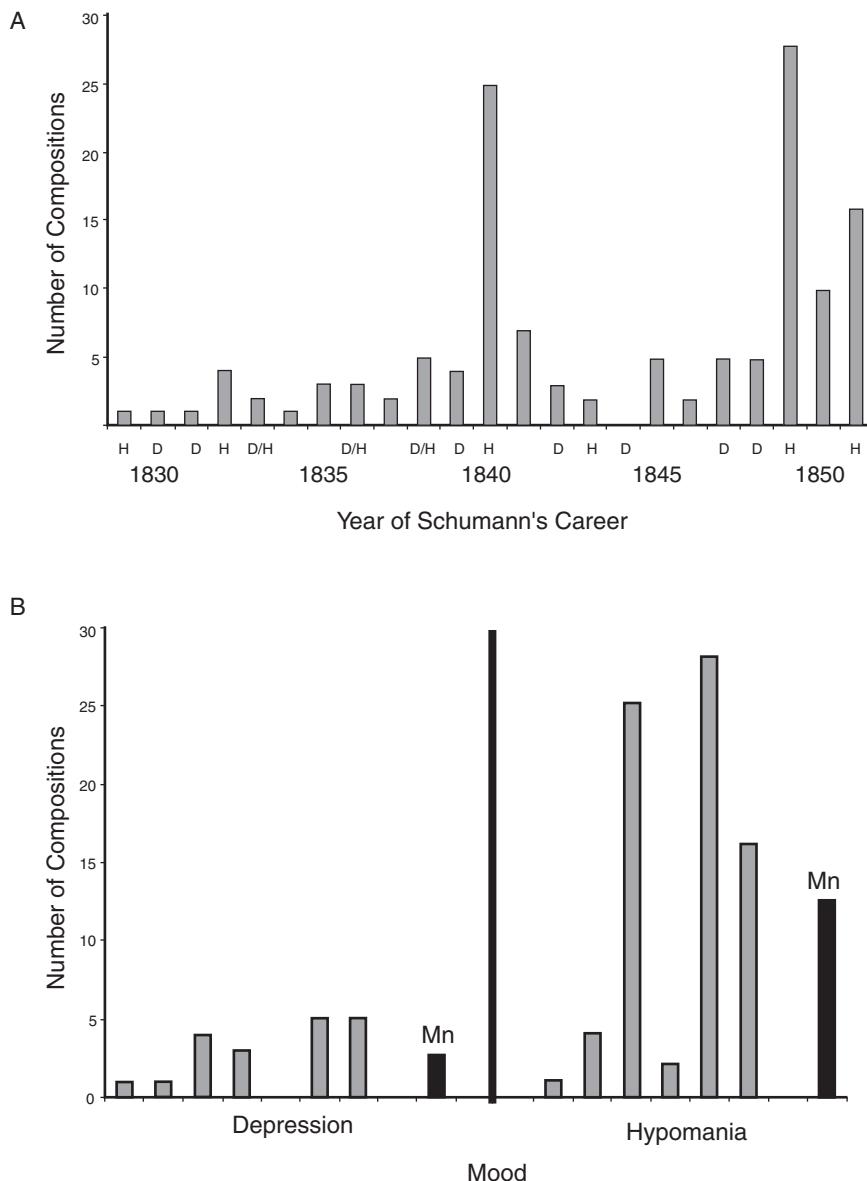


Figure 7.1 Mood and productivity in Robert Schumann:
A, Schumann's productivity over his career (H = Hypomanic;
D = Depressed); B, Schumann's productivity as a function of mood
Source: Weisberg (1994).

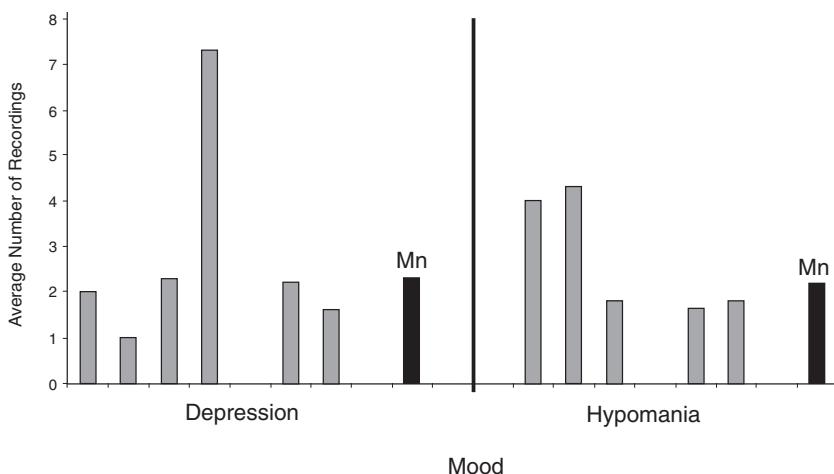


Figure 7.2 Quality of Schumann's compositions

Source: Weisberg (1994).

much popular belief, madness, at least in the form of mania, may not have a positive effect on creative thought. Perhaps more important, the results in Figure 7.2 may be useful to creative individuals who suffer from bipolar disorder. Bipolar disorder can often be brought under control by the drug lithium carbonate. However, many individuals in creative professions who have been diagnosed with bipolar disorder do not take their medication because they are concerned that their creativity will be wiped out (Jamison, 1993). If it is true that mania only increases *output*, without affecting *quality* of creative work, then taking lithium will not wipe out the person's capacity to produce high-quality works. One might produce fewer works, but one could still produce good works. In addition, taking lithium might save an individual from depression and its potentially devastating effects (see also Schou, 1979, for further evidence that mania may not increase creativity and that taking lithium may not wipe it out).

There are several assumptions that should be made explicit underlying the analysis carried out by Slater and Meyer and the extension of their analysis that I carried out. If one classifies the years of Schumann's life according to the dominant diagnosis for the year, one is ignoring the possibility that multiple states might occur in a single year. Second, when one examines Schumann's productivity over the years and draws conclusions concerning the relationship between his emotional state and his productivity, one is assuming that the mood state is the only relevant factor for each year. However, there might have been other factors during those years that could have affected his creativity. For example, during the manic years, there

might have been more stress in Schumann's life (or, perhaps, less stress; the specifics do not matter to the logic of the argument). The stress level might have been what affected his creativity, not his emotional state. The analysis carried out by Slater and Meyer was not able to examine this possibility, and the one I carried out, which built on theirs, also did not address it; I ignored those sorts of questions so that I could go forth with the analysis. However, I believe the conclusions are still of interest because, even if one assumes that only one mood state was involved in each year, and even if one further assumes that only that mood state, and nothing else during that year, was affecting Schumann's compositional process, there is still no support for the notion that mania facilitates creative thinking.

Ramey and I (Ramey & Weisberg, 2004) recently carried out a similar analysis of the career of the poet Emily Dickinson (Ramey & Weisberg, 2004), who has also been diagnosed retrospectively as having suffered from Bipolar I disorder (McDermott, 2000, 2001). We looked at the quantity and quality of the poems produced over the different years of Dickinson's life and compared the quantity and quality of poems produced during manic, depressed, and neutral years. The quality of a poem was measured by determining how often the poem was published in more than a dozen compendia of poetry. As with Schumann, we found large differences in quantity of output, with manic years resulting in high output. However, in the case of Dickinson we also found some evidence that the poems produced during manic years were better ones, so the results for her were not strictly parallel to those for Schumann, and they provide support for the notion that mania may increase creativity. Thus, two studies that have tried to more directly test the notion that bipolar disorder increases creativity have provided mixed support for that idea.

Creativity as a Cause of Mania

The mixed findings from my study of Schumann (Weisberg, 1994) and Ramey and Weisberg's (2003) study of Dickinson leave us with another question. If we assume for the sake of discussion that the correlation between bipolarity and creativity is real—that is, if we assume that there is a tendency for creative individuals either to have or to be related to individuals who have some form of bipolar disorder—then why is there a correlation between the two? It has usually been assumed, as we have seen, that any causal link between mood (in this case, mania) and creativity must involve the mood state affecting the creative process (e.g., Jamison, 1993). However, recent theorizing concerning the development of mood disorders, including bipolarity, raises the possibility that the causal link might be in the opposite direction. That is, rather than mania influencing the creative process, it

has been suggested that hard work in an area that results in creative output might stimulate the development of bipolarity.

As we have seen, there is evidence of a genetic basis for the tendency to develop bipolar disorder (Jamison, 1993), and Depue and Iacono (1989) have proposed that that inherited tendency may be the result of an overly sensitive *behavioral activation system*, which responds in a hyperactive manner to certain sorts of life events and thus produces full-blown mania. The behavioral activation system can be triggered by such events as goal striving and attainment (Johnson et al., 2000), which might occur, for example, as an individual is working on and producing creative works—say, as a poet is composing poems. Thus, contrary to the usual belief, it may be that creative work plays a causative role in the development of bipolar disorder, rather than the converse. This is an interesting twist on the traditional view.

Possible Links between Bipolarity and Creativity: Conclusions

As far as an understanding of the creative thinking process is concerned, we can say that the evidence for a relationship between genius and madness in the form of bipolarity is only correlational, and claims for a cause-and-effect relationship have received mixed support in two studies that attempted to go beyond correlation (Weisberg, 1994; Weisberg & Ramey, 2003). There seems to be no doubt that the extreme mood changes experienced by bipolar individuals affect their motivation to work and hence their output. However, the quality of the work may not change, meaning that the creative thought processes might not be changed by mental illness, at least not by bipolarity.

The Role of Affect in Creativity

As we have seen, the critical characteristic of the bipolar spectrum is *extreme change in mood*. Therefore, when one is examining the possible influence of bipolarity on creativity, one could say that one is examining the possible influence of strong mood states on creativity. Although we have just seen that there is room to doubt that bipolarity causes changes in creativity, some evidence from laboratory research demonstrates that changes in affect, especially increases in positive affect, can play a positive role in creative thinking. Russ (2000–2001) links such results to primary-process thinking, since that mode of thinking is assumed to involve thought content that is heavily affect-laden. However, others have linked studies of affect in creative thinking to the possible relationship between mood disorders and creativity, which is why I am discussing them here. This research has been carried out by Isen and colleagues (summarized in Isen, 1999), who

have examined the influence of *induced mood* on creative thinking. In these studies, undergraduates are exposed to a procedure designed to induce mood (usually positive affect); for example, participants might be exposed to a comedy film or be given an unexpected prize on arriving at the location of the experimental session. Isen and colleagues have shown that a number of different behaviors, some of which seem to be related to creativity, are affected by such manipulations.

In one study (Isen & Daubman, 1984), participants were given a large set of stimuli and were asked to put them into groups that seemed to go together. The participants categorized the stimuli more broadly after positive mood induction. That is, they put more stimuli together in fewer groups, making broader categories. It might be assumed that such categories would facilitate making connections among items that would not have been available otherwise. Induced positive affect also resulted in participants' providing more varied word associations to stimulus words than did control participants (Isen, 1999). Here, too, those varied associations might be expected to facilitate creative thinking. For example, assume that I would typically produce words B and C when given word A; if, when I am happy after watching a comedy, I produce B, C, G, H, and Q, then I might have available a larger set of possibilities out of which to construct a creative response to some situation. Finally, Isen, Daubman, and Nowicki (1987) found that induced positive affect also facilitated problem solving.

Isen and colleagues (1987) and Russ (2000–2001) interpreted those sorts of results as indicating that positive affect serves as a retrieval cue in memory, which cues memories with a positive connotation as well as cuing a large amount of material. This cuing effect results in more varied responses, since there is more material for the thinker to work with, which in turn will facilitate creative thinking. In addition, Russ proposes that strong emotionally laden material in memory would be especially important in artistic creativity, since the arts are centered on affect.

Lubart and Getz (e.g., 1997) have also theorized that the emotional content of memories can play a role in creative thinking. They assume that the emotional content of a situation is stored as part of one's memory of that situation. Emotional content can then serve as a retrieval cue and assist in recalling memories. If the individual encounters a new situation that possesses some emotional tone, that new situation will, through its emotional coloring, retrieve from memory traces of experiences that also possess that emotional tone. Thus, emotion can serve as a link between a present experience and memories that might not be related to it in content. Emotional tone might serve to link a present situation with memories that might not have anything else in common with it, so emotion can serve as a

retrieval cue beyond informational content. In Chapter 1, I discussed Goya's *Disasters of War* as a possible source for some of the characters in Picasso's *Guernica*. It was suggested that Picasso might have thought of Goya's work at that time because of the overlap in emotion between the two projects. That suggestion is consistent with the analysis of Lubart and Getz.

It should also be noted that theorists have postulated that emotions play several roles in the creative process. First, positive affect accompanying discovery and other creative achievement may serve to motivate the creative individual (Gick & Lockhart, 1995). Second, as we have seen, emotions serve as possible linkages between ideas in the creative process.

Questions about Affect and Creative Thinking

The studies of Isen and colleagues (Isen, 1999) have shown that induced affect results in changes in behavior; that is, increased positive affect results in broader categorization, more varied word associations, and facilitation of problem solving. However, let us consider the question of the relationship between those behaviors and *creativity*. The conclusion that induced affect facilitates creative thinking is based on the prior assumption, not usually explicitly stated, that creative thinking is a two-stage process with which we are familiar. The first stage requires what one could call free-associative or wide-ranging thinking; the second stage takes the products of the first stage and shapes them into a useful product. We have already discussed this distinction in this present chapter and in several earlier ones, and we will see it again in later chapters. This two-stage conception was seen in the discussion earlier in this chapter of the possible roles of primary- versus secondary-process thought in creativity. As mentioned, primary-process thinking was assumed by the Freudian view to have a looseness about it that allowed the thinker to bring together ideas that he or she never would have thought about when using secondary-process thought.

We have already reviewed evidence that casts doubt on the view that the creative process begins with free association. As two concrete examples of such negative evidence, let us consider again the case histories of DNA and *Guernica* discussed in Chapter 1, and the other case studies presented in Chapter 5. In all those examples, we were able to understand how the creative achievement was brought about without assuming that there was an initial free-association stage of thinking in which the creator produced wild leaps of far-reaching imagination. Rather, the new achievements built firmly on the old and moved away from it in small steps. If this analysis of creativity applies still more broadly, and there is no compelling reason to believe that it does not, it means that Isen's findings may not be directly relevant to creative thinking. That is, although positive affect may influence

categorization, word associations, and problem solving, it may not do so in the way that Isen believes it does. This leaves us with the question of how positive affect influences those behaviors, to which I have no answer.

Genius and Madness: Schizophrenia and Creativity

As was discussed at the beginning of the chapter, early interest in the relationship between genius and madness centered on the possibility that schizophrenia is the form of madness connected with creativity. This assumption was derived from Freudian theory, which assumed that schizophrenic thought was based more directly on primary process than is ordinary thinking. Therefore, to the degree that creative thinking also depends on primary-process thinking, it was hypothesized that there might be a link between the presence of schizophrenia and creativity. As already discussed, over the last 30 years researchers concentrated instead on the relationship between bipolar disorder and creativity, in part because empirical findings indicated that the thought processes in normal creative individuals were more similar to those of persons with bipolar disorder than those of schizophrenics. In addition, we have seen that studies have indicated that relatives of bipolar patients produced high levels of creative accomplishment in their lives. More recently, however, interest has turned again to the possibility that aspects of schizophrenia may be related to creativity.

The Schizophrenia Spectrum

Like bipolar disorder, schizophrenia is now looked upon as being a spectrum of disorders (Schulberg, 2000–2001), ranging from less-severe levels of mental disorder to full-blown psychosis. Schizophrenic psychosis is characterized by a cutting off of the individual from reality: Individuals suffering from schizophrenia are often withdrawn from the world, with *flat affect*—a lack of emotional responsiveness or inappropriate emotional responsiveness to events—and what can be a lack of general responsiveness to external events. Schizophrenics also experience hallucinations and delusions, further cutting them off from the world. Schizophrenia has, in the history of research on mental illness, usually been characterized as a disorder based on problems in thinking. Two kinds of thought disorder can be seen in schizophrenics: disorders in the *content* and in the *form* of thought. Disordered content of thought is seen in ideas that are false, delusional, deviant, and bizarre (Schulberg, 2000–2001). It should be noted that delusions are not limited to persons with schizophrenia; some individuals with bipolar disorder also experience delusions.

The disordered form of schizophrenic thought is seen when one exam-

ines how thoughts flow: how thoughts occur in sequence, how they are linked one to another, and how they are communicated linguistically. Schizophrenic thought has several distinguishing formal characteristics, among which are illogical patterns in thinking. A male schizophrenic might reason as follows: You are a beautiful woman; I am beautiful as well; therefore, I am a woman. Schizophrenic thought is also characterized by loose associations, where the link from one thought to another cannot be followed by another person, and impoverished speech, which is accompanied by unusual and idiosyncratic language, including the making up of new words. Thought disorder is also seen in bipolar patients, which raises the question of whether different conditions are involved, but presently it is believed that the thought disorder in bipolarity is of a different type from that in schizophrenia. Among other differences, bipolar individuals produce speech that is more comprehensible to the listener, and the structure of their thinking usually can be followed. Schizophrenia is characterized by thinking that is unique to each individual. Milder disorders along the schizophrenia spectrum are seen as *schizotypal* and *schizoid* personality disorders (Sass, 2000–2001). Individuals with these disorders show such characteristics as emotional coldness and difficulty in maintaining intimacy in human relationships, which sometimes manifests itself as social anxiety; they also show unconventionality or eccentricity in behavior, which may manifest itself as a belief in special powers, such as the ability to sense events before they occur or to read others' thoughts.

Schizophrenia and Creativity

Recent examinations of the relationship between schizophrenia and creativity have followed the lead of studies of bipolarity and creativity by concentrating on milder forms of the disorder. Full-blown schizophrenia, with its delusions, hallucinations, and lack of engagement with the world, would seem to be antithetical to creative thinking. Kinney and colleagues (2000–2001) used the Lifetime Creativity Scales to examine creative accomplishment in a unique set of individuals: Each was a normal person with one parent who suffered from schizophrenia, and each had also been adopted and raised by nonschizophrenic individuals. It has been concluded that, like bipolarity, schizophrenia has a strong genetic component (e.g., Kinney et al., 2000–2001; Straube et al., 1994; but see Joseph, 1999, for a dissenting view). Thus, as in the research on bipolarity, it was assumed that the set of adopted individuals with one schizophrenic parent carried some of the genes for schizophrenia but not the full complement, since they, unlike the parent, did not present with the disorder. The adopted individuals with one schizophrenic parent were each matched for age, sex, age at adoption,

and socioeconomic status with an adopted individual who had no family history of schizophrenia, who served as a control.

Compared with the matched control group, the adopted offspring of one schizophrenic parent exhibited higher levels of peak creative accomplishment on the Lifetime Creativity Scales (Kinney et al., 2000–2001). Furthermore, when the creativity levels of the adopted-out children of one schizophrenic parent were examined further, it was found that those individuals who exhibited more schizophrenic traits, but who, it must be emphasized, were not schizophrenic, exhibited the highest levels of creativity. That is, the highest levels of creative accomplishment were shown by those adoptees who exhibited the schizophrenic symptoms of magical thinking, odd thinking, and recurring illusions. To the surprise of Kinney and colleagues, the relationship between schizophrenic tendencies and creative accomplishment also held in the *normal* control group: Normal individuals in the matched control group who exhibited milder symptoms of schizophrenia were more creative than control-group members who did not. Kinney and colleagues also found that the pattern of creative accomplishment in the schizophrenic adoptee group was different in one important way from that found in the relatives of bipolar individuals. As noted earlier, relatives of bipolar individuals showed more creative achievement in their professional lives; in contrast, the adopted offspring of the schizophrenic parents showed more creative achievement in their *avocations*, such as their hobbies. Kinney and colleagues explained this pattern with the assumption that the personality characteristics of the adoptees of one schizophrenic parent—most importantly, social anxiety—probably interfered with professional careers in areas requiring creative thinking: They were concerned about receiving negative evaluation from others. Avocational interests, on the other hand, can be pursued on one's own, with little fear of evaluation by others, so the adoptees with one schizophrenic parent would feel more comfortable pursuing such activities in their private lives.

Sass (2000–2001) has recently examined the broader question of what factors play a role in determining why psychopathological symptoms might be related to creative achievement. He has proposed that there are certain characteristics of the postmodern and post-postmodern movements in the arts that might increase the likelihood that individuals who exhibit some schizophrenic symptoms might participate in them. Those movements, which developed during the second half of the twentieth century, are noted for a “coolness” and an ironic posture, as the artist maintains an attitude of remove from the world so as to comment on it as an outsider. A clear example of an individual taking such a position would be Andy Warhol. Those characteristics—coolness, irony, and remove—also describe the

individual who has the schizotypal or schiziform personality, so it is possible that such individuals would find the postmodern art world a comfortable environment.

This postmodernist philosophy of aesthetics opens for Sass the possibility of a relationship between creativity and the schizophrenic spectrum based on the particular characteristics of the spectrum of schizophrenic disorders. Those conditions have in common a lack of affect or peculiar expressions of affect; apathy and withdrawal from the world; and an indifference to events in the world (Sass, 2000–2001, p. 61). It seems that the person experiencing such symptoms might feel comfortable in postmodern artistic activity. Thus, in addition to characteristics of *thinking* that might contribute to creative accomplishment, there is also a broader issue concerning *personality characteristics* that play a role in determining whether an individual is comfortable in such a career in the first place. The differing value systems advocated by different historical movements in art would change the selection factors that influence who would be attracted to a career in art.

As a further example of the relationship between an artistic movement and personality factors, Sass notes that the artists whom Jamison (e.g., 1993) discusses as probably suffering from bipolar disorder are typically members of the Romantic movement, in which a passionate involvement in one's art was an expected characteristic of the artist. People with the high degrees of energy, emotional outflow, and flamboyance characteristic of the bipolar spectrum might have been attracted to the artistic milieu of the Romantic era. Pursued further, Sass's reasoning would mean that the personality characteristics found in creative individuals might change depending on the prevailing philosophy of the arts, which might emphasize different personal aspects of the artist. Sass also notes that the schizophrenia spectrum of disorders has often been looked upon by researchers as being akin to dementia, with an accompanying belief that those individuals are capable of little or nothing in terms of intellectual achievement. He takes the work demonstrating a possible connection between characteristics of schizophrenia and creative accomplishment as evidence that such individuals are not incapable in such domains.

A study by Ludwig (1998) provides some fascinating data that can be taken as support for Sass's (2000–2001) hypothesis concerning the relationship between creativity and psychopathology, and, more specifically, as evidence of a relationship between psychopathology and the content of a creative domain. Ludwig studied the biographies of eminent individuals in a broad range of creative fields and used them to determine whether the individual had some form of mental disorder at some point in life. Ludwig

concluded that if one differentiates fields into “logical, objective, and formal” versus “intuitive, subjective, and emotional” (e.g., science versus art), one finds clear differences in the frequencies of psychopathology: Scientists are much less likely to suffer from psychopathology than are artists. Furthermore, the same pattern holds *within* the sciences and arts themselves: If one compares the “harder” or more objective sciences with the “softer” social sciences, for example, one finds higher rates of psychopathology in the latter. Similarly, if one differentiates between more- and less-formal or more- and less-emotional domains within the arts, one sees less lifetime psychopathology in the more-formal, less-emotional domain: For example, less psychopathology is evident in architecture than in the performing arts (e.g., music, dance) or expressive arts (e.g., literature, visual arts). And if one goes still deeper, one sees the same pattern within each domain: In painting, say, those who practice more emotional styles show more psychopathology than painters working in more formal styles. Ludwig concluded on the basis of his analysis that there is a relationship between psychopathology and forms of creative expression: The more a profession relies on emotion, subjectivity, and personal expression, the greater the chances that members of that profession will exhibit psychopathology. Ludwig believes that his results show that people who are less emotionally stable may be drawn to certain professions (or to certain subdomains within a given profession). This conclusion is consistent with Sass’s view, although Ludwig’s analysis does not focus on schizophrenia.

Schizophrenia and Creativity: Conclusions

Recent work on the possible relationship between schizophrenia and creativity represents a return to a hypothesis that was investigated a number of years ago and then set aside. However, recent research has approached the question from a different perspective: Instead of building on the assumption that creative thought processes might be facilitated by schizophrenic tendencies, the present work examines the possibility that personality characteristics might play a role in an individual’s choice of an artistic career. So the postulated connection between schizophrenia and creativity has changed drastically over the years.

Social Factors and Genius and Madness

We have seen that there is some evidence of a significant relationship between aspects of psychopathology—aspects of the bipolar and schizophrenia spectrums—and creativity. The underlying basis for this association

is not completely clear at this point, however. Although it had originally been assumed that psychopathology changed the thought processes of an individual, there is some negative evidence for that assumption as far as mood disorders are concerned (Weisberg, 1994). There is as yet no evidence, positive or negative, concerning the influence of the schizophrenia-spectrum disorders on the thought processes. At present, therefore, the idea that possession of schizophrenia-spectrum genes might make thinking more creative is an unsupported hypothesis. All we know is that normal people who are related to people suffering from schizophrenia accomplish more in creative domains than do matched control individuals. Given this lack of data, it is of interest to consider a number of other possibilities concerning the nature of the link between psychopathological states and creativity. We have already considered the possibility that deep involvement and success in creative activity might actually induce mood disorders through the activation of the behavioral activation system (Johnson et al., 2000), which turns the usual assumptions on their heads. At this time there is no evidence that creative accomplishment can induce any of the schizophrenia-spectrum disorders, but that might be a hypothesis worth pursuing further.

The discussion so far has concentrated on the possibility that the creativity-psychopathology link centers on thinking, although the direction of the link is unclear. However, researchers have considered other ways in which creativity and psychopathology might be linked. Sass (2000–2001) has argued that the current emphasis on the possible positive role of madness, and especially bipolar illness, on creativity can be traced to the Romantic movement of the late eighteenth through the early nineteenth centuries. In the Romantics' view, creativity was dependent upon the creative imagination, which produced a spontaneous outflow of feelings unencumbered by rational and critical self-consciousness. Thus, the truly creative poet or painter was assumed to be able to tap into his or her emotions in a direct way, without any interference from society's rules and restrictions, as those are represented in our conscious thought. This upwelling of feeling was assumed to have been within our grasp as young children but lost by most of us as we became socialized adults. The creative artist, however, retains the ability to allow this emotional spring to flow and to channel the output into works of art. Sass quotes Koestler (1964, p. 169), who describes the

temporary relinquishing of conscious controls [that] liberates the mind from certain constraints which are necessary to maintain the disciplined routines of thoughts but may become an impediment to the creative leap; at the same time other types of ideation on more primitive levels of mental organization are brought into activity.

Many others who have studied creativity, some of whom we have already discussed, have arrived at similar views concerning the need for a “primitive” mode of cognition in order to produce novel ideas. Martindale (1989), for example, took it for granted that primary-process thinking, or something much like it, is necessary for creativity. Eysenck (1993), a clinical psychologist who examined the possible connection between psychopathology and creativity, said that creativity depended on a weakening of functioning in “higher” centers, which resulted in an increase in activity in more primitive areas. Similarly, Kris (1952) described the act of creativity as requiring “regression in service of the ego,” meaning a return to a more primitive way of functioning, but in a way that is under control of the more mature processes. That notion of higher-order control is what separates the creative artist from the individual who simply regresses; in the artist, regression is in the service of art. This return to earlier, more primitive functioning serves as the basis for the creative inspiration. The reason artistic symbols have emotional force for other individuals, in this view, is because the artist is able to tap into universal primitive thinking processes and in this way make his or her symbols able to arouse strong feelings in the audience.

This set of assumptions is one reason, in Sass’s (2000–2001) view, for the attractiveness of the idea that bipolarity is linked to creativity: The emotional upheavals that accompany that condition seem to be the sorts of things that might serve as the basis for tapping into basic emotional activities, independent of control by mature rational processes. Thus, in reviewing the literature documenting the connection between bipolarity and creativity, Jamison (1993) says that “From virtually all perspectives, there is agreement that artistic creativity and inspiration involve, indeed require, a dipping into preoperational or irrational sources” (pp. 103–104). This is another way of saying that creativity depends on a regression to a more primitive level of functioning, which allows the creator access to strong emotional experiences, which can serve as inspiration. One notable aspect of bipolarity is that mood swings are sometimes seasonal: Mania is more likely in the spring and summer, depression in the winter. This seasonality, in Jamison’s view, indicates that an individual suffering from bipolarity is in some way in tune with the natural world, so the artist suffering from bipolarity is “closer to the fundamental pulse of life” (p. 129). Thus, the Romantic view, linking inspiration to the creative imagination, fits nicely with the notion that bipolarity and creativity also ought to be linked. As Sass (2000–2001) notes, however, this view of creativity is not universal, which raises some interesting questions concerning causal links between psychopathology and creativity.

Psychopathology and Creativity: Cultural Relativism

Other cultures have views of creativity very different from the regression view that creative inspiration depends on some sort of primitive thought process. Even in Western culture, the regression view of creativity has not been in favor throughout history. Both before and after the Romantic movement, says Sass (2000–2001), the Western conception of creative process has been very different, and in some ways much more “rational.” During the twentieth century, for example, the Modernist and Postmodernist views have looked negatively on Romanticism and the notion that emotional irrationality is at the core of creativity. As a prime example, Andy Warhol produced works that were essentially devoid of emotion and that functioned to draw the audience into a feeling of alienation from the world, rather than passionate involvement in it. In Sass’s view it is not inevitable that high degrees of emotionality are necessary for creative inspiration, and it is also not inevitable that individuals suffering from one of the disorders in the schizophrenic spectrum are doomed to be unable to carry out creative activities.

Schulberg (2000–2001) and Sass (2000–2001) also discuss the relationship between psychopathology and the two kinds of creative work in science that have been discussed by Kuhn (1962). In Kuhn’s view, progress in science comes about in two ways. During *normal* science, the mainstream of investigation in a discipline is carried out within a *paradigm*, a set of shared beliefs concerning how science is carried out, the basic questions that are to be addressed, and the methods used to address them. An example of a paradigm in science is American behaviorism in psychology, which flourished during the first two thirds of the twentieth century. This paradigm focused on elucidating the S-R relationships underlying all behaviors, and behaviorists studied learning in simple organisms as the basis for understanding more complex phenomena in more complex organisms. During a “normal” period, when there is a dominant paradigm in a science, scientists working within that paradigm carry out *puzzle-solving* activities. These activities involve creative thinking, as new experiments are designed and carried out, but the basic assumptions underlying the paradigm are not questioned. In contrast to normal science are periods of *revolution* in science, when the basic assumptions of a paradigm are brought into question and a new paradigm is brought forth to replace the old one. An example of such a revolution can be seen in the changes that occurred in American psychology in the last third of the twentieth century. The cognitive perspective, with its emphasis on analysis of internal cognitive processes and direct study of complex phenomena, such as human problem solving and reasoning, displaced behaviorism.

Schuldburg (2000–2001) notes that individuals with schizophrenic characteristics—antisocial aspects, a tendency to go in their own direction, and occasional eccentricities—might play a large role in revolutionary creative developments. Sass (2000–2001) discusses evidence that individuals who suffer from disorders in the bipolar spectrum tend toward conformity and are concerned about social norms (p. 70). Thus, such individuals might be expected to work more within existing paradigms than to demolish them in revolutionary creative activity.

These analyses have provided alternatives to the notion that psychopathological tendencies and creativity are related in a simple way (i.e., psychopathology causes creativity, or creativity causes psychopathology). Rather, the proposals of Sass and Schuldburg raise the possibility that psychopathological tendencies and creativity may be related only in indirect ways, as the personality characteristics of the individual influencing whether he or she will attempt to participate in a given creative milieu. This analysis adds nuance to the discussion, and, if correct, it indicates that the psychopathology-creativity link may be very indirect. That is, if it were discovered that a person with schizophrenic characteristics participated in a scientific revolution, it might not have anything to do with the person's creative capacities, per se. The schizophrenic characteristics might have had no effect whatever on the person's thought processes; rather, those characteristics might simply have led the person to become involved in a certain kind of scientific activity in which a more social individual might not have invested time and effort.

Sociocultural Influences on Postulated Links between Creativity and Psychopathology

Becker (2000–2001) adds more richness to the discussion of the connection between psychopathology and creativity by placing it in a still-broader sociohistorical context. He has examined the historical development of the relationship between psychopathology and creativity in Western society and has proposed that the link between them during a given historical epoch depends on specific sociocultural factors acting at that time. The postulated positive link between creative genius and various forms of madness is relatively modern, having developed in the early nineteenth century. As already mentioned, the Greeks assumed that the individuals through whom new ideas were transmitted, although they were “out of their minds,” were not mad in the clinical sense of the term. During the Italian Renaissance in the sixteenth century, the term *genio* was applied to those of outstanding creative ability. Contrary to later views (including modern views) of creative genius, which esteemed the genius as the producer of works of great original-

ity, the Renaissance concept of *genio* demonstrated itself in the production of works that were imitative—attempts to copy nature and the works of established masters. This orientation also contrasts with the modern view of the creative genius as breaking away from what came before.

During the Enlightenment, the term *genius* was used to refer to one who possessed innate creative or imaginative power, as manifested in works of great novelty. However, a basic assumption underlying the Enlightenment view of genius was that in order to be effective, the power of genius had to be subject to rational control; unbridled imagination led to extravagance and production of novelty without taste. This view of the rational genius was not only the ideal; it may also have been seen in the behavior of the actual creative geniuses of the time. Wittkower (1973, p. 309, as cited by Becker, 2000–2001) noted, for example, that the masters of seventeenth-century art—Rubens, Bernini, Rembrandt, Velasquez, to name but a few—were not described as mad in any way. It is only later that madness becomes part of the description of the genius. At the end of the eighteenth century, the development of the Romantic movement brought with it a change in the conception of genius.

In Becker's (2000–2001) view, this change was related to the status at that time of creative thinkers—artists, scientists, philosophers. The reactionary political climate arising from Napoleon's defeat meant that creative endeavors, especially in the arts, and those who participated in them were not afforded the respect and freedom that they had received earlier. In order to establish themselves as individuals to be reckoned with by the establishment, Romantic thinkers proclaimed the unbridled expression of imagination in creativity as the single criterion most important in determining the value of a person. This led to admiration for those people who were capable of feeling things more deeply and directly, which in turn paved the way for a return of interest in the notion of genius and madness, but with a new component: It was now assumed that madness *in the sense of insanity* might be a component of the creative individual, due to his or her sensitivity to the emotional turbulence going on below the surface of life. One therefore sees a movement away from the belief that the controlled, rational working of the imagination is what is required for true genius. Rather, in the view of the Romantics as Becker interprets it, any rationality or deliberation would only hinder the application of the imagination, mainly through application of judgment that would not be able to see the potential value in ideas welling up from the imagination. As the poet Schiller says,

It is not well in the works of creation that reason should too closely challenge the ideas that come thronging to the doors. Taken by itself, an idea

may be highly unsuitable, even venturesome, and yet in conjunction with others, themselves equally absurd alone, it may furnish a suitable link in the chain of thought. Reason cannot see this. . . . In a creative brain reason has withdrawn her watch at the doors, and ideas crowd in pell-mell. (qtd. in Becker, 2000–2001, p. 49)

As we have already seen and will see many times in later chapters, the ideas expressed here by Schiller can be found almost unchanged in much modern theorizing concerning the creative thinking in general, and the relationship between genius and madness in particular.

In removing the role of rationality in the creative process and giving the imagination free rein, the Romantics set the stage for the serious reconsideration of the relationship between creative accomplishment and madness, this time with madness conceived as insanity. In Becker's (2000–2001) view, this set of circumstances, with the Romantic thinkers themselves initiating that reconceptualization, led those thinkers to contemplate the possibility that they themselves might show evidence of madness. Many Romantic thinkers, such as the poets Coleridge and Byron, expressed fear of insanity, in others and in themselves. The concern about insanity in individuals of creative accomplishment led to the study of such individuals by those with medical training. However, one problem with those early analyses, in Becker's view (pp. 50–51), was that much of the evidence to support conclusions concerning madness in people of genius was based on the reports of those individuals concerning their own purported illnesses. Those reports served to establish further that the individuals of genius were not like "ordinary" people, but surely such reports are at least a bit suspect since one of the core beliefs of the Romantic movement was that the genius was indeed different from the masses.

This tendency toward an uncritical belief in the reports of creative geniuses concerning their mental states is also seen in modern research in this area; Jamison (1993), for example, provides many self-reports from creative individuals—artists, poets, and writers—concerning their mood swings, fears of going mad, and other concerns. As noted earlier, many of these individuals were members of the Romantic movement (Sass, 2000–2001). Jamison assumes that their self-reports are to be accepted uncritically as evidence of mental states. However, as Becker (2000–2001) notes, several questions can be raised about such reports. First, reporting symptoms pointing to one's own madness may be self-serving, since the criterion for being considered a genius in the Romantic view is that one show such symptoms. Second, one cannot know with certainty that a description of a person's own psychological state, written by a Romantic poet, say, more than a century ago,

uses terms in the same way that they are used today. We should therefore be cautious in concluding that self-reports of madness in Romantic poets are evidence of insanity equivalent to a diagnosis drawn today by a professional on the basis of an in-depth interview with an individual.

Furthermore, to the degree that creative thinkers in the Romantic era believed—and to the degree that present-day creative thinkers also believe—that at least a touch of insanity might be necessary for creative genius, such individuals may actually have *looked for* and *welcomed* any of their own behaviors that might be interpretable as symptomatic of insanity. In addition, modern artists might be more likely to volunteer evidence of such behaviors to a researcher than would people in a “normal” or control group, since among people not in the creative professions, insanity or tendencies toward insanity are usually not something to be prized. Becker (2000–2001) presents the view of the philosopher Jaspers, who concluded that the greater frequency of mental illness in creative geniuses was the result of the way society applies judgments of creativity to people who produce novel works. In this view, the term *genius* is reserved by society for those individuals who demonstrate high levels of creative accomplishment *as well as evidence of mental illness*. That is, in order to call someone a genius, it has become necessary that he or she be at least a bit eccentric or abnormal. Thus, in a closing of the circle, the Romantic notion of genius has changed the way in which the term was and is now applied to people, which means that there will be a correspondence between the Romantic view and reality, if only because the reality—that creative geniuses will indeed be at least a little “mad”—now depends on judgments that themselves are based on the premises of the Romantic view.

A Reconsideration of Some Basic Data

The discussion in the last few sections of the development and cultural relativism of the notion of genius and madness raises several interesting questions, one of which concerns some of the basic data underlying the speculation that we have examined concerning how genius and madness might be related. The whole notion that there is a relationship between genius and madness is based on a seemingly simple fact: Psychopathology seems to be present more frequently among those of genius than among the ordinary population. This seems like a straightforward finding: Creative people suffer from psychopathology more than do ordinary folks. What is complicated about that? Count the numbers and see for yourself. However, consider first how it is determined that someone suffers from psychopathology; that judgment is based on examination of his or her behavior

or on reports concerning his or her behavior, and this is where things get complicated. If an individual in a creative occupation—a poet, painter, or musician—reports symptoms of madness, he or she might be misreporting things for any of a number of reasons. The artist might *overinterpret* a passing thought or fleeting action as indicating more than it does, and therefore might overreport the frequency or severity of that symptom. Thus, the frequency of symptoms in a creative group versus a noncreative control group, a seemingly objective measure, might not reflect the true frequencies of those symptoms in the individuals. The artist might also be more likely to seek help for a “symptom” that we ordinary folk might not get worried about. The artist, because of his or her concern about psychopathology, might be more likely to seek treatment, which is another presumably objective index of the frequency of psychopathology within a given group. In addition, the artist, believing that madness is related to genius, might lie about the frequency of psychopathological symptoms that he or she suffers to enhance his or her stature as a possible genius.

On the other side, to the degree that we observers of the art scene are aware of the possible connection between genius and madness, we might be more likely to see psychopathology in artists than in our ordinary friends and acquaintances. The same harmless eccentric behavior, say, present in ourselves and in an artist, might be given more weight as a symptom of psychopathology in the latter. Finally, we observers are much more likely to look more closely at the lives of geniuses than at those of ordinary people, and therefore we might be more likely to find psychopathology in the former. Surely the biographical scrutiny that geniuses come under, which almost never happens to ordinary folks, makes it more likely that madness will be found in the lives of the greats.

We can thus see that simply determining the frequency of psychopathology in a selected population—say, nineteenth-century British poets—is a complicated activity. Furthermore, just as we saw evidence that creative activity can cause psychopathology in vulnerable individuals through activation of the behavioral activation system, we could argue that a similar relationship might hold between creative activity and reported frequency of psychopathology among creative individuals. That is, an individual’s deciding to become an artist might make it more likely that she will find psychopathology in herself or that the audience at large will find it. Thus, the ostensible fact that creative geniuses are subject to psychopathology with greater frequency than the general population turns out to be a fact of a different sort from the fact that there are more oak trees than maple trees on my block. Determining psychopathology in an individual—especially when that individual is of historical significance and that determination

may take place years after the person lived—depends on data that must be considered very carefully. Thus, the basic finding on which the whole genius-and-madness enterprise rests—creative geniuses are mad, count them and see for yourself—may be more apparent than real.

Genius and Madness: Conclusions

This discussion has made it clear that the relationship between genius and madness is much more complicated than one might have thought at first glance. The concepts of genius and madness are both highly complex, and the simple ideas with which we began the discussion—psychopathology might affect creativity; creativity might affect psychopathology—have become much more nuanced as we have examined a broader range of opinions on the matter. At present, the following conclusions seem to follow from the available results. There may be a connection between psychopathology and creativity: Creative individuals may show more characteristics that can be labeled as psychopathology than do noncreative individuals. However, it is not clear how that increased frequency of psychopathology among creative geniuses we are to interpret. The diagnosis of psychopathology in geniuses may be the result of factors—expectations on the part of the geniuses and of us—that might result in differential criteria for such a diagnosis in the genius versus ordinary individuals. That might mean that the differential frequency of psychopathology in geniuses might not be real.

Even if there is a higher frequency of psychopathology among persons of genius—that is, assuming that the relationship between genius and madness is not an artifact of how we think about geniuses—untangling the causal links in that relationship is a difficult task, since there are several causal scenarios that can explain a link between creativity and psychopathology. Most important, perhaps, is the recently emphasized possibility that creative striving and accomplishment might bring about the development of full-blown psychopathology among individuals who have inherited such tendencies (Depue & Iacono, 1989; Johnson et al., 2000). This finding means two things in the present context. First, at least in some cases, the direction of causality may be the reverse of that typically assumed to be the case. Second, the frequency of psychopathology in geniuses is thus exaggerated in another way, because at least part of the high frequency of psychopathology in geniuses might be the result of their creative work.

The discussion in this chapter also has relevance for the concept of the creative personality, that is, the notion that all creative people have certain personality characteristics in common and that these characteristics play a role in making the person creative. The discussion in this chapter has

indicated that that view too is too simple. We have seen that at the very least there is what one could call a personality-creativity interaction: That is, whether a person's personality is fit for creativity depends on the epoch in which the person is working. For example, pursuing the career of an artist during the Romantic period of the nineteenth century required personality characteristics very different from those involved in pursuing an artistic career in the postmodern period of the later twentieth century. If this conclusion is correct, then there is no such thing as a constant creative personality. The creative personality will be examined further in Chapter 10.

Finally, it is important to note once more that almost none of the studies that have examined the link between genius and madness have actually tried to test directly the hypothesis that psychopathology actually affects the creative thinking process. Two studies that did so, the study of the creative process in the composer Robert Schumann (Weisberg, 1994) and the poet Emily Dickinson (Ramey & Weisberg, 2003), provided mixed support for the theory that madness increases creativity of thought. No other studies have examined creative thinking in bipolar or schizophrenic individuals. Studies have examined the influence of induced positive emotional states on word associations and on problem solving in normal individuals (Isen, 1999), but those studies are at most very indirect support for the genius-madness link because the participants were neither geniuses nor mad. No studies at all have examined the influence of schizophrenia or schizophrenic symptoms on creative thinking. It seems that we need more data before we can conclude that there is a causal link between madness and genius, and the data that are presently available do not strongly support the existence of that link.

CHAPTER

8

Out of One's Mind, Part II

Unconscious Processing, Incubation, and Illumination

In the last chapter, we examined one component of the “out of one’s mind” perspective: the question of genius and madness, and the possible influence of psychopathology on creative thinking. We concluded that there was only mixed support for the simple notion that psychopathology *causes* people to think creatively and that there is a complex relationship between psychopathology and creativity. The causal link might in some cases actually work in the opposite direction, with creativity causing psychopathology. This chapter examines a related notion: that the unconscious plays a critical role in creativity. The logic behind proposals that unconscious thinking is the basis for creativity is the same as that which underlies theories on genius and madness: It is assumed that ordinary conscious thinking cannot produce novel ideas, so some other source is designated.

Outline of the Chapter

The present chapter will consider several variants of the notion that unconscious cognitive processing is crucial in creative thinking. This work centers on the phenomena of *illumination* and *incubation*. Illumination is the sudden appearance in consciousness of a creative idea or solution to a problem when one had not been thinking about the matter consciously—an Aha! experience. Who among us has not had such an experience, if only when remembering suddenly a name that had slipped our mind? The occurrence of illuminations has been taken as evidence for unconscious processing,

because if Aha! experiences do not come from conscious thinking, then, so the argument goes, where else could they come from but the unconscious? It has been proposed that *unconscious incubation*—thinking about the problem unconsciously while you are consciously thinking about something else—is the explanation for sudden illumination. However, not all researchers are comfortable with the concept of unconscious processing as an explanation for psychological phenomena, and several have proposed explanations for sudden illuminations that do not rely on unconscious processes.

I will take a historical perspective in examining the variations on the theories of unconscious thinking that have been proposed by psychologists studying creative thinking. In the literature on creativity, the notion that we can be carrying out unconscious thinking has its origins in numerous reports presented by creative individuals concerning how they produced their creative works. We will begin with a set of those reports produced by a thinker of great renown, the mathematician-scientist Henri Poincaré, concerning his creative-idea production. As we shall see, Poincaré's views have been of great importance in modern theorizing about creative thinking. We will then consider what modern researchers have had to say about unconscious processing by tracing the development of modern views as they have built on and elaborated Poincaré's ideas. I will critically analyze the various views of unconscious processing in creative thinking and the evidence brought forth to support them. The conclusion of the chapter is that evidence for unconscious processing in creative thinking is very weak. The final section of the chapter will examine recent theorizing that has attempted to explain sudden illumination without assuming that unconscious processing occurs. We will consider several alternatives to the view that unconscious processing underlies creative thinking.

Unconscious Associations and Unconscious Processing

There are two components of the idea that the unconscious plays a role in creative thinking. The first component emphasizes unconscious connections among ideas; that is, this theory, which of course stems from Freud, asserts that our ideas are sometimes linked for reasons of which we are not aware. For example, an adolescent may have a dream in which he plays hockey against his father and wins, although neither he nor his father can even ice-skate, much less play hockey. It takes a trained therapist to unearth the real meaning of the dream. In Freudian terms, such a dream would symbolize the boy's Oedipal wishes, which center on his desire to remove the father from his life and have his mother all to himself. This wish, which is too threatening to be allowed to become conscious, must be expressed symbolically in

the dream in a form that is nonthreatening. Similarly, we discussed in the last chapter Freud's proposal that creative products often have meaning on a symbolic level, which also goes far beyond their surface appearances. Consider again the smile on the *Mona Lisa* of Leonardo da Vinci. In Freud's view, Leonardo painted the *Mona Lisa* with that reserved smile because he had lost his mother as a boy. Because of that loss in childhood, Leonardo had an unconscious yearning to be united with a mother figure, a yearning that could never be assuaged, since he was no longer a child. Therefore, he painted women who looked emotionally withdrawn and slightly out of reach, although he himself may not have known why.

We can call this component of the Freudian view the *associative unconscious*, because the links, or associations, that lead from one idea to the next are not open to conscious awareness. The associative unconscious is one facet of the out-of-one's-mind theory, because the person has no conscious awareness of, or control over, the links among his or her ideas. If you ask someone why he or she thought of some idea, and if that idea was the result of the functioning of unconscious associative links, the individual will say that he or she does not know where it came from. This contrasts with the situation in which one can explain to someone else how one's recent ideas led one to the next. The notion of the associative unconscious can be extended directly to creative thinking: The unconscious can link ideas that never would be brought together in conscious thinking. Those unconscious links are active while the artist is working on a project, for example; while Leonardo might have felt that he was consciously working out how to paint the woman in the *Mona Lisa*, unconscious links were providing hidden direction. If you asked the artist why he was painting that woman in that way—with that particular smile, say—he might have replied that he found her of interest, and little further. The true basis for that interest may lie deep below the surface, in emotional links laid down many years earlier.

A second aspect of the unconscious has also received attention from modern researchers. This notion, which I will call simply *unconscious processing*, assumes only that we can be working on more than one project at once, using what is called *parallel processing*. In this view, we can be carrying out some activity of which we are perfectly conscious—say, driving to work and listening to the radio—while at the same time, on an unconscious level, processing may be occurring on some entirely different task—say, solving some problem that has arisen at work. The distinction between *unconscious processing* and the *associative unconscious* is between processes that actually carry out some sort of cognitive activity, albeit on an unconscious level (*unconscious processing*), and the material they work on, which

may be organized through links that are hidden from conscious awareness (unconscious associative connections).

The theory of unconscious processing can also be seen as a variation on the out-of-one's-mind theory. While it is neither psychopathology nor the Muses that produce novel ideas (see Chapter 7), those ideas are still being produced by processes over which the person has no conscious control. The idea of unconscious processing has been elaborated in two ways when applied to creative thinking. On the one hand, it has been proposed that unconscious processing is of the same sort as ordinary conscious processing: All the associative links are the same, and the unconscious is simply conscious thought "gone underground." Nonetheless, unconscious processing can still produce creative leaps: A person can be thinking about one thing when suddenly there flashes into consciousness a novel idea, an *Aha!* experience, which is relevant to a completely different topic. This leap occurs because the person had been processing in parallel, without knowing it. Once the idea occurred, however, since the associative links are the same as those used in ordinary conscious thinking, the person who produced it should be able to understand whence it came.

It has also been proposed that the links through which unconscious processing works are different from those that underlie conscious thinking; that is, unconscious processing can work with unconscious associative links (the associative unconscious). Thus, in this two-component view, a creative leap can come about because (1) the processing has occurred on an unconscious level, which results in the thinker's being surprised by the sudden leap; and (2) the leap is based on connections that the person could never think of using conscious thought, which is a second source of surprise. As we will see, both components of the unconscious have been discussed by researchers. The discussion so far is summarized in Table 8.1. We see there the two dimensions along which we can analyze unconscious processing: (1) whether multiple streams of thought are possible, and (2) whether the links from one thought to the next are comprehensible to the thinker. We have discussed two possibilities on each of those dimensions, so there are four possible structures for the thought processes underlying creativity (as well as all other thinking). Those possibilities will be considered in this chapter. We now turn to a seminal analysis of the role of the unconscious in creative thinking, that of Poincaré (1913).

Poincaré's Theory of Unconscious Creative Processes

It could be argued that the modern psychological study of creative thinking began with Poincaré (1854–1912), who carried out world-class work

Table 8.1 Two dimensions of the unconscious.

Processing mode	Associative links	
	Conscious	Unconscious
One stream (no unconscious processing)	(A) One train of thought; links consciously worked out and are understood; outcome not surprising to the thinker. Example: Painter decides to paint a given subject and will be able to explain why.	(B) One train of thought; some links not understood. If those links contribute to outcome, thinker will not be able to explain how that outcome came about. Example: A painter will not be able to explain why a painting turned out how it did.
Multiple streams (unconscious processing)	(C) Multiple trains of thought; sudden solution to problem is surprising, because person does not know that he or she is thinking about something outside of consciousness; after it occurs, derivation of outcome can be understood. Example: Person will solve a problem in an Aha! experience and will be able to explain where solution came from. (Theorist: Poincaré)	(D) Multiple trains of thought; sudden solution is surprising, because person does not know that he or she is thinking about something outside of consciousness. Some links not understood; if they contribute to outcome, derivation of outcome will be impossible. Example: Person will solve problem in Aha! and will not be able to explain where solution came from. (Theorists: Freud; Koestler; Simonton; Csikszentmihalyi)

in a variety of fields in the latter part of the nineteenth century (Miller, 1996). Poincaré's great accomplishments were recognized in a singular way by the French Academy of Sciences, an honor society whose membership is reserved for those who have made contributions at the highest level to their disciplines. Individuals of great accomplishment are usually elected to the Academy in one discipline in the sciences. Poincaré, in contrast, was elected to the Academy in *all five* of its different disciplines, and was also elected president of the Academy. (A mathematician I know once described Poincaré as the last man to know everything.)

Not surprisingly, Poincaré was also interested in the creative process, and he presented a report describing how several of his most important mathematical breakthroughs came about (Poincaré, 1913). Poincaré's ideas

on this issue are important, because, as we shall see, much modern theorizing concerning creative thinking is based directly on them. Some of the mathematical concepts mentioned by Poincaré in the following excerpts may not be familiar to you, but you can still get the cognitive import of the report even without understanding all the terms.

One point to keep in mind when reading Poincaré's self-reports on his creative process is the inherent weaknesses of those sorts of reports as evidence for scientific theorizing, as already noted in Chapter 2. A self-report, because of its particular nature, is usually unverifiable. This problem exists with Poincaré's reports: We cannot determine if they are accurate. However, since those particular reports have been of singular importance in the development of theorizing about creative thinking, they are worth careful review. In addition, as we examine the theories that have built on Poincaré's ideas, we will have the opportunity to investigate whether more recent work is built on firmer ground than self-reports.

Poincaré's Self-Reports

The first critical segment of Poincaré's work involved his attempt to prove that a certain sort of mathematical function could not exist (Miller, 1996). He was actually interested in the existence of those functions, but he set out to prove the opposite. This is a not-untypical method among mathematicians: They attempt to demonstrate that a mathematical object of potential interest cannot exist, hoping that in doing so they will find a contradiction in their reasoning that allows the conclusion that the object *must* exist—thus reaching the outcome they actually desired from the beginning. Poincaré worked without success for 15 days on this task. His routine was to work on mathematics 4 hours per day, from 10 AM to 12 PM and 7 PM to 9 PM (Miller, 1996). One night, after a typically unsuccessful day, he drank black coffee and could not sleep. He then had an extraordinary experience.

Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making a stable combination. By the next morning I had established the existence of a class of Fuchsian functions. . . . I had only to write out the results, which took but a few hours. (1913, p. 387)

Thus, during this sleepless night of thinking, Poincaré established that one example of the presumed-impossible functions could be shown to exist. He called them *Fuchsian* functions in honor of Lazarus Fuchs, a mathematician whose work had influenced his dissertation research (Miller, 1996). Although Poincaré was obviously conscious when those ideas arose, he felt that the thinking was of an extraordinary sort, since it occurred dur-

ing sleeplessness brought on by the coffee. He felt himself to be merely an observer of what was happening, playing no role in directing the thought process. He therefore concluded that he was observing the workings of his own unconscious, which, as he reports, involved ideas being combined until “stable” combinations were found—that is, new ideas that “held together,” presumably because they were of potential value.

After discovering Fuchsian functions, Poincaré went to Coutances, a city near his home at Caen, to attend a geological conference (Miller, 1996). This previously scheduled trip interrupted his mathematical work. While away, he made another discovery, which was totally unexpected.

The incidents of travel made me forget my mathematical work. Having reached Coutances, we entered an omnibus to go some place or other. At the moment when I put my foot on the step, the idea [of the equivalence of Fuchsian functions and the transformations of non-Euclidean geometry] came to me, without anything in my former thoughts seeming to have paved the way for it. . . . I did not verify the idea; I should not have had time, as, upon taking my seat in the omnibus, I went on with a conversation already commenced, but I felt a perfect certainty. On my return to Caen, for conscience’ sake, I verified the result at my leisure. (1913, p. 388)

So, in the midst of a conversation having nothing to do with mathematics, Poincaré had the realization that the recently discovered Fuchsian functions were identical to a set of functions already existing in mathematics, the transformations of non-Euclidean geometry. At the moment of *illumination*, he was engaged in a conversation about something else, so, as far as he could determine, none of his previous conscious thoughts led up to it. In order to explain this sudden illumination, Poincaré concluded that he must have been thinking about those concepts all along, but on an unconscious level. It is also noteworthy that Poincaré felt certain the idea was correct without having to verify it. Where might such a feeling have arisen? We will shortly learn how Poincaré explained the occurrence of that feeling of certainty.

When he returned from his trip, conscious work demonstrated that his illumination had indeed been correct. A similar phenomenon occurred soon after Poincaré returned to Caen.

[After returning to Caen] I turned my attention to the study of some arithmetic questions apparently without much success and without a suspicion of any connection with my preceding researches. Disgusted with my failure, I went to spend a few days at the seaside, and thought of something else. One morning, walking on the bluff, the idea came to me, with just the same characteristics of brevity, suddenness and immediate clarity, that the arithmetic transformations of indeterminate ternary quadratic forms were identical with those of non-Euclidean geometry. (1913, p. 388)

Again Poincaré made a connection between two concepts, and again that connection seemed to be brought about outside of his conscious thought. Poincaré believed that those incidents demonstrated the importance of unconscious processes in creative thinking. He concluded that a sudden illumination was “a manifest sign of long, unconscious prior work. The role of this unconscious work in mathematical invention appears to me incontestable” (1913, p. 389).

Poincaré’s Theory of Unconscious Processes in Creative Thinking

From his observations during his sleepless night of crowds of ideas colliding until pairs interlocked, Poincaré concluded that the unconscious works by attempting to build combinations of ideas. Although Poincaré was discussing mathematical invention, it has been assumed by him and by others (e.g., Campbell, 1960; Csikszentmihalyi & Sawyer, 1995; Koestler, 1964; Miller, 1996; Simonton, 1995) that similar processes are at work in all creative thinking. Because Poincaré’s theory of unconscious processing is a central component of much modern theorizing concerning creative thinking, I will examine it in some detail to put modern work in historical context.

Poincaré (1913) first examines the question of the definition of creativity in mathematics.

In fact, what is mathematical creation? It does not consist in making new combinations with mathematical entities already known. Any one could do that, but the combinations so made would be infinite in number and most of them absolutely without interest. To create consists precisely in not making useless combinations and in making those which are useful and which are only a small minority. Invention is discernment, choice.

The mathematical facts worthy of being studied are those which, by their analogy with other facts, are capable of leading us to the knowledge of a physical law. They are those which reveal to us unsuspected kinship between other facts, long known, but wrongly believed to be strangers to one another.

Among chosen combinations the most fertile will often be those formed of elements drawn from domains which are far apart. Not that I mean as sufficienting for invention the bringing together of objects as disparate as possible; most combinations so formed would be entirely sterile. But certain among them, very rare, are the most fruitful of all. (p. 386)

Thus, for Poincaré creation ultimately involves discovering valuable combinations of ideas. The combinations that are potentially most fruitful are those that form analogies between facts that, because of their remoteness, had not previously been considered as being related. We have seen two examples of this already, in Poincaré’s reports concerning his discoveries of the equivalences of the transformations of non-Euclidean geometry

with two other entities. However, it is not enough just to combine ideas, even those from domains that are far distant: One must also have a way of avoiding the “sterile” combinations that usually result from bringing together disparate ideas.

Mechanisms of Combination of Ideas

There are at least two possible ways in which valuable combinations of ideas might be produced: (1) The thinker might, by some great skill or intuition, produce only potentially valuable ideas; or (2) the thinker might produce large numbers of combinations, valuable and sterile alike, and then choose for further contemplation only those that are valuable. The *conscious* experience of the thinker corresponds to the first alternative: He or she is aware of only potentially useful ideas, as Poincaré (1913) asserts:

The sterile combinations do not even present themselves to the mind of the inventor. Never in the field of his consciousness do combinations appear that are not really useful, except some that he rejects but which have to some extent the characteristics of useful combinations. All goes on as if the inventor were an examiner for the second degree who would only have to question the candidates who had passed a previous examination. (pp. 386–387)

Although one’s conscious experience is not crowded with useless combinations of ideas, Poincaré believed that the actual creative process works differently: Many ideas are produced by *unconscious processing*, useful and worthless alike, but only potentially useful ideas become conscious. This is the view summarized in Table 8.1C. He continues:

Figure the future elements of our combinations as something like the hooked atoms of Epicurus. During the complete repose of the mind, these atoms are motionless, they are, so to speak, hooked to the wall. . . . On the other hand, during a period of apparent rest and unconscious work, certain of them are detached from the wall and put in motion. They flash in every direction through the space (I was about to say the room) where they are enclosed, as would, for example, a swarm of gnats or, if you prefer a more learned comparison, like the molecules of gas in the kinematic theory of gases. Their mutual impacts may produce new combinations. (Poincaré, 1913, p. 393)

So we have hooked atoms flashing every which way in the chamber of the unconscious, until new combinations—new ideas—are produced. However, in Poincaré’s view there is still a potential problem: The number of possible combinations of ideas is *still* so numerous that even fast unconscious combinatorial processing would not allow us to winnow the potentially important ideas from the chaff of sterile ones. Therefore, logic demands that there be some limitation on the number of ideas entering into even

unconscious combinations. According to Poincaré, the earlier conscious work, which seemed to the thinker to produce no progress, actually makes a positive contribution to creative thinking, because it serves to restrict the combinatorial process to at least those ideas that have some chance, even if it is a remote one, of producing fruitful combinations:

What is the role of the preliminary conscious work? It is evidently to mobilize certain of these atoms, to unhook them from the wall and put them in swing. We think we have done no good, because we have moved these elements a thousand different ways in seeking to assemble them, and have found no satisfactory aggregate. But, after this shaking up imposed upon them by our will, these atoms do not return to their primitive rest. They freely continue their dance.

Now, our will did not choose them at random; it pursued a perfectly determined aim. The mobilized atoms are therefore not any atoms whatsoever; they are those from which we might reasonably expect the desired solution. Then the mobilized atoms undergo impacts which make them enter into combinations among themselves with other atoms at rest which they struck against in their course.

However it may be, the only combinations that have a chance of forming are those where at least one of the elements is one of those atoms freely chosen by our will. Now, it is evidently among these that is found what I call the *good combination*. (Poincaré, 1913, p. 389)

The unconscious combinatorial process thus has two important characteristics. First, some of the ideas that it deals with are those that were set into motion by being considered during preliminary conscious work on the problem. This serves to focus the process at least partly on those ideas that might be potentially useful. Second, those selected ideas are used for high-speed unconscious combination with inactive ideas, to make it possible for the still-numerous potential combinations to have a chance at formation. Thus, in Poincaré's view, the unconscious does not do anything that conscious processing could not do if there were but time available.

Criteria for a Combination's Becoming Conscious

We now have the unconscious combinatorial process at work, and sometimes it is successful: A potentially useful combination is hit upon and bursts suddenly into consciousness, where it is experienced as an illumination. This leads to the question of the criteria for determining whether an unconsciously produced combination should be examined further in consciousness. This requires some sort of judgmental process, which is another function, beyond the simple combination of ideas, carried out by the unconscious. In Poincaré's words,

It is certain that the combinations which present themselves to the mind in a sort of sudden illumination, after an unconscious working somewhat prolonged, are generally those useful and fertile combinations. . . . [T]he privileged unconscious phenomena, those susceptible of becoming conscious, are those which, directly or indirectly, affect most profoundly our emotional sensibility. . . . The useful combinations are precisely the most beautiful, I mean those best able to charm this special sensibility that all mathematicians know, but of which the profane are so ignorant as often to be tempted to smile at it.

What happens then? Among the great numbers of combinations blindly formed by the subliminal self, almost all are without utility: but just for that reason they are also without effect on the esthetic sensibility. Consciousness will never know them; only certain ones are harmonious, and, consequently, at once useful and beautiful. They will be capable of touching this special sensibility of the geometer of which I have just spoken, and which, once aroused, will call our attention to them, and this give them occasion to become conscious. (1913, pp. 391–392)

Thus, an idea becomes conscious when it strikes the (unconscious) sensitivity of the thinker as being “beautiful” or “harmonious.” We now have an explanation for Poincaré’s certainty that his idea on the omnibus was correct: It had already been subject to evaluation by the unconscious sensibility. This sensibility is also why we are never consciously aware of the many sterile combinations that, according to Poincaré, our unconscious must produce: Their sterility insures that they will not get past the unconscious gatekeeper.

Poincaré’s Theory of Unconscious Processing in Creative Thinking: Summary

Poincaré concluded on the basis of his introspections that unconscious processes were crucial in his creative process. Most important, the occurrence of illuminations made it clear to him that processing had been going on under the surface. In addition, the fact that the ideas that occurred to him were always at least potentially valuable led him to the conclusion that some sort of unconscious evaluation process was being carried out. Row A of Table 8.2 presents a summary of this view. It may not be an exaggeration to say that modern psychological theorizing about creative thinking is built solidly on the foundation of Poincaré’s theory. His view has been adapted and modified by more-recent researchers in light of new developments, but the core of those new theories remains much as Poincaré proposed. The remainder of this chapter will examine the development of modern theories of unconscious thinking in creativity, which means in essence that we will trace the influence of Poincaré’s ideas on modern psychology and examine

Table 8.2 Summary of theories of unconscious processing

Theorist	Postulated mechanism of unconscious thinking
(A) Poincaré	Random combinations of ideas; good ideas are those that combine domains previously thought unrelated. All combinations produced in unconscious are possible in conscious thinking, if the person is given enough time. Aesthetic sense determines which ideas reach consciousness.
(B) Wallas	Formalized Poincaré's ideas into four stages; second stage is unconscious incubation.
(C) Hadamard	Poincaré's ideas and Wallas's stages; questionnaire to mathematicians and scientists (including Einstein). Discussed broader evidence for unconscious, such as recognition of faces and production of discourse.
(D) Koestler	<i>Bisociation</i> as the process underlying creative thinking: brings together two previously independent streams of ideas. Unconscious connections based on Freudian primary-process thought.
(E) Simonton	Darwinian view, based on Campbell; unconscious combinations go beyond conscious possibilities: Freudian primary-process thinking. Creative thinker's associations organized into Mednick's flat associative hierarchies.
(F) Csikszentmihalyi	Parallel processing based on associations among ideas in unconscious, versus logical and constrained order of ideas in conscious thinking. Unconscious processing produces unlikely and illogical combinations. Reports by creative individuals concerning how their thought process works provide evidence for unconscious processes.

variations on the themes that he raised. The underlying issue to deal with is how one explains the occurrence of illuminations during problem solving, which is also the agenda set by Poincaré.

Wallas's Stages of the Creative Process

Wallas (1926) formalized Poincaré's ideas into a well-known series of four stages of the creative process. The first stage, *preparation*, centers on initial

conscious work on the problem, in which the thinker immerses him- or herself deeply in the problem, becoming familiar with it and attempting solutions. If this work is unsuccessful and leads to an impasse, the person then breaks off work on the problem. The unconscious, however, keeps working. This stage of unconscious work is called *incubation*, in an analogy to what happens inside an egg when it is warmed by a hen. The discovery of a new and potentially useful combination by the unconscious leads to the third stage, a conscious experience of *illumination*. That is, the incubated egg hatches. Finally, the idea that produced the illumination requires *verification* so that its adequacy can be determined. As we saw with Poincaré's illuminations, this stage requires conscious thought.

Wallas based his discussion on reports written by individuals of creative accomplishment, such as Poincaré and Hermann von Helmholtz, the great physicist, who also provided a report on how he carried out his work (Helmholtz, 1898). Wallas offered advice to thinkers based on these sorts of reports, emphasizing that, if one hopes to be successful, one should sometimes completely stop thinking about a problem and give the unconscious processes time to do their work. Wallas's ideas are a straightforward elaboration of those of Poincaré, with Wallas's original contribution being an explicit labeling of the stages that Poincaré discussed in less formal terms (see Table 8.2B).

Hadamard's Studies of Unconscious Thinking in Incubation

Hadamard (1954), a mathematician who was a disciple of Poincaré, also presented a detailed description of the phenomenon of inspiration and the role of unconscious processes in creative thinking. He gathered together information from individuals in the fields of science (including Einstein, who answered questions from Hadamard concerning his thought process), mathematics, and the arts that was relevant to the general question of inspiration and provided support for Poincaré's conclusions on the critical role of the unconscious. Hadamard also brought forth other types of information that he believed supported the role of unconscious processes in thinking. As one example, Hadamard points to so seemingly simple a phenomenon as recognizing the face of a friend. In order to recognize that face, we use many different features, or pieces of information, but we are aware of none of the complexities of the process, and we cannot describe in any way what we are doing. Thus, there is a gap between our unified conscious awareness ("There's Sue") and the complex recognition processes that, in Hadamard's view, must be occurring. It therefore is necessary to assume that much unconscious processing is involved. The act of synthesis that occurs when you

take the multitude of available features and from them produce the unified perception of a familiar face points to a crucial difference between conscious and unconscious processing. Consciousness is *unified* and *singular*—you are aware of only that single face—while the unconscious is *manifold*—multiple things can be processed at once. In modern terms, consciousness is a *serial processor*, while the unconscious processes information *in parallel*.

Another example discussed by Hadamard (1954) is the production of connected speech. You are talking to a friend, say, and you produce a string of connected sentences in order to describe some event. When you produce the first sentence, asks Hadamard, where is the second sentence in what will be a coherent string of speech? “Certainly not in the field of my consciousness, which is occupied by sentence number one; and nevertheless, I do think of it, and it is ready to appear the next instant, which cannot occur if I do not think of it unconsciously” (Hadamard, 1954, p. 24). Hadamard also makes distinctions among several “layers” of nonconscious processing (pp. 24–28), based on, for example, our ability to produce a string of related sentences. He proposes that the to-be-spoken-sentences are waiting in an unconscious that is close to the surface and at the disposal of conscious processes. Table 8.2C summarizes this view.

In short, Wallas made explicit the stages Poincaré had already discussed only informally. Hadamard marshaled additional evidence for the theory of unconscious processing and tried to demonstrate the wide role of such processing in other areas of cognition.

Koestler’s Bisociation Theory

Koestler (1964) presented an analysis of creative thinking that combined Poincaré’s analysis with Freudian theory. He analyzed many creative advances and concluded that they often involve bringing together two independent streams of associations into one idea, a process he called *bisociation*, in contrast with *association*, which involves only one stream of linked ideas. As an example, we can examine Koestler’s report of Guttenberg’s invention of the printing press with movable type. The printing press is reported to have been brought about when Guttenberg attended a wine festival, where, helped along by some of the wine, he realized that the press used to crush grapes could be used to apply type to paper. Thus, the movable-type printing press was born. Koestler, like others (e.g., Hadamard, 1954), emphasized that the root of *cogitare*, Latin for “to think,” is to *shake together*, which fits with Poincaré’s image of “hooked atoms” zooming this way and that in the chamber of the unconscious until a pair collides and becomes hooked together.

However, unlike Poincaré, Koestler believed that the connections used by unconscious thinking are different from those used by conscious thinking. Koestler assumed that conscious thought processes operate through verbally based logic as well as associative connections based on experience and habit. Creative thinking, on the other hand, demands connections among ideas that go *against* logic and habit. In Koestler's view, Freudian primary-process thought provides the vehicle whereby those new bonds can be forged (1964, p. 183ff.). He provides examples of how some of the primary-process mechanisms we discussed in the last chapter function in creative thinking. Use of *optical puns*, for example, is seen when a thinker conceives of a string of molecules as a snake, as was reported by Kekulé in describing his discovery of the ring structure of the benzene molecule (see discussion in Chapter 2). Kekulé's analysis could also be classified as *symbolization* of an abstract theoretical idea in a concrete image. Einstein reported to Hadamard that his thought was almost never based on words, which supports Koestler's claim that one must use nonverbal modes to break away from the tyranny of logic and verbal habits. Einstein also reported that an important insight concerning relativity theory came about as a result of his imagining what would happen if he were moving at the speed of light in pursuit of a light beam. This is an example of *concretization*, although Koestler (1964) acknowledges that in many cases primary-process thinking is not neat and clean and that often many of the different subprocesses are being used together, which may make analysis a bit difficult.

Thus, Koestler elaborated Poincaré's view by combining it with Freudian ideas on primary-process thinking. (See Table 8.2D.) So we now have two streams of theory concerning how unconscious processing functions in creative thinking: "pure" Poincaré and Poincaré plus Freud (see Figure 8.1). As we shall see, modern views are typically variations on one or the other of those streams.

Campbell's Evolutionary Theory of Creativity: Blind Variation and Selective Retention

The strongest and most direct influence of Poincaré's theorizing on modern psychology can be seen in a stream of research that began with the work of Campbell (e.g., 1960), who developed a theory of creativity based on the notion that creative ideas come about through a process of evolution analogous to the natural-selection process operating in Darwin's theory of organic evolution. In Darwin's theory, *blind variation* and *selective retention* determine how species evolve. That is, there is first a random change or variation in the genetic material, caused by, for example, mutation brought

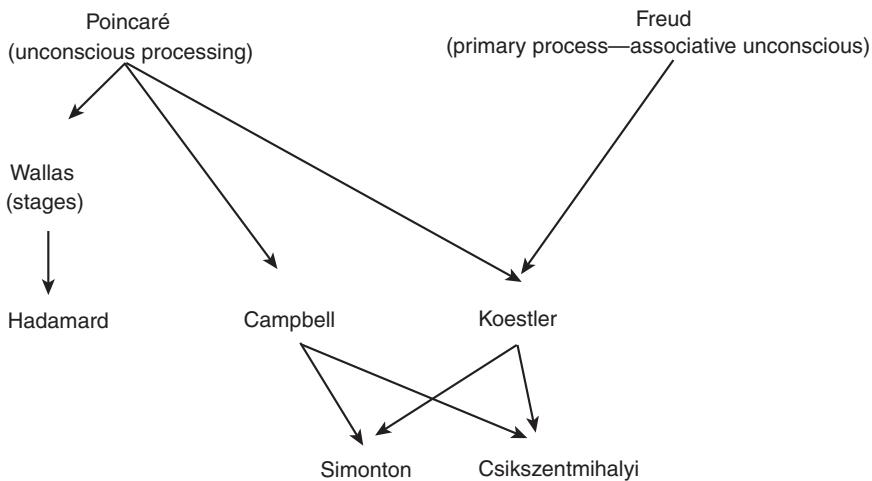


Figure 8.1 Map of historical development of theories

about by radiation. This variation is *blind*, in the sense that the evolutionary process has no foresight concerning which variations might be best for a given species in a given environment. Variations occur randomly; some are useful and some are not. Those that are useful are *retained*, since the organisms that possess them are more likely to survive and pass their genes on to the next generation.

According to Campbell (1960), similar processes determine how creative ideas come about. In Campbell's view, three conditions are necessary for creative thinking, in the form of solution of a novel problem. (1) There must be some means of generating new ideas, or *ideational variation*, analogous to the occurrence of mutations in organic evolution. (2) Once new ideas are produced, those variations are subjected to a consistent *selection process* that retains only those that are successful, again analogous to natural selection in organic evolution. (3) The variations that have been selected must be *preserved* and *reproduced* by some mechanism so that they are available to succeeding generations.

Campbell (1960) concluded that, in order for there to be truly effective variation in ideas when facing a new problem, the ideational variation must be fully blind, as is the production of mutations in evolution. He argues that when an organism is faced with a truly novel problem there is no recourse but to produce behavioral responses that are blind, that is, not only independent of the specific problem situation but also independent one from the next. The response attempts that are produced will have no correspondence to the problem being faced, in the sense of being directed toward solution of that problem. Nor will the various attempts be related to

each other: Later attempts will not be “corrections” of earlier ones. There will thus be no predictability in when the solution will emerge; it will be just as likely to follow an attempt that is totally off the mark as one that is very close to correct.

If one does see foresight and intelligence on the part of an organism approaching a problem, this is of course due to experience. However, argues Campbell (1960), in the history of that organism and/or of the species, there must have been a point before experience, at which totally random variations were produced. Otherwise, according to Campbell, there could not have been the true novelty in behavior that is needed to deal with situations demanding it—that is, those situations in which true creative advances are made. Campbell extensively quotes Poincaré (1913) in order to provide support for the blind aspect of ideational variation. As an example, he quotes Poincaré’s description of his sleepless night as evidence for the random way in which ideas are combined in creative thinking. Campbell’s theorizing is the place where Poincaré’s theory becomes part of the mainstream of psychological theorizing about creative thinking, although Campbell does not explicitly discuss unconscious processing. Simonton (e.g., 1988, 1995b, 1999), whom we will discuss next, explicitly incorporated unconscious processing into Campbell’s point of view.

Simonton’s Chance Configuration Theory

Simonton (e.g., 1988, 1995b, 1999, 2003), one of the most prolific and influential psychologists currently writing on the creative process, has carried forth Poincaré’s ideas as elaborated by Campbell, including the evolutionary analogy and its emphasis on a random component in the production of ideas (see Table 8.2E and Figure 8.1). Simonton noted that Campbell too built on a long tradition. William James, for example, also made explicit an analogy between production of new ideas and production of new organic forms in evolution through random mutations:

The new conceptions, emotions, and active tendencies which evolve are originally produced in the shape of random images, fancies, accidental out-births of spontaneous variation in the functional activity of the excessively unstable human brain, which the outer environment simply confirms, refutes, or destroys—selects, in short, just as it selects morphological and social variations due to molecular accidents of an analogous sort. (1880, p. 456)

In elaborating Campbell’s view, Simonton (1988) proposed that the creative process operates on what he referred to as *mental elements*, which are fundamental psychological units that can be manipulated in some man-

ner, comparable to Poincaré's (1913, p. 393) "hooked atoms of Epicurus." Closely following Poincaré and Campbell, Simonton proposes that those elements must be free to enter into combinations through the process of *chance permutation*. Those permutations are carried out in the unconscious. After combinations of elements have been formed, some selection process must be introduced, because not all combinations should be retained. Again in reasoning that closely parallels that of Poincaré, Simonton proposes that the permutations that are formed differ in *stability*. The greater the stability of a combination, the greater the chance that it will be selected, and the greater attention the combination will command in consciousness. Thus, Simonton's continuum of stability is analogous to Poincaré's notion of selection on the basis of the thinker's unconscious aesthetic sensitivity.

Confronting the question of why certain combinations are more stable than others, Simonton proposes that certain mental elements possess "intrinsic affinities" for each other. That is, there is an attraction of some sort between pairs of elements, something like a magnet's attraction for a paper clip. Intrinsic affinity comes about because sometimes two configurations are structured so that their elements can line up one-to-one. This means that chance combination can result in the thinker's becoming aware of an analogy between hitherto unrelated phenomena, again a point emphasized by Poincaré and others who followed him, such as Koestler (1964). As one example of this realization of a previously hidden analogy, one can recall Poincaré's illumination that the Fuchsian functions were equivalent to the transformations of non-Euclidean geometry. This illumination occurred because those elements turned out to have one-to-one correspondence, which triggered the realization that the concepts were identical. In art, a chance combination can produce a particularly striking metaphor, which will bring together heretofore unrelated domains of experience, where a poet, for example, might discover a previously unrealized relationship between his or her lover, say, and a beautiful flower.

Individual Differences in Cognition: Mednick's Associative Hierarchies

In Simonton's view, individuals can vary along two dimensions that are relevant to their ability to produce novel ideas. First, people differ in the total number of mental elements they possess: The "genius" possesses more elements in his or her database than does the "normal" individual. Obviously an individual with more mental elements has a greater chance of producing a valuable combination. It is not enough, however, to possess a large number of mental elements; the elements must be organized in the manner that is optimal for creative production. That optimal structure depends on the associative organization among the elements in a person's

database. In analyzing the associative relationships among mental elements that distinguish the creative from the noncreative individual, Simonton (1988, 1999) bases his ideas on the theory of Mednick (1962), who published a relatively short but very influential paper on the “associative” mechanisms underlying creative thinking. Here too we can see Poincaré’s influence, as Mednick defined the creative thinking process as “the forming of associative elements into new combinations which either meet specified requirements or are in some way useful. The more mutually remote the elements of the new combination, the more creative the process of solution” (p. 221). This definition echoes Poincaré.

In Mednick’s (1962) analysis, any situation that demands creative thinking can be analyzed as a set of stimulus elements, each of which has many other elements or ideas associated to it. The thinker’s analysis of the situation results in the elements of the situation evoking some subset of all those associated elements. These evoked elements, now “active” in consciousness, can combine to produce a new idea; thinking a new thought is the result of a new combination of elements. Mednick’s analysis leads to a simple conception of how individuals may differ in factors that lead to creative ideas. The basic component is the *associative hierarchy*, or the organization of an individual’s associative responses to a given situation. Some people, those who will *not* think creatively, have restricted hierarchies, in which there are one or two dominant responses. Those responses tend to occur often and quickly, and they therefore tend to block production of less-frequent responses. Such individuals tend to produce stereotyped and familiar responses to a situation, and so they are at a disadvantage when novel responses (i.e., relatively infrequent responses) are demanded. Creative individuals, in contrast, possess associative hierarchies in which a relatively large number of responses, of more or less equal probability, are available. Such individuals have a much greater likelihood of coming up with a relatively unusual response to a situation, which could result in a creative outcome. Mednick’s two types of associative hierarchies are shown in Figure 8.2.

Simonton (1995b), adopting Mednick’s notion, proposes that new ideas are produced by what he calls a nonorderly “free-associative procedure” (p. 471), which he equates with Freudian primary-process thinking. He notes that “the products of this mechanism are unpredictable and uncontrollable, the associative meanderings freewheeling” (1995b, p. 471).

Some Illustrations: Introspections

In support of his view, Simonton presents a number of reports by creative thinkers on their creative thought process. As one example, Einstein, in

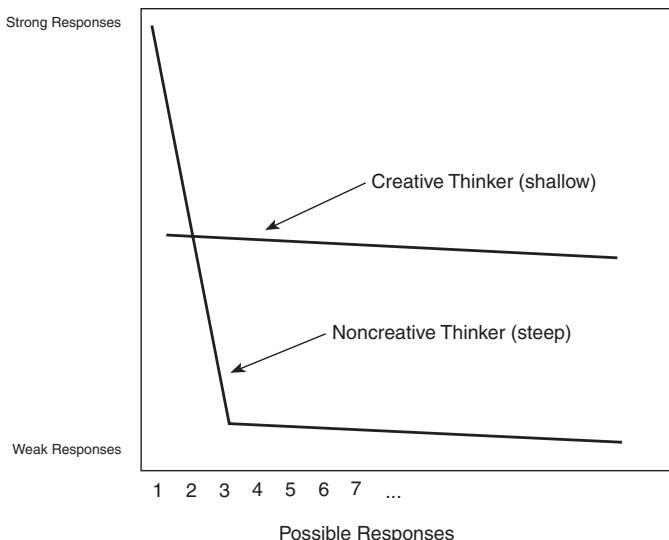


Figure 8.2 Mednick's theory

Source: Adapted from Mednick (1962).

the already-mentioned response to Hadamard (1954, p. 142), says that “combinatory play seems to be the essential feature in productive thought.” That statement may remind one of Poincaré’s report of his sleepless night, when “ideas arose in clouds” and collided one with another until pairs collided. This can be looked upon as a sort of combinatorial play. So Einstein and Poincaré provide examples of Simonton’s postulated free-associative thought of the individual at the highest level of creative genius. Simonton also presents William James’s (1890, p. 456) description of the thought processes in minds of the highest order, which we have already seen in Chapter 4, which also supports the same viewpoint:

Instead of thoughts of concrete things patiently following one another in a beaten track of habitual suggestion, we have the most abrupt cross-cuts and transitions from one idea to another, the most rarified abstractions and discriminations, the most unheard of combination of elements, the subtlest associations of analogy; in a word, we seem suddenly introduced into a seething cauldron of ideas, where everything is fizzling and bobbling about in a state of bewildering activity, where partnerships can be joined or loosened in an instant, treadmill routine is unknown, and the unexpected seems only law.

Simonton proposes that there is a continuum of problem solving. At one end is routine problem solving, such as working out a problem in long division, for which a straightforward procedure is known to everyone. At

the other end are the sorts of problems involved in scientific research, for which there are no well-known procedures. In the latter situations, the free-associative process is crucial. In Simonton's (1995b) words,

For the kinds of problems on which historical creators stake their reputations, the possibilities seem endless, and the odds of attaining the solution appear nearly hopeless. At this point, problem solving becomes more nearly a random process, in the sense that the free-associative procedure must come into play. Only by falling back on this less disciplined resource can the creator arrive at insights that are *genuinely* profound. (pp. 472–473)

Here again Simonton (1995b) makes an explicit connection between his theorizing and the ideas of Poincaré and Koestler:

As Poincaré . . . remarked: “[The most useful ideational permutations] are those which reveal to us unsuggested kinship between other facts, long known, but wrongly believed to be strangers to one another. . . . [Hence,] among chosen combinations the most fertile will often be those formed of elements drawn from domains which are far apart. . . .” So commonplace are fantastic syntheses that Koestler made them the cornerstone of his theory: *bisociation*. . . . [P]robably the only way two irrelevant realms can be brought together is by the crazy confluence of rather haphazard and whimsical trains of association. . . . Thus, the more offbeat is the bisociation, the greater must be the role of chance in generating it, on the average. (p. 473)

In explaining how these unusual combinations of ideas can be brought about, Simonton falls back on an already-familiar premise: The combinations occur in the unconscious. However, on the basis of recent research in cognitive psychology concerning unconscious processing (e.g., Greenwald, 1992), Simonton (1995b) does not assume that unconscious processing is very sophisticated. Rather, he says, “in all likelihood, the unconscious mind is the repository of some rather primitive cognitive and affective associations that can form linkages that the conscious mind would deem preposterous” (p. 475). Thus, the unconscious provides the links that can be used by a not-very-sophisticated associative process to bring together ideas that would never have occurred to the thinker in the conscious state.

It is also interesting to note that in Simonton's view there are several circumstances in which the unconscious free-associative process can become accessible to consciousness. First, if the thought process involves vivid imagery, it will sometimes be attended to consciously, as was the case with Kekulé's discovery of the benzene ring. Also, if the creator can somehow be in a state wherein his or her consciousness is not occupied with some other task, the workings of the unconscious might be glimpsed. An example of this is Poincaré's sleepless night, when he was not consciously engaged in any

other activities and so had the unique opportunity of observing his unconscious at work. Usually, however, when one is engaged in other activities, the unconscious operates outside of awareness. What is usually necessary for the optimal operation of the unconscious is that the individual be engaged in some mundane activity, such as walking, that requires minimal resources and attention to external stimuli. This makes available the capacity for the unconscious to do its work. An example would be Poincaré's illumination while walking on the seaside bluff. Thus, the boundary between conscious and unconscious processing is not hard and fast; it shifts with the circumstances, granting a fortunate few access to the workings of their own minds while functioning at the highest level.

Simonton's Theory of Unconscious Processing in Creativity: Summary

In Simonton's theorizing we can see clear evidence of the continuing influence of Poincaré's theory on modern research. The basic idea of Simonton's theory is that while we are engaged on one task, we can still be working on another. In addition, Simonton's theory also contains a free-associative initial component, which is based on Campbell with links to Koestler and thus can be traced back to Freud. Those connections are outlined in Figure 8.1, and the theory is summarized briefly in Table 8.2E. The notion of unconscious processing, à la Poincaré, is only one component of Simonton's theory, in which he attempts to bring together many aspects of the creative process, the creative person, and the milieu in which that person is functioning. We will examine the broader aspects of Simonton's theory in Chapter 11, in which several broad theories of creativity are reviewed.

Csikszentmihalyi's Theory of the Unconscious in Creative Thinking

The influence of Poincaré's theorizing in psychology can be seen also in the work of Csikszentmihalyi (1996; Csikszentmihalyi & Sawyer, 1995), who has presented an analysis of creative thinking based on interviews with almost 100 individuals who have made significant lifelong creative contributions in the arts, the sciences, technology, and business. In providing the background to his study, Csikszentmihalyi (1996) presents Wallas's stages as the basis for his own theorizing.

The second phase of the creative process is a period of incubation, during which ideas churn around below the threshold of consciousness. It is during this time that unusual connections are likely to be made. When we intend to solve a problem consciously, we process information in a linear, logical fashion. But when ideas call to each other on their own, without our leading

them down a straight and narrow path, unexpected combinations may come into being. (p. 79)

In considering possible explanations of what might be happening during the stage of incubation, Csikszentmihalyi rejects the Freudian primary-process view as “spectacularly implausible” (1996, pp. 100–102). He discusses as an alternative a more “cognitive view,” which assumes, as demonstrated by the passage just quoted, that unconscious thinking involves making connections among ideas based on laws of simple association. This results in essentially parallel processing, which produces what may seem to be random combinations of ideas, rather than the logical and constrained serial processing of conscious thought. Thus, the unconscious will succeed through the production of combinations of ideas that would not have been produced in conscious thinking. This is because conscious thinking is linear and logical, in Csikszentmihalyi’s view, whereas the unconscious uses associative connections that go beyond the bounds of strict logic. Csikszentmihalyi, like Simonton, moves away from Poincaré’s view and includes vestiges of the Freudian view, as filtered through Koestler, in his theory. Csikszentmihalyi does, however, echo Poincaré’s and Simonton’s notions concerning how ideas produced in the unconscious become conscious as illuminations or insights (see Table 8.2): “The insight presumably occurs when a subconscious connection between ideas fits so well that it is forced to pop out into conscious awareness, like a cork held underwater breaking out into the air after it is released” (Csikszentmihalyi, 1996, p. 104). This is analogous to Poincaré’s discussion of how combinations that are aesthetically pleasing are passed from the unconscious to consciousness. As a specific example of how creative discovery can come about, Csikszentmihalyi (1996) presents the case of Kekulé’s discovery of the structure of benzene, which was discussed in Chapter 2:

The German chemist August Kekulé had the insight that the benzene molecule might be shaped like a ring after he fell asleep while watching sparks in the fireplace make circles in the air. If he had stayed awake, Kekulé would have presumably rejected as ridiculous the thought that there might be a connection between sparks and the shape of the molecule. But in the subconscious, rationality could not censor the connection, and so when he woke up he was no longer able to ignore its possibility. (p. 101)

Interviewees’ Opinions on the Unconscious

As new evidence to support the notion of unconscious thinking during incubation, Csikszentmihalyi (1996; Csikszentmihalyi & Sawyer, 1995) presents the opinions of many interviewees concerning the importance of

unconscious processing in their creative process. Many of the individuals have no doubt that creative leaps based on unconscious processing are important in their creative work, and Csikszentmihalyi and Sawyer (1995) note the potential importance of the reports of their interviewees concerning the creative process.

Whereas examples of insight in everyday life tend to be elusive and debatable, they are both more public and more convincing when they occur to scientists whose work results in Nobel Prizes or to artists and writers who enhance our lives with their creative endeavors. (p. 330)

Csikszentmihalyi and Sawyer (1995, p. 331) report that their respondents described their moments of insight as part of a four-stage process, corresponding to the stages of Wallas (1926): preparation, incubation, illumination, and verification.

In contrast to other analyses of unconscious processes in creativity, Csikszentmihalyi and Sawyer's analysis emphasizes the large individual differences that can occur in incubation and illumination (1995, p. 336). Some individuals report working on a problem—including, presumably, unconscious work—for a period of years; others might start working on some problem in the morning and have an illumination in the afternoon. As one renowned example, Charles Darwin worked for many years on the theory of evolution through natural selection before achieving his breakthrough. Csikszentmihalyi and Sawyer propose that the long-time-frame versus short-time-frame insight processes are so different that they might actually represent two ends of continuum. They discuss this continuum in terms of a distinction between *presented* and *discovered* problems. In a presented problem, which usually involves a shorter time frame, the person begins to work on a problem that already exists. In a discovered problem-solving process, which may extend over long stretches of time, the problem is not one people have been dealing with before the individual in question came on the scene.

In the view of Csikszentmihalyi and Sawyer (1995), great creative insights, those that result in shifts in the field, belong to this long-term-insight category. It is interesting to note that they present Darwin's discovery as an example of a long-time-frame process. There is no doubt that Darwin's work resulted in a *paradigm shift*, that is, a radical change in theorizing in biology (see discussion in the last chapter of Kuhn's [1962] notions of revolutionary—i.e., paradigm-shifting—versus normal science), but, contrary to the analysis proposed by Csikszentmihalyi and Sawyer, Darwin solved a *presented* problem. That is, he was dealing with an issue—how to explain the evolution of species—that had been of interest to several generations

of theorists before him, including his own grandfather (Eiseley, 1961). As noted in Chapter 5, Eiseley concluded that Lyell set the problem that Darwin and Wallace solved. Thus, the distinction between presented and discovered problems may not coincide with that between short- and long-term incubation processes.

Interaction between Conscious and Unconscious Processes

Concerning the details of the creative thinking process and, more specifically, the question of the interaction between conscious and nonconscious processes, Csikszentmihalyi and Sawyer (1995) note that several research traditions have suggested that unconscious processing has greater capacity than conscious processing. In these views, more than the unitary Freudian subconscious is working on the problem; the unconscious is seen as many smaller entities, each of which might be working on a different problem, so many problems might be being worked on at once. This conception raises a further question (Csikszentmihalyi & Sawyer, 1995, p. 339): If consciousness is a serial processor with limited capacity, while the unconscious is a parallel processor with much greater capacity, how can the individual coordinate them? Somehow the individual must be able to direct what Csikszentmihalyi and Sawyer call the undirectable subconscious process, so that useful insights result.

Perhaps paradoxically, many of the individuals surveyed by Csikszentmihalyi and Sawyer claimed that they had indeed developed the ability to direct those unconscious processes. Furthermore, although we have all heard of situations in which insight comes about through the action of some external stimulus (the apple that supposedly fell on Newton's head and stimulated the development of his theory of gravitation, for example), Csikszentmihalyi and Sawyer found no evidence for such occurrences in their interviews. Their respondents described their insights as "welling up from the subconscious" (1995, 343), without a specific external stimulus. This is parallel to Poincaré's illuminations on boarding the omnibus and walking on the bluff: In both cases there was no external stimulus that triggered the illumination.

Data: Content of the Interviews

Let us now turn to the content of the interviews carried out by Csikszentmihalyi and Sawyer (1995). The respondents were, as mentioned, individuals who had lifetimes of creative output in many domains and are still active. Even when they were dealing with short-term presented problems—for which, in Csikszentmihalyi and Sawyer's view, incubation is less of a factor than in longer-term discovered problems—many of the

respondents “structured their days to include a period of solitary idle time that follows a period of hard work. Without this time, they would never have their best ideas” (p. 347). The respondents were thus paving the way for the operation of their unconscious. Keeping the mind idle sometimes involves simple repetitive physical activity, as it did for the respondent who said, “Generally, the really high ideas come to me when I’m gardening” (p. 348). All the respondents reported that small-scale insights came during this set-aside time, which an economist describes: “We have this little cabin. . . . We have a little ritual in the morning; [my wife] takes a short bath, and then I have a 40-minute bath and do some exercise” (p. 348). Some recipients carry notebooks with them to take advantage of the ideas when they come. A banker reported: “It often happens [i.e., illuminations occur] when I’m sitting around a hotel room; I’m on a trip and nothing’s going on and I sit and think. Or I’m sitting on a beach . . . and I find myself writing myself notes” (p. 348).

A similar process concerning an insight on a larger scale was described by a physicist-mathematician who was trying to bring together two seemingly incompatible theoretical approaches to quantum mechanics that had been proposed by two other physicists, Richard Feynman and Julian Schwinger.

I spent 6 months working very hard, to understand both of them clearly, . . . and at the end of 6 months, I went off on a vacation, took the Greyhound bus to California. . . . [A]fter two weeks in California, where I wasn’t doing any work, just sightseeing, I got on the Greyhound bus to come back to Princeton and suddenly, in the middle of the night, when we were going through Kansas, the whole thing sort of suddenly became crystal clear, so that was sort of the big revelation for me, the eureka experience. (Csikszentmihalyi & Sawyer, 1995, p. 359)

Concerning the period of incubation, those people who reported long-time-frame insights often reported that the insights occurred during an extended period of time away from work, such as a vacation or sabbatical (Csikszentmihalyi & Sawyer, 1995, p. 352). One respondent, as we have seen from his quotation, carried around a notebook; he had made several contributions that changed the structure of the banking industry. He reported that his major creative insights had always come while he was on vacation, often while on the beach (Csikszentmihalyi & Sawyer, 1995, p. 354). One of his insights is even called the “memo from the beach”; in it, he outlined the structure of the first consumer banking enterprise, in 1974:

I was on a vacation, and I started out saying, “I’m sitting on the beach thinking about the business,” and it went on for 30 pages. And it turned out to be the blueprint. I didn’t sit down and say, “I’m gonna write a blueprint;” I said, “I’m

sitting on the beach thinking,” and I sort of thought through the business in a systematic way . . . and I shared it with my colleagues. (p. 354)

A similar process occurred for this individual during a second insight, which led to a corporate reorganization. This one occurred while he sat on a bench in Florence:

In September I had been kind of tired . . . and I had gone to Italy for a week, just gotten away. . . . I'd get up early in the morning, and I'd wander around, and I sat on a park bench, between 7 in the morning and noon. . . . I had a notebook, and I wrote myself long essays on what was going on and what I was worried about. (Csikszentmihalyi & Sawyer, 1995, p. 354)

In further support of the importance of the subconscious in creative thinking, many of those interviewed by Csikszentmihalyi and Sawyer (1995) had on their own developed theories of the creative process that emphasized the importance of “off time.” These veterans of creative-thinking campaigns had no doubt that the process requires a period of incubation to allow the subconscious to carry out its work. As one example, the physicist-mathematician who earlier described his middle-of-the-night eureka experience in Kansas began his interview by saying: “I’m fooling around not doing anything, which probably means that is a creative period” (p. 352).

Concerning the elaboration stage of the process, in which an insight that has burst into the light must be evaluated and shaped to fit reality, almost all the respondents reported that such work was necessary. One respondent, however, an economist, environmentalist, and poet, reported having illuminations that did not need further elaboration; that is, things came to him complete. He reported, “The last 9 days I was there [in California], I dictated the book a chapter a day and revised it very little actually. I’d been thinking about it for over a year, and it just came through. It was like having an intellectual orgasm, it just comes [*laughs*]” (Csikszentmihalyi & Sawyer, 1995, p. 356).

On the basis of their research, Csikszentmihalyi and Sawyer (1995, p. 358) concluded that the creative leap or insight is the result of a period of incubation, during which information is processed in parallel at an unconscious level. If incubation is successful, an insight will occur, and there is usually then a period of conscious evaluation and elaboration of that illumination. (See Table 8.2F.) This view is compatible with those already discussed. Csikszentmihalyi and Sawyer (1995) build the case for stages of creative thinking from evidence from their interviews. First of all, those high-creative individuals have developed their own theories of creative thinking that rely on the opportunity for unconscious processing. In addition, the interviews provide evidence of the role of unconscious processing in producing illuminations.

Unconscious Thinking in Creativity: Conclusions

We have seen that there is large-scale agreement among theorists that the stages postulated by Wallas (1926) many years ago, on the basis of Poincaré's reports, are a useful description of the process of creative thinking. More specifically, as summarized in Table 8.2, theorists are in general agreement that during incubation unconscious processing is taking place. They also believe that this unconscious processing makes possible connections among ideas that are beyond the capabilities of ordinary conscious thinking. In Poincaré's original conception, those new connections came about because the unconscious was able to work more quickly than was conscious thinking, but he assumed that there were no differences in the associative links that served to guide thought. Most modern theorists, however, have moved closer to something resembling the Freudian view in various ways—even if they do not accept all of it (e.g., Csikszentmihalyi's [1996] explicit rejection of Freudian ideas)—and assume that the unconscious is able to make connections among ideas that conscious processing cannot bring about. There is little disagreement among modern theorists concerning the belief that unconscious processing is able to bring together combinations of ideas that are beyond those available to conscious thinking. Again, Table 8.2 summarizes this work, and the historical connections among the various theories discussed so far in this chapter are outlined in Figure 8.1.

The Question of Subjective Reports

It was noted in Chapter 2 that one can question the value of self-reports as evidence for psychological theory. In that context, it is important to note that all the theories we have discussed so far have been built on such reports. We began with Poincaré, whose theorizing was based on evidence from his own experiences. Poincaré also analyzed his creative process logically and concluded, for more than one reason, that unconscious processes must have been operating. First, he experienced illuminations, wherein the solution of a problem appeared suddenly when he was not working on it. It is difficult to understand how such experiences could occur unless he had been working on the problem at a nonconscious level. Also, he believed that what he called “invention”—creative thinking, in our terms—depends on combinations of ideas. However, he was not aware of the innumerable combinations of ideas that, in his view, must have been occurring. Therefore, he decided, those combinations were being carried out by processes of which he was not aware.

Furthermore, also based on the notion of creativity as combination, it must have been the case that many sterile combinations were formed dur-

ing Poincaré's creative process (1913). He was aware only of potentially valuable combinations, however, which meant that something must have been blocking the occurrence of those useless combinations in his conscious awareness. That blocking must have occurred at an unconscious level. Finally, the combinations that he did become aware of possessed beauty in mathematical terms. This feature led him to the conclusion that all the combinations were being subjected to a process of judgment. He was aware of no such process, but since, based on his logical analysis of the situation, it must have been happening, he concluded that it must have been carried out on an unconscious level.

Wallas (1926) provided little new evidence beyond that of Poincaré, and Hadamard (1954) added reports from Einstein and others, but we still have only self-reports. Hadamard also concluded on the basis of his logical analysis of such psychological phenomena as facial recognition and speech production that unconscious processes must have occurred. Koestler (1964) used self-reports as support for his theory, which incorporated ideas from Freud and Poincaré. Campbell (1960) used Poincaré's reports as evidence to support his theoretical assumption that there must be a blind-variation process in creativity since otherwise there could be no production of new ideas. Campbell did not provide any new data; his adoption of Poincaré's ideas was driven by logic (his perceived necessity of explaining the production of truly new ideas in creative thinking) and by the requirements of his theory (the need to incorporate a process analogous to the blind variation that occurs in organic evolution). Simonton (1988) accepted the arguments of Poincaré and Campbell; he added Koestler's ideas, thereby incorporating aspects of Freud's view. Simonton's adoption of Mednick's (1962) theorizing is also not based on any new data. Indeed, as we have seen, Mednick also cited Poincaré. Lastly, Csikszentmihalyi and Sawyer (1995) also built their theory on that of Poincaré, as filtered through Wallas's stages. For data they rely on subjective reports from 100 highly creative individuals.

Given the potential weakness of subjective reports as support for psychological theory, let us now turn to a consideration of experimental studies that have been designed to provide support for the notion of unconscious thinking in creativity.

Laboratory Investigations of Incubation and Illumination

A number of empirical studies have attempted in several ways to provide support for the notion of unconscious processing in creative thinking. First, attempts have been made to provide verification for the stages of creative thinking postulated by Wallas (1926), and second, researchers have tried

to find evidence specifically for the occurrence of illumination, which would provide at least indirect evidence for incubation and unconscious processing.

Patrick's Studies of Stages of Creative Thinking

C. Patrick (1935, 1937) carried out two often-cited early investigations directed at the question of stages in creative thinking. In the first study, accomplished poets, chosen because their work had already been published, were given a picture and asked to write a poem in response to it. In the second study, artists whose work had been exhibited throughout the world were asked to draw a picture in response to poetry of Milton. In these studies, performance of the creative participants was compared with that of a control group, who were matched in age, intelligence, racial background, and sex, but who had not exhibited creative achievement. Patrick saw each individual in a session at his or her home, during which he or she carried out the creative task while thinking aloud; Patrick took down in shorthand everything the participant said. The task was carried out in a single session. After the poem was written or the picture completed, Patrick interviewed the creative participants concerning their usual methods of working and whether they typically went through periods of incubation that were followed by illumination, among other questions. Although the creative productions were in response to stimuli provided by the experimenter, most of the poets and artists reported that the methods they used in Patrick's study were similar to those they usually used. The poets and artists took about 20 minutes on average to complete their projects, as did their respective control groups.

In order to determine if these sessions provided evidence for Wallas's (1926) hypothesized stages, Patrick divided the single work session into quarters. In the first quarter, she found that her participants made the most shifts from idea to idea, which she took as evidence of preparation. During the second quarter of the session, she noted whether the topic of the poem involved an idea that had been raised during the first quarter but dropped as the participant turned to other ideas. Recurrence of a previously rejected idea, which was most frequent during the second quarter, was taken as evidence of incubation's having occurred. Similarly, in the study of artists, the theme for the painting often involved an idea that had been discussed earlier, then put aside, and then returned to at a later time; again, Patrick took this as evidence of incubation. During the third quarter, the poem or the picture was given general theme or shape, and typically this stayed the same throughout work on the project. This was evidence of illumination, as an idea for the work took shape as the result of incubation. Finally, in the

fourth quarter of the working session Patrick found the highest frequency of revisions of the work, which she took as evidence of verification. Thus, in Patrick's view, her work provided support for the existence of the stages proposed by Wallas.

Although C. Patrick's (1935, 1937) work has often been discussed in the context of Wallas's (1926) stages, the context in which she herself placed it, questions can be raised about whether this research is relevant to the general theory of stages of creative thinking and the more specific theories of unconscious incubation. First of all, the fact that the work was carried out during a single session means that the individual obviously was thinking about the creative project the whole time. In the classic examples of incubation, those provided by Poincaré (1913), he first thought about the problem intensely and then stopped working. Poincaré also reported that during that break he stopped thinking about the problem. The solution to the problem then came to him in another context, in which he claimed that he had not been thinking at all about the problem. Thus, Patrick's data from a single session are not relevant to questions about creative-thinking situations in which a person reaches an impasse and then works—or, as the case may be, does not work—on some problem over a period of time.

One piece of information from C. Patrick's (1935, 1937) studies that might be relevant to the general issue of Wallas's stages, as well as to the specific question of the occurrence of unconscious incubation, comes from the questionnaires she administered to the poets and artists after they produced their creative works. Most of the members of both groups reported that incubation occurred in their work; that is, they thought about an idea, put it aside, and then had the idea come to mind as the theme of a work. Many of the participants reported, however, that they *thought about the idea from time to time during the period of incubation*—that is, during the time in which unconscious processing was assumed to be occurring. Needless to say, if poets and artists think about ideas off and on when they are not formally working on some project, any purported illumination could be the result of these bouts of conscious thinking. If this finding has any validity and generality—and it should be noted that the finding comes from unverified responses to Patrick's questionnaire, because she provided no other evidence to support the claims of her participants—it would indicate that, in some cases at least, it is not necessary to postulate the occurrence of unconscious processes as the basis for illumination. The conscious processing could be doing all the work. This issue will be discussed further shortly.

For the reasons we have discussed, C. Patrick's studies of poets and artists shed little light on stages of creative thinking in general or on unconscious

processing in particular. The design of her studies made it impossible for unconscious processing and incubation to occur.

Eindhoven and Vinacke's Study of Stages in Creative Thinking

One problem with C. Patrick's (1935, 1937) studies, as just mentioned, is that the painters and poets were given only a single session in which to carry out the task of creative production, so a true incubation period was not possible. Eindhoven and Vinacke (1952) extended Patrick's research to try to overcome this difficulty. As in Patrick's study, painters were asked to create a picture in response to a poem, but they were given more time to work on the project: They could take up to four sessions over a week's time. Of the 13 artists studied, almost all took at least two lab visits to complete the painting, and more than half returned to the lab for a third visit. Similarly, of the 14 nonartists who participated as a control group, almost three quarters returned for three visits. In addition, although most of the artists completed their visits during 1 week, several took 2 weeks, and for one artist several months elapsed between his two visits. No time limit was placed on the visits, but an hour was suggested. During the time between visits, the participants were asked to keep a diary in a pocket notebook of any experiences and ideas relevant to the project. Any sketches done outside the laboratory were done on paper provided by the researchers and were brought in to the next session.

The first important result from the Eindhoven and Vinacke (1952) study is the finding that multiple sessions were typically used in order to carry out the project, which indicates that C. Patrick's (1935, 1937) limiting her participants to a single session in her early studies might have resulted in important data being missed. Concerning the specific activities carried out by the participants, results indicated that overall the artists produced many more sketches than did the nonartists. Furthermore, the artists tended to produce new sketches only during the first session and then concentrated on using one of those sketches as the basis for their final work. The nonartists kept producing new sketches over the several sessions. The early sketches produced by the artists tended to be small, as might be expected of a preliminary work. The nonartists produced larger works throughout all the sessions.

Eindhoven and Vinacke (1952) also examined the content of the sketches and found that the motif of the first sketch—the salient theme or feature, such as an abstract composition versus a landscape, or the presence or absence of human forms or artifacts—tended to be repeated in later sketches, indicating that the artists had decided early in the process on the motif and then stayed with it. More specific aspects of the subject matter—the specific

landscape, say—were developed over the series of sketches. Examining the first 5 minutes' work on a picture and comparing it with the last 5 minutes', the researchers found, perhaps not unexpectedly, that both artists and non-artists spent the early time laying out general aspects of the picture—overall composition, outlines of principle objects—and spent later time filling in detail. Those findings parallel those from the study of Picasso's creation of *Guernica* presented earlier (see Chapter 1). Picasso too decided on the subject matter very early in the process and developed the specifics of the painting over a series of sketches. The participants' diaries, although of potential importance, were kept by only seven participants (of whom five were artists), so little information could be gleaned from them. However, poststudy interviews indicated that a majority of participants thought about the project outside the laboratory. That finding supports Patrick's (1937) finding that artists reported that they often thought about a project when they were away from their studios.

In summarizing their results, Eindhoven and Vinacke (1952) draw several important conclusions. First, the typical path taken by their participants involved a significant period of time during which the final product gradually evolved, as the individual increasingly focused on a particular sketch and from it produced the final product. Concerning Wallas's (1926) four stages of the creative process, Eindhoven and Vinacke raise a number of points. They note first that Wallas's description of the stages of the creative process might lead one to expect them to be universal; that is, in all situations demanding creative thinking, all people would behave in the same way, and that behavior would be in accord with the stages. However, the artists in this study behaved in general very differently from the nonartists, which indicates that, irrespective of the general issue of stages in creative thinking, the same process is not occurring in all individuals faced with a situation that requires creative thought.

As regards the specifics of Wallas's (1920) postulated stages in the creative process, Eindhoven and Vinacke concluded that the stages described by Poincaré (1913) and Wallas (1926) could not be isolated as separable entities in their results. The hypothesized stages actually blended into each other in complex ways, so it was difficult if not impossible even to talk of stages. Furthermore, when Eindhoven and Vinacke discuss the stages, it becomes obvious that the term *stage* itself is not particularly apt as a description of what was happening in their study. As an example, they discuss the illumination stage and comment that it was very difficult in their data to find a distinct point where an idea suddenly came into consciousness (although one artist reported that an idea for a sketch came suddenly one night). Eindhoven and Vinacke propose that one might redefine illumination as a

process leading to a definite idea or reorganization of previous ideas. They would then find illumination in their study, and one could then talk of a series of illuminations, as the first sketch is transformed into final form. In response to that proposal, however, one can ask if we would be studying illumination in the sense proposed originally by Poincaré and those who followed him, like Wallas (1926) and Hadamard (1954). If the notion of illumination has to be changed that much in order to find evidence for it, it might be better to simply give up the idea of stages and perhaps even to relinquish the notion of illumination. It might be more informative to simply examine how a product is transformed over time without worrying about specific stages in the process, since there might not be any stages to be found.

As we can see, the studies by C. Patrick (1935, 1937) and Eindhoven and Vinacke (1952) have not provided strong support for the general theory of stages in creative thinking or the specific question of whether unconscious processing occurs in creative thinking. We can now turn to a number of studies that have attempted to demonstrate the occurrence of incubation in the laboratory. These latter studies have used experimental situations designed to capture the essential features of those situations in which incubation and illumination have been reported by creative thinkers.

Attempts to Demonstrate Incubation in the Experimental Laboratory

The basic experimental design that can allow one to demonstrate the occurrence of incubation in the laboratory is shown in Table 8.3A. First, the individual tries to solve a challenging problem (period *a* in Table 8.3A). If the session ends with the target problem unsolved, then the study of incubation can begin. In an analogy to Poincaré's reports, the initial work should end with the person reaching an impasse, but that is not always ascertained. The individuals who do not solve the problem are assigned to one of two conditions: The incubation group has time away from the problem (intervening period *b* in Table 8.3A), while the control group keeps working on the problem. After the incubation period, the target problem is again presented (period *a'* in Table 8.3A) and the incubation group goes back to work on it. The two groups spend the same total amount of time working on the problem (*a + a'*, as shown in Table 8.3A). Performance of individuals given a break is compared with that of individuals who work continuously on the target problem; if taking a break results in better performance, it can be taken as evidence for incubation having occurred when the person was not working on the target problem.

This conclusion is based on the condition that the participants did not think about the target problem during the break. Not thinking about the

Table 8.3 Laboratory studies of incubation

A. Basic design					
<i>Incubation group</i>	Initial work $/ \Leftarrow \Leftarrow a \Rightarrow \Rightarrow / \Leftarrow \Leftarrow b \Rightarrow \Rightarrow / \Leftarrow \Leftarrow a' \Rightarrow \Rightarrow /$	Intervening period	Final work		
	Initial work $/ \Leftarrow \Leftarrow a \Rightarrow \Rightarrow / \Leftarrow \Leftarrow a' \Rightarrow \Rightarrow /$	Final work			
<i>Control group</i>	$/ \Leftarrow \Leftarrow a \Rightarrow \Rightarrow / \Leftarrow \Leftarrow a' \Rightarrow \Rightarrow /$				
	Incubation group total time $a + a' =$ Control total time $a + a'$				
B. What happens during the intervening (incubation) period?					
	<i>Nothing:</i> Individual carries on ordinary activities (ignores problem or is instructed not to think about problem).				
	<i>Distractor activity:</i> Participants carry out a task to stop them from thinking about the problem.				
C. Type of distractor activity					
	1. Unrelated to problem solving (e.g., person rates pictures of faces for attractiveness)				
	2. Other problems of the same sort serve as the distractor activities:				
	<i>Incubation group:</i> Problem ₁ \Rightarrow Problem ₂ \Rightarrow Problem ₃ \Rightarrow Problem ₄ \Rightarrow Problem ₅ \Rightarrow Problem ₆				
	<i>Control group:</i> Problem ₁ + Problem ₄ \Rightarrow Problem ₂ + Problem ₅ \Rightarrow Problem ₃ + Problem ₆				
	Incubation group total time Problem _x + Problem _y = Control total time Problem _x + Problem _y				
D. Summary of laboratory studies of incubation					
Author(s)	Target problem	Distractor tasks(s) (plus continuous-work control	Incubation found?	Comments	
Olton and Johnson (1976)	Farm problem (see panel E)	(1) No distractor (free time) (2) Problem review (3) Set-breaking instructions (4) Relaxation training (5) Visual analogies of solution	None	No measure of impasse. Relatively gross measure used (number of people solving only one target problem).	

Olton (1979)	Chess problem	No distractor (asked not to think about problem)	None	No measure of impasse; only one problem used.
Browne & Cruse (1988, Exp. 2)	Farm problem	(1) Analogical hint (draw shapes) (2) Relaxation (with music) (3) Difficult mental work	1 and 2 (?See comments)	No measure of impasse. Subjects reported that they thought about problem during break. (No true incubation.)
Patrick (1988)	Verbal insight problems (see Figure 6.5B)	(1) Other problems (Table 8.3C2) (2) Other problems + conversation (3) Other problems + mental rotation task	Incubation effect only for high-ability participants. No general effect found.	Incubation effect only for high-ability participants. No general effect found.
Segal	Area (see panel F)	(1) 4 minutes versus 12 minutes (2) Easy task (reading newspapers) versus hard task (crossword puzzle)	With hard task; easy task marginal. No effects of break length.	Measured impasse. Used only one problem.

E. Farm problem

A farmer has a plot of land that he wants to bequeath to his four children. In order to prevent squabbling among them, he must make certain that they receive identically shaped pieces of land. How can the farmer cut his land into four identically shaped pieces so that his children will be happy?



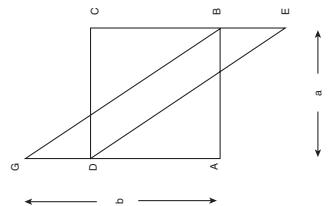
F. Area problem

Given that $\overline{AB} = a$ and $\overline{AG} = b$, find the sum of the areas of square ABCD and parallelogram EBGD.

There are two related solutions:

1. ABG and DCE are right triangles, each of which has area $\frac{1}{2}(a \times b)$, so the area of the total figure is $2 \times (\frac{1}{2}(b \times a))$ or $b \times a$.
2. It can be shown that triangles ABG and DEC form two halves of a rectangle, so the area of the entire figure is $a \times b$.

Source: Segal (2004).



problem during the break is comparable to Poincaré's (1913) report of his incubation experience: He reached an impasse and then left his work at home and went traveling. He says that his travels made him forget his mathematical work. If people do not stop working on the problem during the break, then the question of incubation occurring becomes moot, because the so-called incubation group simply kept on working during the time that they were supposed to take a break from it. Obviously, that continuous work will account for any increase in performance compared to the continuous-work control group, because when you add in the additional time during the break, the incubation group worked longer. As we shall see, the condition that the incubation group not work on the problem during the break is not always met.

An important question in laboratory studies of incubation is what happens during the period away from the problem, when any incubation effects would presumably occur. In most studies the intervening or incubation period is structured in one of two basic ways (see Table 8.3B). In some studies, the participant leaves the laboratory for the incubation period, with the understanding that the target problem will be returned to later. Those participants are asked to carry out their normal activities during the time away from the lab and not to think consciously about the unsolved problem during that time. In other studies, the participant stays in the laboratory and another task is presented, and the participant works on that task for the duration of the incubation period. This second task can be called a *distractor* task, since it is designed to distract the person from thinking about the unfinished target problem during the break. Distractor tasks are used in experiments because experimenters are concerned that people might either intentionally or unintentionally think back to the unsolved problem during the break. As just noted, such conscious thinking about the problem would make invalid any attempt to demonstrate incubation.

As shown in Table 8.3C, the distractor activities in incubation studies are usually of two sorts. In some studies the participants work on a distractor activity that has nothing at all to do with the problem they had been working on. As an example, a person working on a mathematical problem might be asked to rate pictures of faces for attractiveness during the incubation period. In other studies, the person works continuously on a series of problems of the same sort, so the incubation period is filled with other problems. The person presumably cannot think about the unsolved Problem₁ during the incubation period because he or she is working on Problem₂, Problem₃, and so forth. When Problem₁ is presented for the second time (see Problem₁ in Table 8.3C2), one could say that the participant is returning to it after an incubation period.

It is important to emphasize that there are two interrelated issues tied together in these studies. The interest in the possible facilitative effects of taking a break stems, of course, from Poincaré's (1913) conclusion that unconscious processing was occurring when he was away from his desk and not thinking about his work. However, as just noted, the question of whether taking a break facilitates problem solving is independent of whether the facilitation comes about because of unconscious processing. Let us say that we carry out a study such as that presented in Table 8.3A (ignoring at this point how the incubation period is structured), and we find that taking a break facilitates solving the target problem. There then arises the question of the *mechanism* whereby this facilitation comes about. Finding that taking a break from work facilitates problem solving is a necessary but not sufficient step in demonstrating that unconscious processing occurs during creative thinking. There might be other reasons why taking a break helps, reasons that have nothing to do with unconscious processing.

In short, the first question is whether taking a break facilitates problem solving; if this question is answered in the affirmative, then we can turn to the question of the mechanism that brings about the facilitation. So before we theorize about the mechanism underlying illumination, let us examine research that has been designed to demonstrate the facilitative effect of taking a break during problem solving.

There have been a number of laboratory studies that have used the design outlined in Table 8.3A–8.3C, and the results have been mixed even in demonstrating that taking a break facilitates solving the target problem. One difficulty is that many of those studies suffer from flaws in their designs, which makes it difficult to draw conclusions as to whether incubation occurred. As one example, we can examine an early study of incubation by C. Patrick (1938). As noted in the last section, Patrick's two studies of Wallas's (1926) stages in problem solving were problematic (1935, 1937) because she tested each person in a single session, which made it impossible to investigate all the stages. In a later study, C. Patrick (1938) asked individuals to propose scientific methods to investigate the effects of heredity and the environment on humans. The control group worked continuously on the problem, while the incubation group was given a diary and was told to return 2 to 3 weeks later with proposals. They were told to use the diary to record thoughts or ideas that arose during the break from the problem. A basic difficulty with this study becomes apparent immediately: The incubation group did not really take a break from the problem but simply worked on the problem in whatever manner they wanted to over a long period of time. The experimenter exerted no control over what the participants did during the incubation interval, and one might conclude that the instruc-

tions to write ideas in the diary encouraged the people to think about the problem straight through. So this study can tell us nothing about incubation. Several studies that do not suffer from such basic flaws are summarized in Table 8.3D; for reviews of additional studies see Olton and Johnson (1976) and Dodds, Ward, and Smith (in press).

A study by Olton and Johnson (1976) using the Farm problem (see Table 8.3E) examined possible effects of several different sorts of activities during the incubation period (see Table 8.3D). Those activities ranged from unstructured free time to listening to set-breaking instructions (designed to help people break out of any ruts they were in) to being moved to a room in which there were pictures that contained geometric forms that were analogous to the solution. None of the conditions resulted in incubation: All the groups solved the problem at the same rate as the group that worked continuously. In addition, Olton and Johnson derived a method to score people's progress toward the solution, so they had a second measure beyond simple solution of the problem. This progress score also showed no evidence of incubation. This study was also an attempt to replicate one by Dreistadt (1969), which had reported incubation using the Farm problem, so the inconsistent results across the two studies point to difficulties in demonstrating incubation.

In another attempt to demonstrate incubation in the laboratory, Olton (1979) used a specially selected group of participants—experienced chess players—as well as a problem that was selected by a chess master to be challenging: working out the final moves in a chess game. That problem was of the sort that those participants on their own would typically spend much time on. In that way this study mimics what happened with Poincaré (1913): Presumably he was working on problems of intrinsic interest. Olton gave the chess problem to the participants and instructed them to work on it for about 1 hour; if they had not solved it by the end of that time, they were to break off work for about 2 hours. So the break occurred when the participants felt ready for it. During the break the participants could do anything they wanted, as long as they did not think about chess. The problem seemed to have been highly involving, with some people actually voluntarily cutting short the break to continue working on it. A control group worked on the problem without a break.

Although it seems that overall Olton (1979) did a relatively good job of producing in the laboratory a microcosm of situations in which illuminations have been reported, the results of the study were disappointing as far as demonstrating incubation: 50 percent of both the incubation and control groups solved the problem. One participant in the incubation condition reported an *Aha!* experience during the break, à la Poincaré, but overall

the break did not help the incubation group. As Olton notes, “We simply didn’t find incubation” (p. 17).

Browne and Cruse (1988, Experiment 2) also used the Farm problem and examined three distractor activities. One group of participants drew geometric forms during the incubation period, in the hope that one of those shapes might cue the solution to the problem, based on analogy. This was the analogical hint condition. A second group was given relaxation instructions and listened to music during incubation, and the last group carried out difficult mental work (memorizing a passage) during the incubation period, to try to make it very difficult for them to think about the problem during the break. After the experiment, the participants filled out a questionnaire asking them what they had done during the incubation period, to gather evidence for people thinking about the problem consciously when the experimenters thought they were supposed to be taking a break from the problem. Incubation effects were found for the analogical hint and relaxation conditions; there were no effects for the participants carrying out difficult mental work. Browne and Cruse concluded that the positive effects were due to the participants’ working on the problem when they were supposed to be not thinking about it, and the participants’ responses to the questionnaire supported that conclusion: The people in the two conditions that resulted in incubation effects reported that they had thought about the problem during the break. Browne and Cruse concluded that perhaps all results previously attributed to some underlying mechanism working during the incubation period were in actuality the result of people consciously thinking about the problem without the experimenter’s realizing it.

A. S. Patrick (1986) carried out a study using verbal insight problems such as those shown in Figure 6.5B (p. 299). The participant first worked through a series of 30 problems, and 5 problems randomly chosen from the unsolved problems were used to test for incubation. Those test problems were ones that the participant could not solve during the initial presentation time, so the person was at an impasse for each of them. After the initial series of problems, some participants worked continuously on the five test problems, one at a time for a maximum of 8 minutes or until the problem was solved. Three other groups each had an incubation period, in which one of three activities occurred (see Table 8.3D). One group worked on the problems but cycled through them for 2 minutes at a time, as outlined in Table 8.3C2, until they had worked a total of 8 minutes on a problem or had solved it. A second incubation group also cycled through the five incubation problems for a maximum of 8 minutes, but before beginning the next cycle of problems they also spent an additional 5 minutes talking with the experimenter about activities not relevant to the experiment. So their incubation time between

each attempt on a given problem was longer than that for the incubation group that just cycled directly through the problems. The final group cycled through the problems and carried out a difficult mental rotation task for 5 minutes at the end of each cycle before returning to the problems.

This study seems to meet the criteria for a well-designed study: Participants reached impasse before stopping work on each problem; several problems were used to test for incubation; and experimental controls made it difficult for people to think about the problems they were not working on during the incubation periods. However, once again strong incubation effects were not demonstrated. A. S. Patrick (1986) looked separately at high-ability versus low-ability participants, whose ability was measured by their performance on the initial series of problems, and he found that only one condition—problems plus mental rotation with high-ability participants—produced a significant increase in performance compared with continuous work. In none of the other remaining five comparisons (two ability level and three incubation conditions) was the incubation group significantly better in performance than the continuous-work group. So this study produced at best weak evidence for incubation.

The final incubation study presented in Table 8.3D was carried out by Segal (2004). He used the geometry problem presented in Table 8.3E, and he began the incubation period only after the participant had indicated that he or she had reached an impasse. The incubation periods were either 4 or 12 minutes and the distractor activities were easy (reading newspapers) or difficult (working on a crossword puzzle). Incubation was found with the hard task for both incubation-period durations; the effect was less strong for the easy task, with only the short interval resulting in increased performance compared with the continuous-work group. So again we have a study that found some evidence for an incubation effect, but the lack of an overall strong pattern of incubation raises questions about the robustness of the phenomenon.

Laboratory Studies of Incubation: Conclusions

The results from laboratory studies of incubation are at most mixed: It has been extremely difficult to demonstrate consistently within a single study even that taking a break facilitates problem solving, so one never gets to the question of whether unconscious processing might be the cause of that facilitation. One might dismiss the negative findings in Table 8.3D because the laboratory studies are sterile and are far removed from the real-life situations in which incubation results in illumination. However, it should be noted that at least one study specifically designed to meet those objections—the chess study of Olton and Johnson (1976)—produced negative results. In addition,

if incubation is a phenomenon of critical importance in problem solving, as for example Poincaré's (1913) reports might lead one to believe, then one would expect that it would be easy to demonstrate it in the laboratory. If, for the sake of discussion, we take the evidence from the laboratory studies at face value, it leads to the conclusion that there is no strong and consistent laboratory evidence to support the notion of incubation during creative thinking, and therefore there is also no strong and consistent laboratory evidence to support the related notion of unconscious processing.

In this context it is interesting to note again that Browne and Cruse (1988; see Table 8.3D) interpreted their results as indicating that what has been called incubation—the facilitation of problem solving by taking a break from the problem, perhaps brought about by something like unconscious processing during that time period—comes about because people think about the problem consciously during the break. Olton (1979) raised a similar possibility, that what he called “creative worrying” (actively thinking about a problem when one was supposed to be not thinking about it) was the basis for reports of incubation. I will consider that possibility further at the end of the chapter.

There is also one other point to note concerning the lack of evidence for incubation and illumination in the studies just discussed. Those studies provided a very weak test of Poincaré's notions, and yet they still found little support for unconscious processing. It will be recalled that Poincaré (1913) reported that his illuminations came to him as Aha! experiences when he was away from his study—boarding an omnibus in Coutances or walking on the bluff at the seaside. The studies summarized in Table 8.3D almost never report such Aha! experiences; all they measure is whether taking a break and not thinking about a problem helps people when the problem is presented again. This is not quite a parallel to what happened in Poincaré's case: He solved the problem when he was not working on it. Thus, even in the studies in Table 8.3D that found that taking a break facilitated problem solving, one can still raise the question of whether such results provide evidence for Poincaré's incubation, since nothing like spontaneous illuminations occurred (e.g., Olton and Johnson, 1976, reported only one person as having an Aha! experience when away from the problem, which is the sort of evidence that would have provided strong support for Poincaré's theorizing). Thus, the weak results in the studies just discussed are doubly troublesome for the question of unconscious processing during creative thinking: They provide support neither for Poincaré's strong claims about unconscious processing—illumination occurring while away from the problem—nor for the much *weaker* claim that taking a break should facilitate solution.

These negative conclusions leave us with only the anecdotal reports of illumination as evidence of unconscious processing in Poincaré's strict sense. It now becomes of interest to look again at the anecdotal evidence for the presence of unconscious processing and illumination.

Evidence for Incubation and Illumination: A Critique

We have just seen that there is at best weak empirical support from the laboratory for the occurrence of unconscious processing in creative thinking. We have also seen that over the last 100 years many students of creative thinking—including, over the last 40 years, many cognitive psychologists—have built theories of creative thinking in which unconscious processing is given pride of place. The postulation of unconscious processing in creative thinking is based mainly on anecdotal reports. Those reports now have an especially heavy burden to bear: They must convince us that unconscious processing is at the core of creative thinking. The evidence that was discussed earlier in this chapter, when each of the various theories was outlined, is presented in Table 8.4.

Questions about Poincaré's Self-Reports

Poincaré's reports, as we have seen, have surfaced again and again over the years in the discussion of unconscious processing in creative thinking (Table 8.4A). We have already considered some problems with self-reports, including Poincaré's, as data for a scientific theory. There are several additional questions that can be raised about how much confidence we should have in those particular reports. First of all, Poincaré's public discussion of his discoveries was presented some 30 years after the events in question occurred. Furthermore, two of Poincaré's reports—stepping on the omnibus and walking on the bluff—dealt with *Aha!* experiences, that is, events of an extremely brief duration. It seems very difficult to believe that Poincaré's recounting of those experiences could be accurate after so long a period of time; it is hard enough to recount *Aha!* experiences immediately after they occur.

In Chapter 5, we discussed Perkins's (1981) study of insight in solution of the Antique Coin problem, and we examined how Perkins had designed his study to ensure that his reports would be of maximum accuracy. We noted that he made sure that the reports came as soon as possible after solution and that the participants were given some practice in the reporting task. Fleck and Weisberg (2004, 2006) and Chrysikou and Weisberg (2005), who also collected verbal protocols, also spent time designing their studies and training their participants (for detailed discussion of conditions for collect-

Table 8.4 Critical review of evidence for unconscious processing in creative thinking

Theorist	Evidence	Critique
(A) Poincaré	<ul style="list-style-type: none"> (1) Boarding the omnibus; on the bluff (2) Sleepless night (3) Logical analysis as the basis for concluding unconscious processes occurred: infinitude of possible combinations 	<ul style="list-style-type: none"> (1) Self-report; original Aha! experiences took seconds to unfold; reported 25+ years later. (2) Self-report; also, Poincaré was conscious (3) No empirical evidence; question of infinite regress; homunculus.
(B) Wallas and Hadamard	<ul style="list-style-type: none"> (1) Poincaré's stages (2) Self-reports 	<ul style="list-style-type: none"> (1) See above. (2) See above.
(C) Koestler	<ul style="list-style-type: none"> (1) Analysis of creative advances: Unlikely combinations of ideas (e.g., Guttenberg) (2) Kekulé (3) Einstein's report of "combinatorial play" 	<ul style="list-style-type: none"> (1) Self-reports. (2) Self-reports—see above. (3) Einstein: Self-reports. <ul style="list-style-type: none"> (a) Combinatorial play; conscious. (b) Riding on light beam; conscious.
(D) Simonton	<ul style="list-style-type: none"> (1) Logical analysis: numbers of combinations; unlikely combinations needed for important problems (2) Poincaré; Kekulé (3) Other opinions: William James, etc. 	<ul style="list-style-type: none"> (1) No new evidence presented—reasoning based on Poincaré and Campbell. (2) Self-reports—see above. (3) Not empirical evidence.
(E) Csikszentmihalyi and Sawyer	<ul style="list-style-type: none"> (1) Reports of interviewees: Nobel Prize winners, etc., are "more public and more convincing" (2) Insights while gardening: "Generally, the really high ideas come to me when I'm gardening." (3) Physicist on the bus: "In the middle of the night, when we were going through Kansas, the whole thing sort of suddenly became crystal clear." (4) Banker's "memo from the beach": "I'm sitting on the beach thinking about the business,' and it went on for 30 pages." 	<ul style="list-style-type: none"> (1) Why are reports more convincing when reported by Nobel Prize winners? Still subjective reports. (2) Gardening: Is she not thinking? (3) He was not consciously thinking? (4) He was thinking and writing memos, and was surprised at length and the result—how is that evidence for unconscious processes?

ing protocols, see Ericsson and Simon, 1996). In this context, it must be noted that Poincaré's reports were made by an individual who, although no doubt of the highest level of intellect, had no specific experience in the behavioral sciences. If one assumes that training in the behavioral sciences prepares one even a little for observing and reporting behavior, even one's own—and the discussion of Perkins's studies indicates that training is necessary to ensure that behavioral data are accurate—then Poincaré's reports, coming from a mathematician-scientist with no training as a behavioral scientist, again come into question.

It should also be noted that the first of Poincaré's (1913) reports, which describes the sleepless night when he observed his ideas colliding and combining, actually says nothing at all about the unconscious, since Poincaré was conscious during that episode. As we have seen, Poincaré concluded that, since he did not take an active part in directing the thought process, he must have been observing his unconscious at work, but there is absolutely no evidence for that conclusion. The objective evidence (assuming that we can take his report at face value) is that he was conscious. So the hooked atoms of Epicurus, which Poincaré and others (e.g., Simonton, 1995) refer to either directly or indirectly in building theories of unconscious processing in creative thinking, occurred in conscious thinking, and so seem irrelevant to theorizing about the unconscious. Ultimately, Poincaré's evidence consists merely of several first-person anecdotal reports that were made public many years after the events in question. In most areas that cognitive psychologists study they do not use subjective reports or anecdotes as the basis for theorizing.

Poincaré's Logical Analysis

Poincaré (1913) also used logical analysis to support the proposal that unconscious processing served creative thinking. He only became conscious of potentially useful combinations, but he believed that numerous combinations must have been formed somewhere during his work. Therefore, he concluded that those useless combinations that he never became aware of were formed by unconscious processing and did not possess the aesthetic qualities needed to be passed on the consciousness. However, this logical analysis, while perhaps reasonable on its face, is based on several assumptions, about the thinking process in general and creative thinking in particular, that are not the only possible assumptions. The critical assumption underlying Poincaré's conclusion is that thinking works by making combinations of ideas, one after the other, until something potentially useful captures attention. Poincaré's theory of thinking is therefore an example of what we have called a *bottom-up* view of the thought processes (see Chapter 3), in the sense that it works by combining the basic elements or

ideas, without any planning; planning is called *top-down* processing, because plans are based on ideas generated from the top. We are also familiar with the bottom-up/*top-down* distinction from the discussion in Chapter 5 of heuristic-based restructuring in insight.

Contrary to Poincaré's bottom-up conception, it is possible to conceive of creative thinking as working in a more top-down manner, so that the goal the thinker is working toward plays a role in determining how ideas are combined. In this view, many combinations would never be tried out because they would not ever be considered. As an example, consider Watson and Crick's discovery of the double-helix structure of DNA (see Chapter 1). They did not start by combining available ideas without planning. Their thinking shows evidence of planning, in several ways. First, and most important, they used Pauling's success with alpha-keratin as the basis for the general helical orientation that they took toward their work. Therefore, all the ideas they considered were germane in some way or other to the general idea of helices. This was not, however, because unconscious processing produced those combinations and passed them along to consciousness, as Poincaré assumed. Rather, it was because of the top-down nature of the process: Their conscious decision to deal with helical structures meant that, from the very beginning of the process, only certain ideas would be considered, which radically limited the breadth of (conscious) search. Other case studies in Chapters 1 and 5 also support that conclusion.

Poincaré's conclusion that unconscious processing must have been involved in his thinking was based on the fact that he was never conscious of the innumerable ideas that were totally irrelevant to his problems. His critical assumption was that he combined all those ideas *somewhere*, so if he was never conscious of them, they must have been combined in unconscious processing. However, that assumption may simply be incorrect. If there are not innumerable hidden combinations of ideas that need to be explained, we do not need unconscious processing.

As we can see, Poincaré's evidence of unconscious processing is of little substance when examined with a critical eye. His empirical reports were given years after the fact and even turn out to contradict the notion of unconscious processing, since at least one—the sleepless night—was based on conscious processing, and his logical analysis supporting the necessity for postulating unconscious processing is based on assumptions that can be questioned. The views of Wallas and Hadamard (Table 8.4B) are built directly on that of Poincaré, and therefore they add nothing new to the discussion. Wallas's (1926) stages are built on Poincaré's reports and on those of others, but those other reports are no more rigorous and reliable than are those of Poincaré. Hadamard (1954) attempted to go further, but

the evidence he provided was of the same sort as Poincaré: self-reports, although from a wider range of individuals. The numerous individuals whose reports of illuminations fill the literature (e.g., Ghiselin, 1952; see also Csikszentmihalyi & Sawyer, 1995) may believe that their creative thought involves unconscious thinking, but that belief, *per se*, does not help in the scientific study of the phenomenon. These criticisms are also relevant to Koestler (1964; Table 8.4C), all of whose theorizing about the unconscious is based on self-reports.

Modern Views of Unconscious Processing

We have examined modern theorists' advocacy of unconscious processes, and we have found that those theories are based on data that are not different in kind from those available to Poincaré. Simonton (1995; Table 8.4D; see also Miller, 1996), for example, simply assumes that Poincaré's analysis is valid on its face, without providing further evidence to justify that assumption. Csikszentmihalyi and Sawyer (1995) present many subjective reports as data (Table 8.4F), but those are simply additional after-the-fact self-reports by thinkers and do not add anything new to what we learned from Poincaré. As noted earlier, Csikszentmihalyi and Sawyer (1995, p. 330) claim that self-reports concerning unconscious processing are of value when they come from Nobel Prize-winning scientists or from artists and writers of renown. However, I would raise the same objections to those reports as have already been raised to those of Poincaré. Do we have any independent evidence for what those reports claim? And why would we want to believe the report of a Nobel Prize-winning chemist, say, about her unconscious processing? What does she know about such things, other than that sometimes she may suddenly have an idea occur to her and she cannot trace where it came from? That chemist's credentials *qua* chemist are of little value here, since the study of creative thinking is a domain totally unrelated to her area of expertise. As was noted earlier in the discussion of Poincaré's lack of training as a behavioral scientist, it is not a given that anyone can produce and collect behavioral data that are valid as a basis for the construction of theories.

Furthermore, questions can be raised concerning the interpretation of several of the reports presented by Csikszentmihalyi and Sawyer (1995). One respondent quoted earlier talked about ideas coming to her while she is gardening (p. 348). That report has nothing to do with unconscious processing: She is gardening, but that does not preclude her thinking about some other things at the same time. Gardening is exactly the kind of mindless physical activity that allows one to do one thing while thinking about

something else. Similarly, the physicist-mathematician who was trying to synthesize the work of Feynman and Schwinger described how, on the bus during the night in Kansas, he was able to unify those two seemingly incompatible approaches to quantum mechanics. Here is the crucial part of the passage quoted earlier: “[S]uddenly, in the middle of the night, when we were going through Kansas, the whole thing sort of suddenly became crystal clear, so that was sort of the big revelation for me, the eureka experience” (Csikszentmihalyi & Sawyer, 1995, p. 359). When I read that passage, it seems to me that he was conscious the whole time, thinking about the problem, when the solution suddenly came to him. If my interpretation is correct, this report also has nothing to do with the unconscious.

Finally, consider the banker’s “memo from the beach,” in which he outlined the structure of the first consumer banking enterprise (Csikszentmihalyi & Sawyer, 1995, p. 354). He reported: “I didn’t sit down and say, ‘I’m gonna write a blueprint;’ I said, ‘I’m sitting on the beach thinking,’ and I sort of thought through the business in a systematic way . . . and I shared it with my colleagues” (p. 354). Again, this report seems to have nothing to do with unconscious processing. He was thinking about the business, and he wrote a memo. Perhaps that memo was more detailed and elaborate than he had expected; however, that has no relevance to the issue of unconscious processing. He simply wrote a memo, which is a conscious act.

I do not wish to belabor the point further with an analysis of each quoted example. It is important to emphasize, however, that those reports are being brought forth as evidence for unconscious processing, so they should be subject to the same scrutiny that is afforded any scientific evidence. When examined in this way, the modern evidence for unconscious processing is no stronger than that brought forth by Poincaré a century ago. It follows that the empirical support for the idea of unconscious processing in creative thinking consists of a number of anecdotal reports, several of which have been repeated so frequently over the years that many investigators now assume that the case is closed. Anecdotal reports, however, are not adequate grounds on which to build a scientific theory of creative thinking. I will therefore conclude that, as the evidence stands, unconscious processing cannot explain the occurrence of illuminations.

Illumination without Unconscious Processing?

Assuming that the self-reports of illuminations in the literature are accurate, we still have a phenomenon to explain. Accordingly, I now turn to explanations of illuminations that do not postulate unconscious processes.

Selective Forgetting

Many years ago, Woodworth (1938) formulated an explanation of facilitation in problem solving brought about by taking a break that did not rely in any way on the notion of unconscious processing. He argued that, since the problem had not been solved as a result of the initial attempts, those attempts were in the wrong direction. If we assume that some dynamic cognitive factors had played a role in determining the initial incorrect directions taken by the thinker, then with the passage of time those factors might be replaced by others. In other words, assume that when the problem is first presented the individual makes some decisions about how the instructions are to be interpreted and what sorts of solution attempts should be made. It is not unreasonable to assume that the factors or cues that influence those decisions might change over time, because when the person returns to the problem after a break, he or she is no longer the same person as before the break. Therefore, the direction taken by the thinker when the problem is re-presented might be different, but only because the intervening time allowed those misdirecting factors to become less important; one could say that the misdirecting factors were selectively forgotten during the interval away from the problem (see also Simon, 1986). According to this view, nothing positive, of either a conscious or unconscious nature, occurs during the interval; the interval merely serves to allow a change in at least some of the cues eliciting the mode of attacking the problem.

This view has more recently been revived by Smith (1995; see also Segal, 2004, for a slightly different view), who proposed that initial problem-solving attempts may result in thinkers' falling into *mental ruts*, unsuccessful approaches to a problem that interfere with thinking of new ones. According to Smith, the cues eliciting those unsuccessful approaches must be forgotten before anything different can be thought of with regard to the problem. Time is needed for this forgetting to occur, and that is the purpose served by the incubation period. Smith tested this hypothesis using an experimental design like that shown in Table 8.5. People were first exposed to word problems and presented with cues to the solution. Sometimes the cues were designed to be helpful (see Table 8.5A), but in the more interesting condition (Table 8.5B) the cue was designed to *interfere* with solution to the problem. Smith hypothesized that those misdirecting cues would have to be forgotten before solution could occur. After attempting and failing to solve the problems with the misdirecting cues, people were given breaks of various lengths away from the problems. After the breaks, the unsolved problems were presented again, and the participants were asked to try to solve them again, and they were also asked to try to recall the cue that had originally been presented with each problem. The results (see Table

Table 8.5 Smith's study of incubation

A. Example problems

Each problem represents a familiar phrase. What is the phrase?

- (1) r | e | a | d | i | n | g (Answer: "reading between the lines")
- (2)
$$\begin{array}{r} \text{EGGS} \\ \hline \text{EASY} \end{array}$$
 (Cue: breakfast) (Answer: "eggs over easy")

B. Example problem with a misleading cue

YOU JUST ME (Cue: beside) (Answer: "just between you and me")

C. Results

Condition	Clue memory	Improvement after incubation
Control (no break)	.8	0
5 min. break	.4	.25
15 min. break	.4	.30

Source: Smith and Blankenship (1989).

8.5C) indicated that the chances of solving the problems increased as the break was lengthened. Most important, Smith also found that the chances of recalling the misdirecting cues decreased as the break lengthened, and that solving the problem was inversely related to the chances of recalling the misdirecting cue. That is, the highest solution rates occurred when the original misdirecting cue could not be recalled. The results thus support the hypothesis that getting out of mental ruts depends on changing the way the problem is analyzed, and that in turn depends on the cues used to access information used to deal with the problem.

Selective Forgetting and Illumination: Critique

One problem with the selective-forgetting explanation of illumination and incubation is that it requires that the problem be reconsidered at a later time in order for the new cues to work. However, consider once again the situation that initiated this stream of work, Poincaré's (1913) illuminations on the omnibus and on the bluff by the seaside. In those situations, at least as he reports them, the problems were not re-presented to him; he did not sit down again at his desk for another session of work. Rather, the problems *spontaneously came to mind*. In Smith's version of the selective-forgetting hypothesis, there seems to be no mechanism that would allow the occurrence of spontaneous solutions to a problem. Therefore, the selective-forgetting hypothesis is at best incomplete: It can explain how breaking away from

a problem can result in more efficient solution when the problem is encountered at a later time. It does not, however, seem able to deal with the phenomenon of sudden illumination, in which there is no re-presentation of the problem. In those cases, solution seems to be spontaneous, and the selective-forgetting view has no place for such a phenomenon.

Failure Indices: The Opportunistic-Assimilation Model

Seifert and colleagues (Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995) proposed a theory, also based on memory, that attempts to deal with the spontaneous nature of illumination after breaking away from a problem. They propose a mechanism whereby seemingly spontaneous solutions to problems can be explained even when the problem has not been re-presented. In their view, which has been adopted by others (e.g., Simonton, 2003), when an impasse in problem solving leads to breaking off work, there occurs storage of the unsolved problem in memory. That is, the person would remember that he or she had not solved such and such a problem. However, according to Seifert and colleagues, the problem is also stored with a “failure index,” which makes it a unique type of memory. Those failure indices specify the general type of information needed to solve the problem. One could say that the problem is stored as containing a *gap*, along with a general description of the type of information that might fill that gap. When the individual encounters an environmental or mental event that matches the information needed for a given problem, that problem is retrieved, and the thinker experiences an Aha! moment. That is, Seifert and colleagues assume that a specific environmental event can retrieve a problem from memory, thereby initiating or cueing solution. Seifert and colleagues called their view an “opportunistic-assimilation” model of illumination and insight: The individual assimilates relevant environmental events that he or she happens to run across, so he or she is opportunistic in taking advantage of what the environment presents.

Seifert and colleagues (1995) developed a laboratory analogue of what they believe occurs in the real world under circumstances that other investigators have labeled incubation and illumination. The experiment consisted of three phases. In phase 1 (see Table 8.6A) the participants were given a set of general-information questions to answer (those were the problems to be solved). An example is “What is a nautical instrument used to measure the position of a ship?” (Answer: sextant.) Approximately one third of the time, the participants were not able to answer the question and abandoned their attempts. After all the problems were presented, the experiment moved to phase 2, which involved a word-recognition task. A series of verbal stimuli was presented, and for each the participant judged whether

Table 8.6 Study by Seifert et al. (1995) and its relation to Poincaré's reports

A. Experimental design of Seifert et al.

Phase 1	Phase 2	Phase 3
Problem \Rightarrow impasse ("failure index")	\Rightarrow Break (solution word)	\Rightarrow Problem presented \Rightarrow solution

B. Experimental results: Solutions during phase 3

Question type	Target exposure during phase 2?	
	Yes	No
Old	55	38
New	48	38

C. Original reports of Poincaré and structure of phenomena

Phase 1	Phase 2
Poincaré: Problem \Rightarrow impasse	\Rightarrow Break \Rightarrow illumination (sudden realization of solution of problem)
Seifert et al.: Problem \Rightarrow impasse ("failure index")	\Rightarrow Break (relevant external stimulus) \Rightarrow illumination

it was a word. Examples are *mantiness* (no) and *lacuna* (yes). As far as the participants knew, there was no connection between phase 2 and phase 1; however, some phase 2 words were correct answers to phase 1 problems. The next day, the participants returned for phase 3, which again involved a set of information questions, some of which were new and some of which were repeated from phase 1. In addition, as just noted, for some of the old and some new questions, the answers had been exposed during phase 2, although of course the participants were not told of this.

The results of the study are shown in Table 8.6B, and they indicate that presentation of the target words during phase 2 facilitated solution of the old problems when those problems were re-presented during phase 3. Furthermore, the old questions without answers during phase 2 were not answered more than the new questions introduced in phase 3, which means that there was no incubation effect without exposure of the target word during the break (i.e., during phase 2). Based on these results, Seifert and colleagues (1995) concluded that incubation does not play a role in problem solving. Rather, a break may help problem solving because the course of daily events may lead to an accidental encounter with an external object or event that is especially relevant to solving the original problem (p. 87).

Illumination as the Result of Spontaneous Retrieval of a Problem: Critique of the Failure Index Hypothesis

Seifert and colleagues (1995) concluded that the results in Table 8.6B supported their failure index explanation of illumination. However, it should be recalled that their model is designed to explain Poincaré's (1913) original report, which described spontaneous retrieval of the solved problem when one had not been thinking about it. Their model assumes that the availability of a *cue* in the environment can result in spontaneous retrieval and solution of a previously blocked *problem*. Their experimental situation and results, on the other hand, provide evidence only that re-presentation of an unsolved *problem* (in phase 3 of the experiment, after the phase 2 word-recognition task) can retrieve a recently seen *word* (from that phase 2 word-recognition task) that solves it. That is, it seems on close analysis that the results are not relevant to the failure index model or to Poincaré's reports of his experiences.

The structure of Poincaré's experiences, as he reported them, and the structure of the model of Seifert and colleagues are outlined in Table 8.6C, and the lack of correspondence between the experiment and Poincaré's reported experiences and the model can be seen. In my interpretation of Seifert and colleagues' (1995) model, presentation of the solution words *during the word recognition task* (phase 2) should have spontaneously retrieved the blocked problems *at that time*, which would have been a demonstration of an analogue of Poincaré's illumination experiences under controlled laboratory conditions. Presentation of the relevant word during the word-recognition part of the experiment meets the definition of an external event that should have retrieved the relevant problem. Exposure to those words facilitated solution when the problems were re-presented, which means that at least some of those words were effective cues for some problems. However, it would seem to follow from Seifert and colleagues' model that those cue words should have spontaneously retrieved the relevant problems during the word-recognition phase of the experiment (phase 2), but they did not.

The failure of spontaneous solutions to occur during the phase 2 word-recognition task in the study by Seifert and colleagues (1995) seems to contradict their model. The experimental data indicate that a recent encounter with information relevant to a problem can assist solution when the problem is presented later, but they do not support the view that Poincaré's illuminations were due to environmental cues that provided information critical to the retrieval and "spontaneous" solution of the problems he was working on.

A number of other studies have also investigated the predictions of the opportunistic-assimilation view, and overall the results have not supported them. Dodds and colleagues (Dodds, Smith, & Ward, 2002) used three-word

verbal insight problems (see Table 6.5B, p. 299) to examine the influence of environmental cues on solution of a previously unsolved problem. Participants first worked through a series of 20 problems, with 30 seconds given for each. The problems had been pretested, so the experimenters knew that most people would not be able to solve most of them. The participants were then told that because the problems were difficult, later in the session they would get a second chance to work on any problems they had not solved. The participants then worked through a series of activities, and before beginning them, half the participants received instructions that information from those activities might help them on the word problems when the problems were presented again. The series of activities began with several problems of various sorts that were not related to the word problems. There was then a set of anagram-like tasks in which the participant was to make three words from the letters of each of 20 words on a list. The stimulus words in that anagram list were either the answers to the earlier problems, words semantically related to the answers (e.g., the word *oatmeal* was related to the answer “cookies”), or unrelated words. After the anagram task, the initial list of 20 verbal problems was presented again.

Based on the opportunistic-assimilation model, one would expect that the presence of the answers and the semantically related words during the session—immediately before the participants attempted to solve the critical problems the second time—would facilitate solution on the second try, but that was not found. Over a series of experiments, Dodds and colleagues (2002) concluded that the presentation of those solution words and related words was only helpful when the participants had been warned that the activities would contain information relevant to the problems. The mere presence of the solution word shortly before the problem was considered again did not facilitate solution. Dodds and colleagues concluded that their results did not support the opportunistic-assimilation view (Seifert et al., 1995), which would seem to predict that the recent presence of the relevant words should facilitate solution.

In addition, as noted earlier, Seifert and colleagues (1995) proposed their model to account for Aha! experiences such as those reported by Poincaré (1913). As noted in my earlier critique of the experiment by Seifert and colleagues, it stands to reason that the appearance of the solution word during the anagram task in the study by Dodds and colleagues (2002) should have brought about Aha! experiences in their participants. However, not only did that not happen, but, as we just saw, the presence of the solution words did not even facilitate solution when the problems were presented shortly thereafter. This study supports the negative conclusions I derived earlier from critical examination of the study by Seifert and colleagues.

A study by Anolli and colleagues (Anolli, Antonietti, Crisafulli, & Can-toia, 2001) found similar results. In this study, a problem similar to the Radiation problem (Table 4.1, p. 156) was used as the target. Participants worked through a series of pages in a booklet, and the target problem was on the last page. The earlier pages contained a series of activities, including several filler stories that were not related to the target problem. In addition, on some pages there was a question that asked about some element of a story on an earlier page, so the participant had to remember something about a story presented earlier. Most important, on one of those pages was a situation that was analogous to the target problem (*relevant base* situation, comparable to the General problem and the Radiation problem; see Table 4.1). That base provided information that was potentially relevant to solution of the target problem. The target problem was presented on page 7 of the booklet given to participants in the control group, whose group simply started to work on it. Participants in the other groups saw the target on page 8 of their booklets, with different information on page 7. The Reminder group saw on page 7 a question they were to answer about the base situation presented earlier, but nothing was said about the potential relevance of the base to the upcoming target. The Hint group read on page 7 a hint: The base information could suggest a solution to the upcoming target; there was no specific question or information about the base on the page. The Reminder + Hint condition answered the question about the base situation and was also told that that information was relevant to the target. The target was then presented to those groups, and the question of interest was which of those conditions, if any, resulted in facilitation of solution compared to the control group.

Anolli and colleagues (2001) found that solution of the target problem was facilitated only when participants heard the hint that the base information was relevant. Simply activating the base information by asking the participant a question about it—the reminder condition—had no effect on solution rates. This result would seem to contradict the opportunistic-assimilation model, which would predict that there would be facilitation by the person's thinking about that base information just before attempting the target problem. Furthermore, one might also predict that presentation of the target problem might result in spontaneous retrieval of the base (an *Aha!* experience), because they are structurally related. However, Anolli and colleagues reported no occurrences of such phenomena, which probably means that they did not occur. So again we see a critical difference between what Poincaré (1913) reported and what happened in an experiment.

In contrast to the studies just reviewed, Christensen and Schunn (2005) presented evidence that at first glance supports the opportunistic-assimilation prediction of spontaneous retrieval of an unsolved problem by an environ-

mental cue during an incubation period. Cues for earlier unsolved problems were presented as the participant worked through a series of problems. If the person did not solve the third problem in the series, for example, a solved problem that was analogous to that problem was presented, but not until after several intervening problems. So the unsolved problem and the cue were separated in time. As an example, if the person had failed to solve the Radiation problem, then the General problem *with its solution* would be presented as a cue (see Table 4.1). When the cue problem was presented, the participant's task was to stop solving the other problems and rate the difficulty of that new problem. That task was presumably not relevant to the problem-solving task being carried out. The participant then returned to solving the problems in the series. No mention was made of the relation of the cue problem to the unsolved problem. No restrictions were placed on the participants, so they could turn back to any unsolved problems at any time, including after a cue had been presented. The question of interest was whether presentation of the cue problem would cause the participant to return to the unsolved problem to which it was related. That is, would the presentation of the cue result in the retrieval of the unsolved problem to which it was analogous?

The results of the study supported the prediction from the opportunistic-assimilation theory: Presentation of a cue that was analogous to an unsolved problem resulted in retrieval of that problem and its being solved. There were control cues presented that were not analogous to any of the unsolved problems, and those cues had no effect on performance. These results seem to provide a laboratory analogue of Poincaré's (1913) reports of his illuminations: The person broke away from the problem and then an environmental event cued its solution. So perhaps that was what happened with Poincaré: When he was away from his work—boarding the omnibus or walking on the bluff—some cue in the environment provided him with the information he needed to make his leap, which he mistakenly attributed to unconscious processing.

However, there is one critical difference between Christensen and Schunn's (2005) experimental situation and the situations in which Poincaré (1913) experienced his illuminations. Poincaré's spontaneous retrievals—his illuminations—occurred in contexts very different from those in which he had been working on the problems: that is, on the omnibus or on the bluff above the beach. In the Christensen and Schunn study, the cues were presented by the experimenter in the same situation as the unsolved problems. It is true that the cue was not a problem to be solved—but it was a problem and its solution—and it is also true that nothing was said about a possible connection between the cue and any of the problems—but the cue

was presented in the middle of the experimental session. That co-occurrence information was something that Poincaré did not have. In order to replicate the critical condition of Poincaré's experiences as he reported them, it is necessary to present the cues in a context different from that in which the problems were presented, to see if the cues, *per se*, can retrieve the unsolved problems. As discussed in Chapter 4, Spencer and Weisberg (1986) showed that context had a strong effect on whether spontaneous analogical transfer occurred during problem solving: When the General problem and the Radiation problem were presented in different contexts, there was no transfer from one to the other. Thus, the Christensen and Schunn results, while interesting and potentially important, do not provide unequivocal support for the opportunistic-assimilation view of Seifert and colleagues (1995).

Models of Illumination: Conclusions

A number of models have been developed to explain the occurrence of illuminations in Poincaré's creative endeavors. However, neither of the models we have considered, the updated selective-forgetting view of Smith (1995) and the failure index view of Seifert and colleagues (1995), seems to be able to account for the phenomena in question. The selective-forgetting view can explain why taking a break might facilitate solving a problem when the person returns to the problem, but it cannot explain how and why a person might suddenly and spontaneously experience the solution to a previously blocked problem. The failure index view explains such a phenomenon by assuming that the occurrence of an environmental event relevant to the solution of a previously blocked target problem can serve as a cue to retrieval and solution of the problem. A laboratory study designed by Seifert and colleagues to provide an analogue to Poincaré's experiences, however, did not produce the predicted results. The presentation of relevant stimuli during a break did facilitate solution when the blocked target problems were re-presented at a later time. However, initial presentation of those relevant external stimuli, in the absence of the blocked problems, did not, contrary to the failure index view, result in spontaneous retrieval of the solved problems. Such a finding would have been analogous to what happened to Poincaré. So we must look elsewhere—beyond the unconscious and beyond memory retrieval by events in the environment—for an explanation of illumination in problem solving. Other studies (e.g., Anolli et al., 2001; Dodds et al., 2002) have not supported the view of Seifert and colleagues.

Creative Worrying? Conscious Thinking During a Break

Since we are still left with the problem of explaining illuminations—assuming that Poincaré's reports are worth considering—let us look at one

more hypothesis. Olton (1979) has proposed that much of what has been attributed to unconscious incubation can be explained by assuming that thinkers never really stop thinking about their problems, especially significant problems. They constantly return to them, if only for short periods of thought. Olton calls this process "creative worrying." We have discussed a closely related view already in this chapter (e.g., Browne & Cruse, 1988). If creative worrying occurs, one would not have to even consider unconscious thought as a possible explanation for illumination in problem solving: Any progress a person made on a previously blocked problem would be explainable as a result of conscious thought. Some evidence to support this view was presented briefly earlier, where we saw that C. Patrick (1935) and Eindhoven and Vinacke (1952) reported that participants in their studies said that they had been thinking about their problems when they were away from them (see also Browne & Cruse, 1988).

The creative-worrying explanation does not seem to be acceptable as it stands, however: After a bout of conscious work on a problem, we are usually able to report that work, as we saw in reviewing the findings from C. Patrick (1935, 1937), Eindhoven and Vinacke (1952), and Browne and Cruse (1988). However, Poincaré (1913) and many other individuals have provided anecdotal reports that indicate that they carried out no conscious work on their problems before solutions presented themselves. Therefore, if one wishes to conclude, as I have done earlier, that no *unconscious* processing occurred at those times, then the *conscious* processing to which I am turning for a possible explanation of illuminations must have been different from ordinary, garden-variety reportable conscious thinking. In the next section, I propose an extension of the notion of creative worrying that may be able to account for illumination without assuming unconscious processing. The discussion that follows is totally speculative and, at this time, without any support whatsoever. I present these speculations because, based on the discussion in this chapter, at this time we have no viable candidates for an explanation of illumination effects.

Degrees of Creative Worrying: Brief Conscious Interludes

I suggest that a thinker can to different degrees "worry creatively" about a problem (i.e., consciously think about a problem). The ordinary occurrence of creative worrying would entail a relatively extended bout of conscious work, which would be apparent to the thinker and reportable to others, at least for a short period of time after it occurred. It might also be possible to think very fleetingly about a problem, however, without a conscious decision or the internal "announcement" of an intention to do so. For example, there are times when I briefly anticipate my wife's coming home at the end of the

day as I am working in the kitchen. It seems to me that I do this by the merest shadow of an idea flitting across consciousness, which leaves as quickly as it comes. If this idea could be projected outward so that others could see it, they would not know what it means, but I do. I could for a very brief period of time report that fleeting thought to others, but not for very long, as it quickly fades away. On the other hand, other internal experiences of mine, like those visual or verbal images involved in explicit conscious work on a problem, would be much more likely to be understood by others if they could be projected publicly, and these would be remembered for a much longer time.

In a related vein, when one is returning to a problem that one has been working on for a while, it is my experience that one does not have to say "Now I'm thinking about that problem again" and wait to see if anything happens. One simply has what one can call, for want of better words, a feeling of thinking about something; if I were asked, I could say "I've been thinking about a difficulty I am having in Chapter 8," even though I said nothing of that sort to myself and did not have clear images that could simply be translated into such a sentence.

Let us assume, then, that it is possible to think about a problem extremely briefly. In one of those *brief conscious interludes*, something relevant might come to mind or might not. If not, then one might not be able to report that one had even been thinking about the problem, except perhaps immediately after the interlude, and perhaps not even then. If the problem were solved during one of these brief conscious interludes, one might not know where the solution had come from, and one might not be able to report that one had been consciously thinking about the problem. The occurrence of the solution to a previously blocked problem would surely be attention-getting, so that the brief conscious interlude that brought it about would quickly be forgotten and become unreportable.

As an example of the kind of event that might be involved in those brief conscious interludes, I just had an experience that might be analogous. I typed the word "previously" in a sentence and then went back to correct what I thought was a mistake. I thought, presumably on the basis of feedback from my fingers, that I had omitted the *i*. However, on looking at the word, I realized that there had not been a mistake; I had typed the word correctly. One possible explanation for my feeling that I had made a mistake is that I had typed the string of letters so quickly that I missed the awareness of typing all of them. My typing was a conscious act, and I believe that, if I had been interrupted just after typing the *i* and had been asked what I had just done, I could have reported it. A second or two later, however, I could not recall typing it. This might tempt one to say the letter had been typed unconsciously, but it really was not unconscious; it was just

done very quickly and was easily lost from memory because of the speed at which it was done and interference from the other letters typed at about the same time. The person is conscious, but the output happens so quickly that one's conscious postresponding report is limited.

As I indicated, I have just presented complete speculation in the last several paragraphs. I have no data available to support what one could (with charity, perhaps) call hypotheses concerning how thinking might work. Obviously, speculations are not sufficient support for hypotheses. The only reason that I have even ventured to present those ideas is that we seem to have hit a dead end in our attempts to explain the phenomena reported by Poincaré and others. If we assume that, at least in outline, those reports are accurate and illuminations do occur, then we must try to develop theories that can explain them. This section is an attempt to do that, although it may fall far short of adequacy.

Incubation, Illumination, and the Unconscious: Conclusions

This chapter has taken us on a long journey, covering more than 100 years. We have seen that modern theories of the unconscious in creativity have not advanced very far beyond the seminal work of Poincaré (1913). His reports of the circumstances in which he made several of his mathematical discoveries, and his logical analysis of the processes that must have been involved, led him to the belief that unconscious processes led to his experiences of illumination, the sudden appearance in consciousness of the solution to a problem that had previously been abandoned at an impasse. Much modern theorizing is built directly on Poincaré's ideas and logic, and the data called on to support modern theorizing are often Poincaré's self-reports and/or comparable reports of others. However, analysis of theories of creativity based on unconscious processing has uncovered little strong support. Self-reports, even those from individuals of Poincaré's renown, are not acceptable as data in support of theory, and theories of unconscious processing in creativity are supported by no hard data. It might therefore be time to move away from those theories or at least to make a concerted attempt to develop new experimental methods with the potential of providing data relevant to the question of unconscious processing. Such an endeavor is not encouraged by the consistent negative findings arising from studies that have attempted to demonstrate incubation in the laboratory (see Table 8.3D).

If we do move away from the unconscious as an important factor in creative thinking, we are still faced with the phenomena of incubation and illumination, assuming that we can accept Poincaré's (1913) reports.

Unfortunately, the discussion in this chapter indicates that an alternative explanation of incubation and illumination is not yet available. We examined two memory-based explanations of incubation and illumination, the selective-forgetting view (Smith, 1995) and the failure-index or opportunistic-assimilation view (Seifert et al., 1995), but those explanations were not able to explain all the phenomena connected with incubation and illumination. At the end of the chapter, I presented some speculations concerning how one might modify Olton's (1979) "creative worrying" hypothesis to account for Poincaré's reports. There are no data relevant to that proposal, so at this point our conclusion is that we are still waiting for some closure on an issue that has been of interest to students of creativity for 100 years. However, such a situation should be looked upon less as a failure than as an opportunity for the students reading this book: There are opportunities for creative individuals to develop new theories and methods to test them.

CHAPTER

9

The Psychometric Perspective, Part I

Measuring the Capacity to Think Creatively

The discussion in the book so far has centered on the creative thought process. We have examined the cognitive perspective that creative thinking is equivalent to ordinary problem solving (Chapter 3) and the role of knowledge and expertise in problem solving and creative thinking (Chapters 4 and 5). Chapters 6–8 examined three variants on the general notion that creativity depends on extraordinary thought processes—that is, thought processes that are different from ordinary conscious thinking. In Chapter 6, we considered the idea that creative thinking, as exemplified by problem solving, comes about through leaps of insight. In Chapter 7, we examined the hypothesis that creative thinking can be fostered by psychopathology, and in Chapter 8 we explored the hypothesis that the unconscious underlies creative thinking. In each of those chapters, the support was not very strong for the idea that extraordinary thought processes underlie creativity. The upshot of the discussion in those chapters was that it is possible to understand a wide range of phenomena associated with creativity if one assumes that the creative process is based on ordinary thought processes.

In this chapter and the next, we will look more broadly at creativity and examine research and theory that go beyond the thought process. We will consider the question of whether one can classify people according to their creative abilities, and whether one can develop tests that enable us to predict who among us will be creative in their lives. Can we predict which third-grader will develop into a world-class scientist and which into the next Picasso?

The general view that one can use tests of various sorts to measure people's

creative capacities and potential has been around since the turn of the twentieth century, but the modern interest in such questions began around 1950 and evolved out of the mental-testing or *psychometric* movement in the United States. In examining research coming out of the psychometric perspective, we will in this chapter consider the issue of whether there is a small universal set of general creative-thinking skills that underlie all creative thinking. Based on the discussion in Chapter 4 of the importance of domain-specific expertise in creative thinking, we would expect that there would not be such a set of general skills, but many researchers believe that general creative skills play a role in creative thinking, so we will examine research addressing that question. In the next chapter we will consider the question of the “creative personality.” We will address the question of whether there is a small set of psychological characteristics—personality characteristics—that distinguish creative from noncreative individuals and play a role in making some people creative.

Outline of the Chapter

This chapter begins by placing the psychometric perspective on creativity in its historical context, with a brief review of its development. The chapter then examines the work of Guilford (1950), which has been of seminal influence in setting the agenda in this area. Guilford was the first modern researcher to outline possible mental abilities underlying creativity, and he developed a set of tests to measure them. We shall review Guilford's research and that of those who followed him, paying particular attention to the validity of the tests that have been developed to measure the capacity to think creatively.

Guilford and the Modern Psychometric Perspective on Creativity

It is not an exaggeration to say that we can trace the beginnings of the modern psychometric perspective on creativity to 1950 and the publication of Guilford's 1949 presidential address to the American Psychological Association (APA; Guilford, 1950). Guilford was at that time one of the leaders of the psychometric movement in the United States. The president of the APA gives an address at the organization's annual convention, and in 1949 Guilford used his address to propose that psychology take up the study of creativity. Guilford noted that very few studies of creativity had been carried out in psychology over the 25 years or so before his address, and he presented his ideas in the hope of stimulating other psychologists to take up the challenge of measuring creative-thinking capacity and creative

The Psychometric Perspective, Part I

potential, as well as the psychological characteristics of the individuals who succeed in being creative.

Guilford (1950) first noted that the term *genius* had come to be used—incorrectly, in his view—to describe a person of high intelligence. The original referent of that term was someone who made unique creative contributions, and Guilford proposed that psychology should return to that original use. Psychologists should acknowledge that high intelligence quotient (IQ) was something different from the capacity to think creatively, which meant that one could not use existing IQ tests to measure people's ability to think creatively. IQ tests are composed of problems and questions, each of which has one correct answer (see items in Table 9.1), but situations that demand

Table 9.1 Examples of items from IQ tests

1. Two men, starting at the same point, walk in opposite directions for 4 meters, turn left, and walk another 3 meters. What is the distance between them? (a) 2 meters (b) 6 meters (c) 10 meters (d) 12.5 meters (e) 14 meters
2. Which of the following sentences given below means approximately the same as the proverb "Don't count your chickens until they are hatched"? (a) Some eggs have double yolks, so you can't really count eggs and chickens. (b) You can't walk around the henhouse to count the eggs because it will disturb the hens and they won't lay eggs. (c) It is not really sensible to rely on something that has not yet happened and may not ever happen. (d) Since eggs break so easily, you may not be accurate in your count of future chickens.
3. Following the pattern shown in the number sequence below, what is the missing number? 1 8 27 ? 125 216 (a) 36 (b) 45 (c) 46 (d) 64 (e) 99
4. Which of the designs best completes the following sequence?  (a)  (b)  (c)  (d) 
5. Continue the following number series with the group of numbers below that best continues the series. 1 10 3 9 5 8 7 7 9 6 ? ? (a) 11 5 (b) 10 5 (c) 10 4 (d) 11 6

Answers: 1. c; 2. c; 3. d; 4. a; 5. a

creative thinking do not necessarily have only one correct answer. Indeed, a situation that demands creative thinking may not be a kind of situation in which there is even a correct answer: When a painter is painting a landscape, is there a *correct* way to do it? If this analysis is accurate, then creative-thinking capacity must be based on a set of skills different from those measured by IQ tests, and a new set of tests would have to be designed to capture it. Thus, Guilford began his address by trying to convince psychologists—many of whom were, as he was, psychometricians who spent much of their time thinking about and testing IQ—that they needed to develop a whole new set of measures and concepts in order to examine a different and at least equally important set of skills.

Although he argued that creativity could not be measured with intelligence tests, Guilford nonetheless based his approach to the study of creativity on his extensive experience in psychometrics. Just as psychologists had had success in developing tests that could be used to measure intelligence and to predict performance in school, so Guilford wanted to develop tests to measure creativity and, perhaps more important, creative potential. That is, the tests should not only allow us to designate who is creative *now*, they should also allow us to predict, for example, which of our children would be creative in the future—as adults. If we were able to do that, we could then provide enrichment opportunities for those individuals so that they could maximize their potential, to the ultimate betterment of all. In addition, we could provide enrichment opportunities for other children so that they might be more creatively productive in their lives than they otherwise would have been.

Guilford argued that creative children were our most valuable resource and that it was important that they be identified and nurtured as early in life as possible to maximize the likelihood that they would put their potential to use. At the time of Guilford's address, there was great concern in the United States that Communism was on the way to overwhelming the democratic West, and Guilford believed that identifying and nurturing creative talent was our best chance of winning the war for people's hearts and minds. Accordingly, in his address, Guilford (1950) laid out a group of methods that could be used to test people for their capacity to think creatively, just as we test people for their capacity to think intelligently.

Most significantly, in a further connection to the psychometric tradition, Guilford (1950) proposed that the entire person was involved in creativity, which meant that creativity was part of the *personality* of the person. Guilford's view is thus an early example of what can be called a *confluence* view of creativity (Sternberg & Lubart, 1996; see Chapters 2 and 11), which assumes that the *confluence* or *coming together* of several factors is necessary to produce creativity. According to Guilford, simply possessing creative-

thinking ability was not enough to guarantee creative productivity in one's life: It was also necessary that the individual possess the relevant personality characteristics and motivation before that ability would bear fruit.

Guilford (1950) was successful in his desire to stimulate psychologists to think about creativity: The last 50+ years have seen innumerable studies that have owed their existence to Guilford's ideas, as psychologists attempted to measure the cognitive and personality characteristics of creative individuals. As will be discussed in Chapter 11, numerous confluence theories of creativity have been developed over the years since Guilford's address, as psychologists have grappled with the complexities of creativity. In addition, many modern theories of creativity have built on the confluence perspective that he advocated.

Methods of Measuring Creativity

Psychologists and educators have developed many different types of measuring instruments designed to determine whether a given individual is creative (or has been creative), as well as to determine whether a person who as yet may not have produced anything creative has the potential to become creative. Instruments have also been developed that are designed to assess the characteristics of creative individuals once those individuals have been identified (Hocevar & Bachelor, 1989). Those instruments range from tests designed to measure the ability to think in a creative manner to biographical indices that ask the respondent to list accomplishments that would be considered creative.

Measures of Creative Accomplishment

I will now review some of the measures that have been used to assess an individual's creative accomplishments and potential. I begin with measures of accomplishment.

Achieved Eminence

A relatively direct measure of an individual's creative achievement is the eminence that he or she has achieved in a field that is assumed to require creativity for success, such as architecture, literature, painting, poetry, or the sciences. One can ascertain who is eminent by determining, for example, whose career and work are discussed in standard reference works in the field. One can examine anthologies of modern poetry to determine which living poets are represented. Alternatively, one can ask experts in the field to list people whose work has broken new ground. If one is interested in studying the psychological characteristics of individuals of creative achievement,

this method leaves little doubt that one has identified such individuals. Researchers have brought eminent individuals into the laboratory in order to interview them in detail about their life experiences and to assess their personalities, working styles, and so forth (e.g., MacKinnon, 1962). In addition, the work of Simonton (e.g., 1999) and Martindale (e.g., 1990), which uses historiometric methods (and has already been discussed in several places in this text), has directly examined the products of eminent individuals. Similarly, the case studies presented elsewhere in this book have directly studied eminent individuals. In the latter cases, the individuals of eminence usually have been deceased, but the same principles apply: One studies individuals whose achievements within a creative profession have been acknowledged in some way by others in the field.

One important issue raised by the study of eminent creative individuals is whether conclusions drawn from such studies are relevant to the general population. For example, if one examined the personality characteristics of eminent poets, say, would any characteristics found in such individuals also be found in “ordinary” people who write poetry only as an avocation? Similarly, are the thought processes used by eminent creative individuals—for example, the thought processes underlying creation of poetry that winds up in an anthology—the same as those used by ordinary individuals when they are producing poetry? As noted in Chapter 1, one cannot assume that the same processes are involved in production of world-class creative products and “ordinary” creative works.

Ratings of a Person’s Creativity

One way to acquire information about a person’s creativity is to ask others about it. If children are the subjects of study, for example, one can ask teachers to rate their students according to their creativity. The teachers could then be provided with examples of the kinds of behaviors that would be considered indicative of creativity: The teacher might be told that a creative child is one who produces unusual but useful ideas on class assignments, and who produces more ideas than other children. Similarly, to assess the creativity of research scientists at a company, one could ask their supervisors to rate them. One might also assess creativity by asking for peer evaluations—by asking a group of physicists, for example, to rate the most creative people in their field. We have already mentioned this as a method for determining eminence, and rating eminence may simply be one example of rating creativity, assuming that in some fields eminence depends on one’s creative production. Some studies of children’s creativity have also used children’s ratings of their peers as the index of creativity.

Judgments of Products: Consensual Assessment Technique

A relatively straightforward way to assess the creativity of an individual is to rate the creativity of an actual product that he or she has produced. This method was used in the study by Getzels and Csikszentmihalyi (1976) in which they studied “problem finding” in art students’ production of still-life drawings (see Chapters 3 and 12), and it has been used extensively by Amabile and her colleagues (see Chapters 2 and 11; for reviews, see Amabile, 1983, 1996). Researchers sometimes ask undergraduates to produce a poem, say, or a collage, which is then rated for creativity by poets or artists, respectively. In other studies, the judges have been nonexperts in the area. The technique has also been used with children, both as participants—that is, producers of the creative products—and as the judges of those products’ creativity.

Tests of Creative-Thinking Capacity: Testing Divergent Thinking

Beginning with the work of Guilford (e.g., 1950), researchers have developed tests designed to measure a person’s capacity to think creatively. Guilford grouped together several different subskills of thinking into the category of *divergent thinking*, which refers to the capacity to produce ideas that *diverge* from the ordinary, on the assumption that divergent thinking produces creative ideas. (See items in Table 9.2.) Tests have been designed for assessing divergent-thinking skills in children of various ages, as well as in adults, such as college students. Several critical assumptions underlie the development of such tests. First, it should be noted that materials such as those in Table 9.2 have nothing to do with specific creative domains of the sort in which researchers might usually be ultimately interested, such as painting, literature, science, or entrepreneurship in business. It is assumed that asking people about bricks and white edible things (see Table 9.2) can

Table 9.2 Divergent-thinking exercises

- | |
|---|
| (A) Suppose that humans suddenly no longer had to eat. List all the consequences that you can think of that would arise. (Give yourself 5 minutes.) |
| (B) List all the problems or difficulties you can think of with the present-day toaster (5 min.). |
| (C) List all the uses you can think of for a brick (3 min.). |
| (D) List all the uses you can think of for a newspaper (3 min.). |
| (E) List all the uses you can think of for a paper clip (3 min.). |
| (F) List all the white edible things that you can (3 min.). |
| (G) List all the words you can think of in response to the word <i>mother</i> (3 min.). |
| (H) Figurative test items |

provide us with information that will be useful in predicting which individuals possess the thinking capacity to accomplish much in those creative domains. This assumes further that the specific processes underlying creative thinking must be relatively general in their applicability. So, for example, the ability to think of many members of a particular class (see Table 9.2F) might be relevant to thinking of a word or concept when one is writing a story. Second, it is assumed that creative thinking is separate from intelligence as a mode of thought. As noted earlier, a critical assumption behind Guilford's (1950) proposal was that IQ as measured by intelligence tests was a different mode of thinking from the thinking underlying creative accomplishment. Those two sets of assumptions—the generality of creative-thinking skills as measured by divergent-thinking tests and the difference between IQ and creativity—have been the subject of much debate among researchers (see, e.g., Brown, 1989; Hocevar & Bachelor, 1989; see also Kaufman & Baer, 2002). I will examine those issues later in this chapter.

In Guilford's (1950) original suggestions concerning tests to measure creative-thinking capacity, he presented divergent thinking as only one component of that capacity. Other skills also played a role, including "convergent thinking," as well as the ability to evaluate ideas after they were produced (see Baer, 1993, and Runco, 1991). Convergent thinking is carried out after one has available several possible methods to solve a problem. One selects among them, converging on the final solution. Sometimes researchers have ignored those other aspects of Guilford's analysis and have taken divergent thinking to be equivalent to creative thinking, and have labeled divergent-thinking tests as "creativity tests." It must be kept in mind that those tests do not measure creativity: They only measure one component—although, in Guilford's view, an important one—of the creative capacity. That distinction should be kept in mind while working through the important issues in this chapter.

Similarly, some investigations of the personality characteristics of creative individuals have used performance on divergent-thinking tests as the sole criterion for classifying people as creative (for review, see Brown, 1989). Again, those tests do not provide that sort of information. Furthermore, sometimes creativity-training programs have used changes in divergent-thinking performance as evidence that the program has been successful in increasing creativity. Once again, however, increasing performance on divergent-thinking tests is not the same as increasing creativity. In Guilford's (1950) view, divergent thinking was only one component of creative thinking, and the tests were to be used only to determine one component of the potential to think creatively. That distinction should be kept in mind throughout the discussion.

Table 9.3 Sample items from attitude and interest inventories

- | |
|---|
| 1. I have a good sense of humor. |
| 2. I like to try new activities and projects. |
| 3. I like to invent things. |
| 4. I like to write stories. |
| 5. I often daydream about unsolved problems. |
| 6. I have to learn things in my own way, rather than accepting ideas or relationships suggested in textbooks. |
| 7. If I had the necessary talent, I would enjoy being a sculptor. |
| 8. I would like to be an inventor. |

Attitude and Interest Inventories

These questionnaires ask the person to agree or disagree with items such as those in Table 9.3, and they are based on the not unreasonable assumption that creative individuals will show interest in creative activities.

Personality Inventories

As noted earlier, Guilford (1950) proposed that an individual's being creative was a function of his or her entire personality, and he suggested that personality be examined in order to provide a more complete understanding of the creative person. A number of researchers have developed personality inventories—questionnaires of various sorts—that are designed to measure the personal characteristics of creative people. An example of one sort of such an inventory is shown in Table 9.4. Researchers have also developed scales with which teachers rate the personality characteristics of their students (for review see Hocevar and Bachelor, 1989, pp. 55–56) in an attempt to determine whether a given child possesses personality characteristics assumed to be related to creativity. Many studies have investigated whether there are personality characteristics that distinguish people of creative accomplishment from other individuals (see Feist, 1999). In addition, some researchers have proposed that creativity is critically dependent on personality characteristics rather than being a particular mode of thinking. In this view (e.g., Dellas & Gaier, 1970), the creative individual is one whose personality is oriented toward production of new things and breaking away from the ordinary, and who uses his or her cognitive capacities to accomplish that task.

Biographical Inventories and Self-Reports of Creative Activities

These questionnaires ask about the person's life experiences, such as whether he or she attempted to make things as a child, and the hobbies and

Table 9.4 Gough Adjective Checklist, A Creative Personality scale

Please indicate which of the adjectives best describe yourself. Check all that apply.	
<input type="checkbox"/> Capable <input type="checkbox"/> Artificial <input type="checkbox"/> Clever <input type="checkbox"/> Cautious <input type="checkbox"/> Confident <input type="checkbox"/> Egotistical <input type="checkbox"/> Commonplace <input type="checkbox"/> Humorous <input type="checkbox"/> Conservative <input type="checkbox"/> Individualistic <input type="checkbox"/> Convention <input type="checkbox"/> Informal <input type="checkbox"/> Dissatisfied <input type="checkbox"/> Insightful <input type="checkbox"/> Suspicious	<input type="checkbox"/> Honest <input type="checkbox"/> Intelligent <input type="checkbox"/> Well-mannered <input type="checkbox"/> Wide interests <input type="checkbox"/> Inventive <input type="checkbox"/> Original <input type="checkbox"/> Narrow interests <input type="checkbox"/> Reflective <input type="checkbox"/> Sincere <input type="checkbox"/> Resourceful <input type="checkbox"/> Self-confident <input type="checkbox"/> Sexy <input type="checkbox"/> Submissive <input type="checkbox"/> Snobbish <input type="checkbox"/> Unconventional
Scoring key:	
<input type="checkbox"/> + Capable <input type="checkbox"/> - Artificial <input type="checkbox"/> + Clever <input type="checkbox"/> - Cautious <input type="checkbox"/> + Confident <input type="checkbox"/> + Egotistical <input type="checkbox"/> + Commonplace <input type="checkbox"/> + Humorous <input type="checkbox"/> - Conservative <input type="checkbox"/> + Individualistic <input type="checkbox"/> - Convention <input type="checkbox"/> + Informal <input type="checkbox"/> - Dissatisfied <input type="checkbox"/> + Insightful <input type="checkbox"/> - Suspicious	<input type="checkbox"/> - Honest <input type="checkbox"/> + Intelligent <input type="checkbox"/> - Well-mannered <input type="checkbox"/> + Wide interests <input type="checkbox"/> + Inventive <input type="checkbox"/> + Original <input type="checkbox"/> - Narrow interests <input type="checkbox"/> + Reflective <input type="checkbox"/> - Sincere <input type="checkbox"/> + Resourceful <input type="checkbox"/> + Self-confident <input type="checkbox"/> + Sexy <input type="checkbox"/> - Submissive <input type="checkbox"/> + Snobbish <input type="checkbox"/> + Unconventional

Source: Gough (1979).

other interests of the person as an adult. They also ask about the person's family, such as the education levels of the parents, whether the parents died at an early age, presence of other siblings, and so forth. Items from one such inventory, the Lifetime Creativity Scale, are shown in Table 9.5 (Richards, Kinney, Benet, & Marzel, 1988). The Lifetime Creativity Scale is based

Table 9.5 The Lifetime Creativity scale: Examples and interpretation

A. Items from biographical inventory

1. Were you raised in a two-parent household?
2. Do you have any siblings? What are their ages relative to yours?
3. What were the occupations of your parents?
4. What is the highest degree achieved by your parents?
5. What occupations have you pursued in your adult life?
6. Describe your major responsibilities and accomplishments within each occupation listed for the previous question.
7. Describe your main avocational interests (hobbies).
8. Describe your major accomplishments in the avocational interests listed for the previous question.

(continued)

on an individual's responses during an interview and is completed by the interviewer rather than being filled out by the individual.

A relatively direct method of determining the creative capacity of people is to ask them to list their accomplishments in creative domains. One can ask if a person has had poems published, for example, or has had a gallery or museum show of paintings. Interviewers can also ask people about creativity in their ordinary activities, such as whether they produce new recipes when they are cooking (Carson, Peterson, & Higgins, 2003; see Table 9.6). One can also ask raters to judge the creativity of people's creative works, based on those people's descriptions of those works. King and colleagues (King, Walker, & Broyles, 1996), for example, asked a group of college undergraduates to list and describe any creative achievements from the past 2 years. Those lists of items were given to other individuals, some of whom simply counted the items, while others rated them for creative achievement. This method combines aspects of the consensual-assessment technique and self-reports of creative activities.

Measuring Creativity: Summary

We have now briefly surveyed the wide range of techniques that researchers have used to assess creative potential, creative accomplishments, and the characteristics of creative people. We will encounter many of those techniques in this chapter and the next one, as we examine research that has attempted to measure creative capacity and the creative personality. We turn first to studies of the creative-thinking capacity, which have used tests such as those in Table 9.2 in attempts to identify individuals with the capacity to produce novel ideas. Such individuals would seem to have the potential to be creative.

Table 9.5 (continued)

B. Examples of results obtained from analyzing responses to questions such as those in panel A (or from an interview)

Level	Example 1	Example 2
<i>Vocational history</i>		
No significant peak creativity	Mixed and carried mortar for local bricklayer for 20 years, then inherited a large income-paying trust fund and retired to a passive life on a country estate.	Washed store windows for 3 years under foreman's supervision, spent 5 years on assembly lines in two factories, and for the past 11 years has done routine quality-control tasks in a brewery.
Some peak creativity	Longtime owner and manager of a small dairy farm who, after 10 years of producing cheese and other dairy products, expanded and began marketing through a local distributor.	Optician who spent 4 years selling optical items, then acquired a small optical shop, and now grinds lenses to prescription while managing the retailing of standard optical products.
High peak creativity	Former avant garde dancer and choreographer who developed and directed a variety of unusual productions for several dance companies but postwar has worked solely as a hotel clerk.	Entrepreneur who advanced from apprentice to independent researcher of new products before starting a major paint manufacturing company, and whose operation surreptitiously manufactured and smuggled explosives for the Danish Resistance during World War II.

Avocational history	
No significant peak creativity	Once read movie magazines intensively but now spends most evenings with the new family television. Also does much needlepoint following specified patterns and, on weekends, watches spouse play handball.
Some peak creativity	Active church member who has ushered at church services for over 20 years, has sung for the last 10 years in the alto section of the church choir, and recently has been volunteering on a committee designed to expand parish membership.
High peak creativity	Amateur archaeologist who for years has spent summers and other free time seeking new sites, initiating archaeological digs with professionals from a nearby university, researching artifacts, reconstructing aspects of primitive societies, and collaborating in writing articles on this work.

CREATIVITY: UNDERSTANDING INNOVATION

Table 9.6 Creative achievement questionnaire (incomplete)
by Shelley Carson, Harvard University

<p>I. Place a check mark beside the areas in which you feel you have more talent, ability, or training than the average person.</p> <p><input type="checkbox"/> visual arts (painting, sculpture) <input type="checkbox"/> music <input type="checkbox"/> dance <input type="checkbox"/> individual sports (tennis, golf) <input type="checkbox"/> team sports <input type="checkbox"/> architectural design <input type="checkbox"/> entrepreneurial ventures <input type="checkbox"/> creative writing <input type="checkbox"/> humor <input type="checkbox"/> inventions <input type="checkbox"/> scientific inquiry <input type="checkbox"/> theater and film <input type="checkbox"/> culinary arts</p> <p>II. Place a check mark beside sentences that apply to you. Next to sentences with an asterisk (*), write the number of times this sentence applies to you.</p> <p>A. Visual Arts</p> <p><input type="checkbox"/> 0. I have no training or recognized talent in this area. (Skip to Music). <input type="checkbox"/> 1. I have taken lessons in this area. <input type="checkbox"/> 2. People have commented on my talent in this area. <input type="checkbox"/> 3. I have won a prize or prizes at a juried art show. <input type="checkbox"/> 4. I have had a showing of my work in a gallery. <input type="checkbox"/> 5. I have sold a piece of my work. <input type="checkbox"/> 6. My work has been critiqued in local publications. * <input type="checkbox"/> 7. My work has been critiqued in national publications.</p> <p>B. Music</p> <p><input type="checkbox"/> 0. I have no training or recognized talent in this area (Skip to Dance). <input type="checkbox"/> 1. I play one or more musical instruments proficiently. <input type="checkbox"/> 2. I have played with a recognized orchestra or band. <input type="checkbox"/> 3. I have composed an original piece of music. <input type="checkbox"/> 4. My musical talent has been critiqued in a local publication. <input type="checkbox"/> 5. My composition has been recorded. <input type="checkbox"/> 6. Recordings of my composition have been sold publicly.</p>	<p>* <input type="checkbox"/> 7. My compositions have been critiqued in a national publication.</p> <p>C. Dance</p> <p><input type="checkbox"/> 0. I have no training or recognized talent in this area (Skip to Architecture). <input type="checkbox"/> 1. I have danced with a recognized dance company. <input type="checkbox"/> 2. I have choreographed an original dance number. <input type="checkbox"/> 3. My choreography has been performed publicly. <input type="checkbox"/> 4. My dance abilities have been critiqued in a local publication. <input type="checkbox"/> 5. I have choreographed dance professionally. <input type="checkbox"/> 6. My choreography has been recognized by a local publication. * <input type="checkbox"/> 7. My choreography has been recognized by a national publication.</p> <p>D. Architectural Design</p> <p><input type="checkbox"/> 0. I do not have training or recognized talent in this area (Skip to Writing). <input type="checkbox"/> 1. I have designed an original structure. <input type="checkbox"/> 2. A structure designed by me has been constructed. <input type="checkbox"/> 3. I have sold an original architectural design. <input type="checkbox"/> 4. A structure that I have designed and sold has been built professionally. <input type="checkbox"/> 5. My architectural design has won an award or awards. <input type="checkbox"/> 6. My architectural design has been recognized in a local publication. * <input type="checkbox"/> 7. My architectural design has been recognized in a national publication.</p> <p>E. Creative Writing</p> <p><input type="checkbox"/> 0. I do not have training or recognized talent in this area (Skip to Humor). <input type="checkbox"/> 1. I have written an original short work (poem or short story). <input type="checkbox"/> 2. My work has won an award or prize. <input type="checkbox"/> 3. I have written an original long work (epic, novel, or play). <input type="checkbox"/> 4. I have sold my work to a publisher. <input type="checkbox"/> 5. My work has been printed and sold publicly. <input type="checkbox"/> 6. My work has been reviewed in local publications. * <input type="checkbox"/> 7. My work has been reviewed in national publications.</p>
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The Psychometric Perspective, Part I

Table 9.6 (continued)

<p>F. Humor</p> <p><input type="checkbox"/> 0. I do not have recognized talent in this area (Skip to Inventions).</p> <p><input type="checkbox"/> 1. People have often commented on my original sense of humor.</p> <p><input type="checkbox"/> 2. I have created jokes that are now regularly repeated by others.</p> <p><input type="checkbox"/> 3. I have written jokes for other people.</p> <p><input type="checkbox"/> 4. I have written a joke or cartoon that has been published.</p> <p><input type="checkbox"/> 5. I have worked as a professional comedian.</p> <p><input type="checkbox"/> 6. I have worked as a professional comedy writer.</p> <p><input type="checkbox"/> 7. My humor has been recognized in a national publication.</p>	<p><input type="checkbox"/> 3. I have received a scholarship based on my work in science or medicine.</p> <p><input type="checkbox"/> 4. I have been author or coauthor of a study published in a scientific journal.</p> <p>* <input type="checkbox"/> 5. I have won a national prize in the field of science or medicine.</p> <p>* <input type="checkbox"/> 6. I have received a grant to pursue my work in science or medicine.</p> <p><input type="checkbox"/> 7. My work has been cited by other scientists in national publications.</p>
<p>G. Inventions</p> <p><input type="checkbox"/> 0. I do not have recognized talent in this area.</p> <p><input type="checkbox"/> 1. I regularly find novel uses for household objects.</p> <p><input type="checkbox"/> 2. I have sketched out an invention and worked on its design flaws.</p> <p><input type="checkbox"/> 3. I have created original software for a computer.</p> <p><input type="checkbox"/> 4. I have built a prototype of one of my designed inventions.</p> <p><input type="checkbox"/> 5. I have sold one of my inventions to people I know.</p> <p>* <input type="checkbox"/> 6. I have received a patent for use of my inventions.</p> <p>* <input type="checkbox"/> 7. I have sold one of my inventions to a manufacturing firm.</p>	
<p>H. Scientific Discovery</p> <p><input type="checkbox"/> 0. I do not have training or recognized ability in this field (Skip to Theater).</p> <p><input type="checkbox"/> 1. I often think about ways that scientific problems could be solved.</p> <p><input type="checkbox"/> 2. I have won a prize at a science fair or other local competition.</p>	
<p>Scoring of the Creative Achievement Questionnaire</p> <ol style="list-style-type: none"> 1. Each checkmarked item receives the number of points represented by the question number adjacent to the checkmark. 2. If an item is marked by an asterisk, multiply the number of times the item has been achieved by the number of the question to determine points for that item. 3. Sum the total number of points within each domain to determine the domain score. 4. Sum all ten domain scores to determine the total CAQ score. 	

Cognitive Components of the Creative Process: Testing for Creative-Thinking Ability

The modern psychometric perspective on creativity began with Guilford's (1950) discussion of how one might go about measuring ordinary people's capacity to think creatively. That is, let us say one has a group of college students or a group of schoolchildren, none of whom has yet achieved

eminence. How might one determine which of those people is capable of thinking creatively and may develop into a person of accomplishment and perhaps even eminence in some creative domain? Since the people of interest are not yet specialists in any domain, one must develop tests that can be presented to nonspecialists and will tap into what one could call the essence of creative thinking. Thus, Guilford began by analyzing the ability to think creatively into its critical components, and he built his tests to measure those components.

It is notable that Guilford's (1950) analysis of the creative thought processes was not based on the study of creative people thinking creatively: He carried out no investigations of the creative thought processes in action. Rather, his postulation of the necessary components of the creative-thinking processes was based on his intuitions about, and logical analysis of, how the creative mind had to work, given the task of producing novel outcomes. This raises the question of whether it was best to begin by relying on one person's intuition about the creative process (even if that person was a psychologist who had done creative work). It might have been more useful to first collect information about how the creative process worked and to use that information as the basis for developing tests designed to tap creative thinking (Brown, 1989). We will return to this issue when we evaluate research using Guilford's tests and others like them.

Sensitivity to Problems

In Guilford's view, in order to get the creative process started, an individual must see deficiencies in some aspect of the world (Guilford, 1950). Only then will he or she spend time contemplating what might be done to correct those problems, which is the first step toward producing a creative outcome. This view, of course, is a variation on the old idea that necessity is the mother of invention, and Guilford can be looked upon as making a broader claim: Necessity is the mother of creativity. As an example, a potential inventor might discover a problem with her car: Let us say that on one very hot summer day, when she gets into her car with the take-out lunch she just bought, she notices that none of the cup holders in her car is big enough to hold the extra-large drink she bought to stay hydrated. This discovery could stimulate the search for a way to overcome that problem. Another person might simply decide to stay away from extra-large drinks and not even consider the absence of a large cup holder to be a problem, and so would not think further about it. Only the first person would have the chance to produce a creative idea in that situation (e.g., making some sort of large-sized holder to fit into the existing small one, to accommodate large-sized drinks).

Similarly, two scientists might read a research paper in which one result did not come out as expected. The first scientist might simply conclude that that result was due to random error in the experiment, and ignore it. The second scientist, in contrast, might find that aberrant result curious and consider it something to be explained, which might lead him to design a new experiment in order explore that finding further. That new experiment might lead to a creative advance in theory. Thus, as a first step toward creative thinking, a person must be *sensitive to problems*: Even the most creative thinker will produce nothing new if he or she does not think that there is any difficulty with the present situation. Exercises A and B in Table 9.2 are designed to measure a person's sensitivity to problems; in each exercise, the person must be able to analyze the situation to determine what follows from it, including possible problems, which could then set the creative process into motion. One can test a large number of people, college students, say, or corporate executives, or advertising executives, on exercises such as those, and one can then determine the average number of problems found for each group. One can then determine if a given person finds more or fewer problems than average by comparing students to students and executives to executives. This would allow one to rank people on their sensitivity to problems.

Is Necessity the Mother of Creativity?

A question can be raised about the basic notion that sensitivity to problems is critical in setting the creative process in motion. It is no doubt true that many people are motivated to carry out creative activities because of problems they sense in their personal or professional environments. However, there is historical evidence that the creative process can be set in motion without necessity, even in the domain of invention. As one example, consider the invention of the airplane. At the end of the nineteenth century a number of research projects were underway whose purpose was the invention of a flying machine. We discussed several of those projects in Chapter 5. At that time, there was no need for such a machine; only gradually, after the Wright brothers were successful in inventing the airplane, did the broader implications of that invention become apparent. So the driving force behind the invention of the airplane seems not to have been necessity: There was no *need* to fly; people simply *wanted to*. Individuals sometimes think creatively because they want to accomplish something that might be possible but that has never been done before, or because they are curious as to what might happen when certain actions are carried out. Thus, necessity is not a mandatory condition for creativity.

Components of Creative Thinking

Let us now assume that the creative process has been set in motion, either because a problem has been identified, or because the person is challenged to produce something heretofore deemed impossible, or because he or she is curious as to what might happen if certain activities are carried out. The person must then begin to think about how to bring about whatever goal he or she is now working toward. We have now arrived at the core of the creative thought processes. In this context, Guilford (1950) concentrated on the generation of ideas. It seemed obvious to him that the more ideas a person can produce, the greater the chances that he or she will produce a useful one. That is, generating more ideas results in greater chances of a creative outcome. Therefore, he proposed that *fluency of thought*—that is, *the capacity to produce a large number of ideas in a given period of time that are relevant to some situation*—would be one characteristic of creative thinkers. In order to test for fluent thought, one can give people a task that requires that they produce multiple ideas, such as exercises C–H in Table 9.2. As with sensitivity to problems, one can determine if a given person has produced more or fewer ideas than average for his or her peer group. The exercises in Table 9.2 are of two kinds, verbal (C–G) and figurative (H). The inclusion of figurative exercises was designed to allow the assessment of creative-thinking capacity in individuals whose language might be less than fully developed, such as young children.

In addition to being fluent in idea production, the creative thinker must also be a *flexible* thinker. According to Guilford (1950), creative thinking may require that one break away from one's habitual ways of thinking and strike out in new directions. (This is a familiar idea by now.) One can score exercises C–F in Table 9.2 for flexibility of thought by determining whether a given person tends to stay within a category when generating ideas or to switch from one category to another. For example, in producing names of white edible things, a hypothetical person who says *milk, cottage cheese, sour cream, vanilla ice cream, vanilla frozen yogurt* would be relatively inflexible, since at most only two categories are used. A flexible person might say *milk, white-chocolate-covered raisins, white corn, white wine, tofu, lobster*, and in so doing would use six categories. The second person, in Guilford's view, is more flexible in thinking, and so would be more likely to break away from habitual modes of thought and come up with novel ideas to deal with difficulties. Presumably, the person's propensity to change categories when listing white edible things would be related to his or her ability to take a new perspective when, say, solving a problem or when creating a work of art.

The creative thinker will also produce *original ideas*: ideas not produced by many other people. In addition to scoring the exercises in Table 9.2 for

fluency, one can also score all of them for originality of ideas. For example, if a student lists a particular use for a brick that most students list, then there is little originality in that idea; however, if he or she lists a use for a brick that was thought of by no one else in a large group of people, that is an original idea. A person who produces many original ideas would in Guilford's view be likely to produce creative solutions to problems, because difficult problems are presumably difficult because the solutions that are obvious to everyone do not work on them. Again, the underlying assumption is that producing an unusual use for a brick is related to producing unusual ideas in response to a problem or developing an unusual perspective in artistic endeavors.

Guilford took measures of fluency, flexibility, and originality and combined them into *divergent thinking*, a mode of thinking that in his view plays a critical role in the creative process by enabling the person to produce ideas that *diverge*, or move away, from the usual. He assumed that divergent thinking is a general characteristic or *trait* of people, and that it is relevant across a broad range of activities that might be approached creatively. Thus, one can take a person's performance on a battery of tests, such as those in Table 9.2C–H, and use them to predict that person's performance in situations far removed from the testing context. As noted earlier, divergent thinking is contrasted with *convergent thinking*, which occurs when one uses available information to *converge on* the single answer that solves a problem. In a situation demanding a creative response, one would not have a method available, so one would first use divergent thinking to produce many possible ideas. Convergent thinking can then be used to narrow down those ideas to something potentially useful.

As we have seen, over the years since Guilford's original proposal, the notion of divergent thinking has gradually become the core of the psychometric view of creative thinking. (See discussion in Brown, 1989.) In a strict interpretation of Guilford's views, this is not correct, since divergent thinking is only one component of a multicomponent process. However, in keeping with the thrust of the literature, much of this chapter's discussion of the creative thought process will focus on divergent thinking.

We noted earlier that Guilford used his expertise with IQ tests in developing tests to measure creative-thinking capacity. In a further analogy to the psychometrics of IQ, Guilford (1950) believed that each person is capable of creative thinking, at least to some degree. That is, divergent-thinking ability is normally distributed among the population. People who produce great creative advances (e.g., Picasso, Edison, Mozart) may possess the divergent-thinking capacities to a great degree, but we all have some of that ability. Indeed, if one did not make such an assumption, one could not talk about testing "creativity" and studying "the creative personality,"

since usually one is not able to test people like Picasso and Mozart. Therefore, one must assume that there is *continuity* between the processes that the great creative thinkers use and those used by the rest of us when we produce our small examples of creativity, such as when we think up a new use for a paper clip.

It should be kept in mind, however, that this assumption of continuity of process is just that—an assumption. It does not necessarily follow that the processes involved in creative thinking are the same for all of us, as has already been discussed in several earlier chapters. It is entirely possible, for example, that Picasso and Mozart thought differently from the rest of us. In order to conclude that there is continuity of process involved across all humans, it is necessary to provide evidence that the same sorts of processes are actually used. That is one reason why case studies of seminal creative advances are presented in many places in this book, since such case studies can provide evidence for continuity of thought across people. It is interesting to note further that, while I believe that the case studies provide evidence of continuity of thinking, I do not believe that they provide evidence for divergent thinking as the basis for creativity. This point will be elaborated shortly.

Other Tests of Creative-Thinking Capacity

Guilford's proposed tests of creative-thinking capacity were elaborated and extended by him and his research group over the years (e.g., Guilford, 1967), but other researchers also developed batteries of tests to measure creative-thinking abilities (e.g., Kogan & Wallach, 1965; Torrance, 1974). Those batteries owed much to Guilford; when one examines the tests, one finds the same basic types of items, with variations in content rather than basic differences in the logic underlying the design of the tests. In addition to tests measuring divergent thinking in adults, researchers also developed comparable tests designed for children (Kogan & Wallach, 1965) to allow educators to determine as early as possible who among their students was capable of producing creative ideas if given the chance. This would allow educational institutions to provide additional support and enrichment for such children, thereby ensuring that society made the best use of this valuable resource. As noted earlier, Guilford's early work on testing and measuring creativity was carried out during the cold war era, when there was much concern that the United States and its allies might be overrun by the Communists, and there is an urgency in some of Guilford's writing as he warns about the possible dire consequences if the Western democracies do not make the best use of their creative thinkers (e.g., Guilford, 1950).

One aspect of the administration of divergent-thinking batteries became a source of further research. Guilford's tests were given in an atmosphere

much like that in which IQ tests are given: a formal classroom atmosphere. However, Wallach and Kogan (1965) proposed that measurement of creative capacity, especially in children, should be carried out in a different sort of environment. They developed a battery of tests that were similar to Guilford's in content but designed to be given in a playlike atmosphere. Numerous studies have examined the effects of different testing environments on performance on divergent-thinking tests (for review, see Barron & Harrington, 1981).

Mednick's Remote Associates Test

A different slant on assessing the capacity to think creatively was developed by Mednick (1962) from the idea that creative people are able to generate unusual ideas because of the structure of the associations in their memories. Mednick's view has already been briefly discussed in Chapter 8, in the context of Poincaré's (1913) ideas concerning remote associations and creativity and Simonton's (1988) theory of unconscious processing in creative thinking. Mednick approached the question of creative thinking from the then-dominant S-R perspective in American psychology. He proposed that one could analyze a situation that requires creative thinking as a *stimulus*, which produces associated *responses* in the thinker. Creative thinking means that one produces unusual or infrequent responses to a stimulus. The critical question is what enables some people to produce those responses. According to Mednick's analysis, the crucial difference among thinkers is the organization of their *associative hierarchies*, or sets of associative responses to stimulus situations. Noncreative people, shown in Figure 9.1A (presented earlier as Fig. 8.2), have *steep hierarchies*, with a strong or *dominant* response to a given situation, that will tend to be given all the time, and producing it will make it harder for the thinker to produce a less frequent response. As an example, if someone says *up*, all I can think of is *down*; it is my dominant response to that stimulus.

The creative person, on the other hand, has a *flat hierarchy* (see Fig. 9.1), with several responses available to the situation, none of which is particularly strong. Therefore, this person will have a greater tendency to produce unusual responses and thus may think of an original response to the situation, which could result in a creative solution to a problem. Mednick (1962) was proposing a theoretical mechanism to explain differences among people in Guilford's divergent-thinking ability: People with flat associative hierarchies would be divergent thinkers. Mednick's (1962) distinction between steep and flat associative hierarchies has been influential in psychology. Simonton (e.g., 1988, 1995) incorporated those ideas into his theory, discussed in detail in Chapter 11 (see also Chapter 8), and other psychologists also

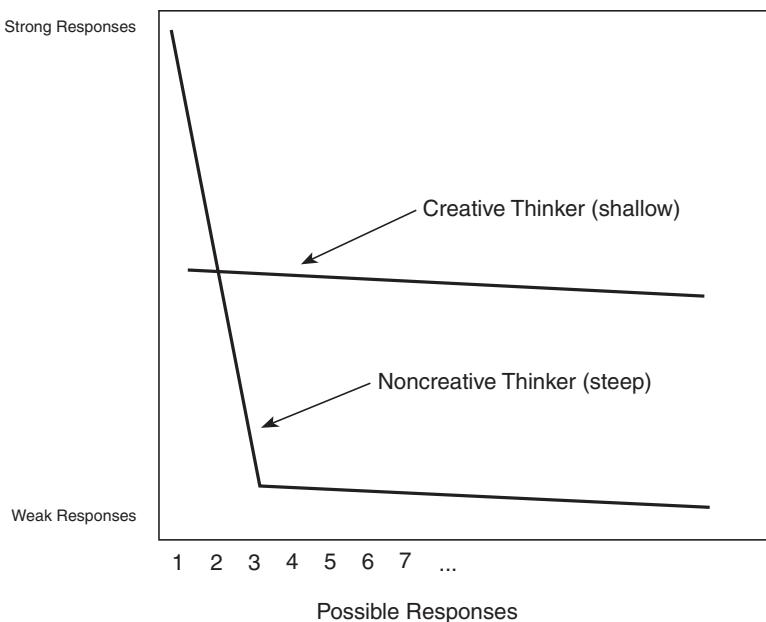


Figure 9.1 Mednick's theory

Source: Adapted from Mednick (1962).

refer to Mednick's ideas when discussing factors that influence the ability to produce novel ideas (e.g., Ansburg & Hill, 2003).

In order to measure people's associative hierarchies, Mednick developed the Remote Associates Test (the RAT). Some examples of the items on this test are shown in Table 9.7. The three words in each RAT item are each related to a single target word, but only weakly. Therefore, in order to think of the answer, one has to be able to move beyond the dominant responses to each of the words to the less common ones. We are already familiar with RAT-like problems from the discussion in Chapter 6 of Bowden and Beeman's (1998) work on insight in problem solving. The verbal problems that they used were based on RAT items (see Figure 6.5D, p. 299). Mednick assumed that the person who is able to answer RAT items correctly possesses flat associative hierarchies, which should enable him or her to produce original and potentially creative responses in other situations.

One might think that the RAT is curious as a test of creative-thinking capacity, since the RAT itself does not seem to require creative thinking in that there is a single correct response to each item (e.g., Ochse, 1990). That is, correctly answering an item on the RAT does not seem to require divergent thinking. This would seem to go against the whole purpose of testing creative thinking. However, in Mednick's defense, it should be em-

Table 9.7 RAT-related items

Each of the three words in each stimulus set is related to the same fourth word, with which it can be combined to produce a familiar English phrase.	
Stimulus set	Solution
piggy/green/lash	back
mark/shelf/telephone	book
surprise/political/favor	party
stick/maker/tennis	match
cream/cottage/cloth	cheese

phasized that the RAT itself is not directly measuring creative thinking; it is measuring the *capacity* to think creatively. This point has already been discussed in the context of Guilford's tests. If one can answer RAT items correctly, it is presumably because one possesses flat hierarchies, which can then be put to use in other situations, such as those demanding open-ended creative thinking. As an analogy, if one wants to test the potential of someone to do well in marathons, one might measure lung capacity rather than running speed. Lung capacity is presumably related to the ability to successfully compete in a marathon, and so measuring lung capacity might be a good test even though no running is involved. Similar logic lies behind the design of the RAT.

Tests of Creative-Thinking Capacity: Summary

The tests developed by Guilford and those who were influenced by his work and Mednick's (1962) RAT can be looked upon as measuring complementary aspects of the creative process. Guilford (1950) developed tests to measure, among other things, divergent thinking. In his view, divergent thinking is made up of the basic components of creative thinking, which is built on fluent, flexible, and original thinking. He developed a number of different measures that allow one to determine relatively easily how a given person compares with the average in this ability. Those tests, and others like them developed by other researchers, have been used in many different settings: from schools, where they are used in screening children for gifted programs; to industry, where they are used in hiring decisions; to research settings, where they are used to select "creative" participants for research studies. Mednick's RAT is designed to illuminate the mechanism assumed to underlie the capacity for divergent thinking: the associative hierarchies of the would-be creative thinker. The person with steep hierarchies will not be able to produce the remote associates necessary in confronting situations that demand divergent thinking.

It should be clear from this discussion that the basic perspective outlined by Guilford and adopted by those who use tests to measure creative-thinking capacity is that creative thinking involves a set of traits that are different from those underlying ordinary thinking. As noted in Chapter 2, this perspective has been adopted by many psychologists who do not directly use tests to measure creative thinking. Guilford's notion of divergent thinking as the cognitive capacity forming the foundation of creative thinking, and the flat hierarchies proposed by Mednick as the basis of that skill, are assumed to occur in various degrees across people. The creative thinker of the first rank is assumed to possess those capacities to an extreme degree, so much so that such an individual can be assumed to be basically different from the average person (e.g., Csikszentmihalyi, 1996; Simonton, 1999).

Testing the Tests: The Reliability and Validity of Tests of Creative-Thinking Capacity

I have now outlined the structure and the logic behind tests designed to measure creative-thinking capacity. As noted earlier, since Guilford's (1950) address and his pioneering work in developing tests to measure the capacity to think creatively, there has developed a wide and deep stream of research that has followed his lead. That research, which has concentrated on using tests to measure the creative capacity as well as relating test performance to other aspects of personality, has become a dominant stream in the psychological study of creativity. However, along with this stream of research carrying Guilford's ideas forward, there have developed questions as to the usefulness of tests designed to measure creative capacity. Because of the important role of those tests in the modern study of creativity, it is critical that we examine in detail both sides of the question of the usefulness of the purported creative-thinking tests.

Are Tests of Creative-Thinking Capacity Reliable?

The first question that one must ask about any measurement instrument, whether it is a bathroom scale or a test of creative-thinking capacity, is whether it is reliable. That is, does the test produce consistent outcomes? For example, if you weighed yourself three times within a minute and your scale gave readings of 150 pounds, 100 pounds, and then 200 pounds, it would be obvious that the time had come to replace the scale: It is not a reliable instrument. Similarly, if you test a group of eighth graders using a battery of divergent-thinking tests and come back in a few weeks and do it again, the scores should be about the same (assuming for the sake of discussion that there is not much carryover from the first test and also

that the students did not do any special preparation in the interval). This stability of a test over several administrations is called *test-retest reliability*. Demonstrating test-retest reliability is of critical importance for any test, because it means that we can have confidence in the scores obtained by people when they take it.

Another form of reliability becomes important when a psychological measuring instrument contains multiple items, as do the divergent-thinking tests presented in Table 9.2. One would like to combine all those items together in scoring each person, because more items would mean a more stable score. That means that one would hope that the various items would give similar scores, since they have been designed to measure the same capacity (i.e., the capacity to think creatively). In order to determine the consistency of the various items on the test, one can divide the test into halves, by taking alternating items, say. One can then determine each person's score on each half of the test. If the two sets of items are reliable in measuring the same capacity, a given person's score on the two halves of the test should be about the same. This is called *split-half reliability*.

Research studies have found that divergent-thinking tests are reliable; that is, they produce outcomes that are reasonably consistent (Barron & Harrington, 1981). That means, as noted, that we can be confident that a person's score is representative of his or her performance. There is, however, one caution that must be given here: It is sometimes found that performance on divergent-thinking tests is affected by the conditions under which the tests are given. For example, if you instruct people to *be creative* in their responses, they may score higher than if you say nothing about being creative on the test. This seems to indicate that divergent-thinking ability is a *strategy* that can be applied to a testing situation, rather than some automatically engaged and unchanging trait or characteristic of a person.

It is interesting to consider further what we might conclude from the finding that one can change people's performance on a divergent-thinking test by telling them to be creative. Consider performance on an intelligence test as an analogous situation. Presumably, performance on IQ tests would not be affected by instructions to "be smart." One does not have to tell schoolchildren to try to do their best to answer the questions when they take an IQ test, or that they are not to produce multiple answers for each question, or that they are to mark the answer they think is best, or that they should try to be accurate. There is only one strategy that seems reasonable on such a test, and schoolchildren know what it is. On the one hand, that result might lead one to the conclusion that an IQ test is measuring some constant characteristic of a person, and creative-thinking tests are therefore deficient in some way. However, the reason that children's performance on

IQ tests would not be affected by instructions to be smart might be that they have been exposed to such tests from an early age, and so they have been socialized to deal with them in the ways that the administrators of the tests expect them to.

Tests designed to measure creative-thinking capacity are a different matter, for several reasons. First, since there is no single correct answer for the items on such tests, the test taker has at least two strategies available: to produce common responses or to produce unique responses. In addition, divergent-thinking tests are not usually given in most schools. Given the typical child's lack of familiarity with the tests, it may not be surprising that additional instruction may sometimes be needed. Thus, it is not necessarily a flaw in the tests that they might be affected by instructions. On the basis of the available evidence, it seems that creative-thinking tests are reliable instruments.

Are Creative-Thinking Tests a Valid Measure of Creative Capacity?

The conclusion that tests designed to measure creative-thinking capacity are reliable leads to a second question: Just what is it that those instruments measure? Obviously, use of the tests is based on the assumption that they measure the capacity to think creatively, which is what they were designed to measure. However, we do not as yet have any evidence that that is what the tests do. As was mentioned earlier, Guilford (1950) designed the tests on the basis of his analysis of what must be involved in creativity. However, because he did not study creative thinkers to determine how they actually think (Brown, 1989), we have no idea whether Guilford's intuitive analysis of the creative process was accurate; accordingly, we have no idea whether the creative-thinking tests actually measure creative-thinking capacity. The question of whether a test measures what it was designed to measure is the question of whether the test is *valid*: A valid test measures what it is supposed to. If a test is not valid, then it may be reliable, but it will be useless. Your bathroom scale may be extremely reliable, but it is useless if you want to measure your IQ or the amount of money in your savings account.

It is possible to discern three periods in the development of tests of creative-thinking capacity. The first period began with Guilford's (1950) APA address, which stimulated a great deal of research on creativity using his tests and similar ones developed by others (e.g., Kogan & Wallach, 1965; Torrance, 1974). However, some researchers began to raise questions about the usefulness of such tests, including some of the researchers who developed them (e.g., Crockenborg, 1972; Kogan & Pankove, 1974). By the 1980s, strong reservations were voiced concerning the value of that direction of research, and some researchers in the field began to move

away from these instruments (e.g., Brown, 1989; Weisberg, 1986). In response to those criticisms, supporters of the psychometric perspective have presented new findings and have reanalyzed old results in an attempt to demonstrate that rejection of divergent-thinking tests was an error (e.g., Plucker, 1999a). I will trace these developments in the debate on the validity of tests designed to measure the capacity to think creatively. As we just saw in the case of reliability, there are several different sorts of validity that we can examine.

Discriminant Validity

Tests of creative-thinking capacity should measure something unique, especially something different from what intelligence tests measure. That is, these tests should be *discriminating* between what they measure. If a divergent-thinking test measures a capacity that IQ tests do not measure, then the former test is said to have *discriminant validity*. Barron and Harrington (1981) reviewed many studies that examined the relationship between the two types of tests, and the results varied. Some studies reported relatively high correlations between divergent-thinking scores and IQ scores, which might mean that they do not involve two different abilities. However, other studies reported nonsignificant relations between the two, indicating that they might be independent. Barron and Harrington noted that the inconsistent results might be due to the specific sample of individuals being tested, to the specific tests used (especially the divergent-thinking tests), and to the conditions under which the tests were administered. As we saw earlier, for example, scores on divergent-thinking tests can be significantly affected by the testing environment.

It is also interesting that it has been found that ratings of students' creativity by their teachers are sometimes very highly and positively correlated with the teachers' ratings of the students' intelligence (for review, see Hocevar & Bachelor, 1989). Although that result has nothing to do with the validity of creative-thinking tests, *per se*, it does raise an interesting question as to whether creativity and intelligence are independent dimensions of a person's performance. Some have proposed that creative thinking is carried out by the same processes as those involved in performance on IQ tests—that is, that there is no special "creative-thinking process," *per se*. According to this view, the only difference between the creative and the noncreative individual is the difference in attitude that they bring to tasks: The individual who produces creative outcomes wants to use his or her intelligence to produce new things (e.g., Dellas & Gaier, 1970). The cognitive position that underlies this book is related to that view (see Chapters 3 and 4), and this issue will be discussed further in the next chapter.

Face Validity

Sometimes test items obviously measure what they were designed to measure. Under such circumstances, one can say that the test is valid *on its face*; that is, the test can be said to have *face validity*. For example, if one had designed a test to measure a person's knowledge of professional basketball, and some of the test items required recalling the names of the professional teams or of the recent championship teams, then the test would seem to have face validity. As for creative-thinking tests, I feel that one can question their face validity. Most researchers accept on its face Guilford's (1950) analysis of the creative process—that is, most researchers agree that divergent thinking, defined as the production of many and varied ideas, is the foundation for creative thinking. Similarly, there is near-universal acceptance that "remote" associations, à la Poincaré (1913) and Mednick (1962), are critical in bringing about production of creative ideas. Those two assumptions are, as noted earlier, two facets of the same general perspective: The remote-associates concept can be looked upon as the mechanism underlying divergent-thinking ability.

However, there is evidence that this remote-associates view of creative thinking may not be correct. Based on the information that we have available concerning the way the creative process works, from the case studies presented earlier as well as from studies of problem solving discussed in Chapters 3 and 6 (e.g., Fleck & Weisberg, 2004), one can challenge the theory of remote associates as the basis for creative thinking, and, *ipso facto*, the face validity of the creative-thinking tests that we have examined. In considering in this context the case studies from the arts (e.g., Picasso's creation of *Guernica*; Calder's invention of mobiles), the sciences (the discovery of the double helix), and invention (Edison's invention of the light bulb; the Wright brothers' invention of the airplane), we have seen that the creative process does not seem to work in the way that Guilford (1950) and others assumed when they developed divergent-thinking tests. The basic assumption behind the divergent-thinking tests in Table 9.2 is that producing many ideas is critical for producing creative ones. This is based on the further assumption that the creative process works in two stages: first by producing many ideas and then by keeping the good ones. The creative products that we have examined, however, were not produced by such a two-phase process. Rather, from the beginning the creative process was focused in a top-down manner, so that promising directions were taken right from the beginning. There was in none of those cases an initial period during which ideas were simply randomly produced in the hope that something relevant might be found at a later stage. If the conclusions from the case studies are valid, they indicate that most tests of creative-thinking capacity possess only *apparent*

face validity. That is, although Guilford's description of the creative process seems plausible to many people, it still may not be accurate.

Laboratory studies of problem solving, including studies of solution of insight problems, have produced similar conclusions (see Chapter 6). The study of insight problem solving by Fleck and Weisberg (2004, 2006; see also Weisberg, 1980; Weisberg & Suls, 1973) has shown that those problems too are not approached in two stages, the first of which involves something like divergent thinking. Top-down processes are operating from the very beginning in problem solving also, meaning that tentative solutions that are produced are based on the analysis of the problem and the match between that analysis and the person's knowledge, rather than on some divergent-thinking process that is independent of the problem the person is facing.

Mednick's RAT (1962) was designed to assess an individual's potential to think creatively, as hypothesized by Mednick in his analysis of creative thinking in S-R terms. In Mednick's view, the ability to produce creative responses in some situation is the result of a flat associative hierarchy. One can raise the same criticisms about the face validity of Mednick's analysis of the creative process as have been raised concerning that of Guilford (1950). That is, Mednick did not obtain detailed records concerning how the creative process actually worked when people were producing new things; he assumed that the process worked through remote associations. He made no attempt to set up laboratory situations or to examine case studies to determine if there was evidence that the creative process could be described as relying on remote associations. In contrast to Mednick's assumptions, however, results from case studies of seminal creative advances, as well as from laboratory studies of problem solving (all of which were reviewed earlier in this book), do not support the notion that creative thinking depends on remote associations.

For example, we saw that Watson and Crick did not think remotely when they were deciding on a general strategy for pursuing the structure of DNA: They used Pauling's modeling approach, which came from the content of their expertise. In addition, in choosing the specific path that they would take, they assumed that DNA was helical, again an idea that was not remote from their expertise. Similarly, Picasso's creation of *Guernica* was deeply rooted in his expertise and required no radical break into some area remote from his ordinary ways of thinking. So, although many researchers seem to accept the face validity of Mednick's (1962) approach, and his notion that creative thinking depends on remote associations (which, as noted earlier, Mednick traces back to Poincaré), the face validity of those ideas may be illusory.

In sum, one can on several grounds raise questions about the face va-

lidity of divergent-thinking tests of creative capacity. It should be noted, however, that a lack of face validity is not necessarily a critical flaw in a test. A test can still be useful even if it does not possess face validity: It still might serve as the basis for classifying and selecting individuals for some purpose. As a hypothetical example, let us say that there is a significant positive correlation between the number of letters in a horse's name and his or her performance in the Kentucky Derby. (Don't concern yourself with why that might be the case; for the time being let us simply assume that it is true. I would guess that it is not true, although I have not checked.) If one were interested in wagering on the Derby, one could then use name length as the basis for choosing the horse on which to bet. In such a case, the "test" does not possess face validity, but it is nonetheless useful. It has *criterion validity*: It correlates with some criterion performance in which one is interested (i.e., running fast in a horse race). One could also say that the name-length test possesses *predictive validity*: It enables us to predict performance in some other situation. So we can also review studies that have examined the predictive validity of divergent-thinking tests. Criterion and predictive validity are usually discussed separately in the literature, but they are closely related, since in both cases one is using performance in one situation to predict performance in another. The only difference between them is whether the second performance (the predicted performance) is assessed in the same situation or at a later time. So we now turn to the question of whether divergent-thinking tests possess criterion and predictive validity.

Criterion and Predictive Validity of Divergent-Thinking Tests

If tests of creative capacity possess criterion validity, performance on those tests should be correlated with some external criterion of creative performance. As an analogy, when IQ tests were developed around the turn of the twentieth century by Alfred Binet, their initial purpose was to differentiate between bright and dull schoolchildren (Brown, 1989). The success of the tests was relatively easy to determine: One had only to look at how well the tests differentiated children who performed well in school from those who performed poorly. The reason Binet's test was adopted was that it was possible to determine that it was successful. That is, the test demonstrated criterion validity. When Guilford (1950) presented his suggestions for creativity tests, in contrast, his bases for the various measures, such as those outlined in Table 9.2, were his intuitions on how the creative process must work: It seemed reasonable to Guilford that the creative person would first produce many ideas and then select the good ones for use. Thus, there was no external criterion of creative performance that guided Guilford's work and that could be pointed to as an indicator of success of

the divergent-thinking tests as predictors of creative-thinking capacity. He and his colleagues did not attempt to correlate their tests with criterion measures of creative performance. Indeed, Guilford noted that before bothering creative individuals by asking them to submit to testing, it was first necessary that the tests be developed to a considerable degree.

Over the years there have been studies on the relationship between performance on creative-thinking tests and various criterion measures of creativity, and the results have been mixed (for reviews, see Brown 1989; Hocevar & Bachelor, 1989). In one example, Baer (1993) carried out a number of studies in which people of various ages, ranging from school-children to adults, were asked to produce creative products of various sorts (e.g., write a poem or a story in response to a picture; construct a collage). The participants were also given a divergent-thinking test, and it was consistently found that divergent-thinking performance was not significantly correlated with performance on the creative tasks. Such results raise doubt about the criterion validity of divergent-thinking tests.

Guilford (1950) originally proposed that tests of creative-thinking capacity would be useful in allowing us to predict who among us would develop into creative adults. That is, he believed that such tests would have predictive validity. In addition to criterion validity, the question of predictive validity is critical for any creative-thinking test. As noted, criterion and predictive validity are closely related: One could say that predictive validity is criterion validity with a time delay. As with other aspects of the validity of divergent-thinking tests, the support for their predictive validity is mixed. It is somewhat difficult to review this literature, because consistent findings are not easy to discern. Baer (1993) reviews the literature on the predictive validity of divergent-thinking tests and concludes that support is poor. In contrast, Plucker (1999) has concluded that the tests are of value. I will review several studies that have used divergent-thinking tests to try to predict the future creative accomplishments of individuals and will demonstrate the mixed outcomes of such studies (for further review, see Brown, 1989; Hocevar & Bachelor, 1989).

Cropley (1972) gave divergent-thinking tests to junior high school students. Five years later, the creative achievements of the students were assessed in four areas: art, drama, literature, and music. Cropley found no significant correlations between divergent-thinking scores and creative achievements, so the predictive validity of the tests was not supported. Similar results were reported by Kogan and Pankove (1974), who used the Wallach and Kogan tests (1965) to measure creative-thinking capacity in children. The children were tested in the 5th and 10th grades, and they filled out a questionnaire about their overall accomplishments when they were

high school seniors. The question of interest was whether their divergent-thinking scores had predicted the creative accomplishments they reported as seniors. The 10th-grade divergent-thinking scores made what was called a “marginally significant contribution” in predicting activities and accomplishments reported 2 years later. That is, there was a weak effect. However, there were no significant predictions from the 5th-grade tests to the senior year. Thus, while there might have been a small amount of predictive usefulness of the test scores, it was only helpful over a relatively short period of time. In addition, Wallach and Pankove found that IQ scores obtained at both grades made stronger predictive contributions than did the divergent-thinking scores for both grade levels at 12th grade. This takes us back to the question of the discriminant validity of divergent-thinking tests: In this study, it looks like obtaining divergent-thinking scores did not provide any information above what would have been provided by IQ scores.

In another investigation of the criterion validity of divergent-thinking tests, Hocevar (1980) tested 94 university students and obtained measures of intelligence and ideational fluency, which, as noted above, is one component of divergent thinking. A self-report index of creative activities (similar to that in Table 9.6) was used to assess creative achievement. Results indicated that neither kind of test—IQ or divergent thinking—predicted creativity with more than modest accuracy. In addition, Hocevar reported that there were large differences in the predictive ability of the two types of tests across domains, and in some cases IQ was the superior predictor. So this study also fails to provide strong support for the predictive validity (or for the discriminant validity) of divergent-thinking tests.

In a study mentioned in Chapter 3, Getzels and Csikszentmihalyi (1976) had fine-arts students draw a still life that they had first created out of objects that the experimenters made available to them. In addition to carrying out the drawing task, the artists were also given personality tests and divergent-thinking tests. The quality of the still life drawings was judged by a panel of artists. It was found, as noted earlier, that the student artists who spent the most time preparing the still life produced paintings that were judged most favorably by the panel of artists. This indicated that preparation was critical in determining the quality of the final product. Getzels and Csikszentmihalyi (1976) called this preliminary time period “problem finding,” although, as noted in Chapter 3, in my view the student artists were simply solving the problem of arranging a still life that was to be drawn. (For further discussion of this issue, see Chapter 12.) In addition, the artists who produced the highest-quality paintings also had a greater tendency to change their arrangements as they were working; they were more open to changes in the structure as they were working. The other student artists tended to close off their options earlier.

As just noted, Getzels and Csikszentmihalyi (1976) also had the student artists take divergent-thinking tests, and none of those scores was related to the ratings of the drawings, so they were not effective predictors of artistic performance. In addition, a follow-up study was carried out 7 years later, when the students had had a chance to establish their careers. Although 7 years is not a lot of time, there were already some clear differences in career success among the artists. Some had dropped out of the art world; others were working as commercial artists, which meant that they had for the time being changed their career path within art in a direction away from fine art. One artist had had a solo show, and one of his paintings had been purchased by a museum, which indicated that he had achieved early success. Getzels and Csikszentmihalyi reexamined the measures obtained in the initial study to see which of them, if any, might predict career success. The preparation-time ("problem-finding") measure, which was related to the quality judgments of the original drawings, was also related to career success several years out of art school. This indicates that the student artists' early habits and attitudes toward their works were also important in their long-run success. Of direct relevance to the present discussion, performance on the divergent-thinking tests was not related to career success, so in this study the tests were not valid predictors of later creative performance. As noted earlier, Csikszentmihalyi (1999) reported an 18-year follow-up study, and again only the problem-finding measures significantly predicted career success.

We have now reviewed several studies that have provided at best weak support for the predictive validity of divergent-thinking scores. As noted earlier, however, this area is not one in which simple conclusions can be drawn. Several other studies have produced results that have been taken as support for the validity of divergent-thinking tests. Reviewing those studies will provide evidence of the complexities involved in assessing people's creative-thinking capacities.

Soon after Guilford's (1950) discussion of creativity testing, Torrance (e.g., 1974) developed a battery of tests of a similar nature. Torrance was concerned about the predictive validity of his tests and carried out several studies examining whether the tests were useful in predicting creative accomplishment, both short term and long term. Torrance reported 12 studies examining the short-term predictive validity of the Torrance tests. The participants ranged from kindergarten children to adults, with sample sizes from 12 to 133. Torrance examined a wide range of behaviors, some of which have been called into question by other researchers as criteria for creative accomplishment. The predicted behaviors included psychiatrists' assessments of fourth graders' sense of humor and strength of self-image. Those measures were obtained by having the children respond to projective techniques, such as the Thematic

Apperception Test (TAT). The originality of stories written by sixth-grade students was assessed. For younger children—kindergartners and first graders—one criterion behavior was development of Piagetian conservation (e.g., conservation of liquid: the child's developing belief, first examined by Piaget, 1965, that the amount of liquid stays constant when it is poured from a tall thin container, say, into a wide low one). For adults, one criterion was success in teaching in inner-city schools. Torrance reported significant correlations between divergent-thinking scores and various criterion variables, but one can question the validity of those criteria as measures of creativity (Baer, 1993). What do the strength of a child's self-image and the development of conservation of liquid have to do with creativity? Similarly, one might successfully teach in an inner-city school without being creative. Given the questions that can be raised about the criteria, one might conclude that those short-term studies do not provide evidence either for or against the predictive validity of the Torrance tests.

Torrance (1974) also reported six long-term correlational studies, which are more germane to the present discussion. Two of those studies are major studies, in that they involved more participants, the participants were followed over longer time periods, and more rigorous procedures were used to measure creative accomplishment. I will examine in more detail those two studies, because of their importance and because one of them has become the focus of a recent reanalysis. The first study began in 1959, when all 329 students in grades 7–12 in the University of Minnesota High School were given Torrance Verbal Tests. They were very able students: Their mean IQ was 118. Twelve years later, 234 of those students completed questionnaires about their activities in a variety of areas. Examples of activities that were included in the assessment of creative achievement were subscribing to a professional journal; learning a new language; writing songs, plays, and so on; changing one's religion; performing on TV or radio; and publishing a professional paper. The researchers obtained three key indices from those responses. First, the *quantity* of creative achievements was determined. Second, the *quality* of creative achievements was measured. Independent judges scored each respondent's three most creative achievements. Finally, respondents were scored for the *creativity of their aspirations*: what they would like to do in the future.

The results of the study were consistently positive: The three criterion indices correlated +.27 to +.45 with scores from tests taken 12 years earlier. So this study indicates that one can use divergent-thinking scores (at least, verbal divergent-thinking scores) to predict creative achievements in the future. However, as noted for the short-term studies, one can raise questions about the results here also (e.g., Baer, 1993). First of all, one can again ques-

tion the relevance of the criterion variables to creativity, and this seems to be especially true with the quantity measures. Are those achievements creative achievements? If not, then the more or less accurate predictions are irrelevant. A different problem concerns the relationship of those achievements to general intelligence. The criterion variables (e.g., subscribing to a professional journal, learning a foreign language) are things intelligent people do. In this regard, it is important to note that in this study the correlations between intelligence and the criterion creativity variables were as high as those between the Torrance tests and the criteria. In addition, the Torrance tests also correlate with intelligence, so perhaps the predictability of the creative achievements (ignoring for the moment the question of whether those achievements on the whole involve true creativity) is based on intelligence and not on divergent-thinking ability. One problem with the design that Torrance used is that it does not allow one to determine which variable (Torrance scores or IQ) is the stronger predictor of the criterion variables. Torrance did not use a multiple-regression design, which would have allowed that more sophisticated question to be answered. Baer (1993) makes several other criticisms of this study, and the interested reader should see his discussion.

It thus seems that one of the major studies of the long-term predictive validity of divergent-thinking tests has possible design flaws that render it of little use in drawing firm conclusions concerning the usefulness of such tests. However, Plucker (1999a) recently reanalyzed the data from a second long-term study conducted by Torrance (1974) and found more positive results concerning predictive validity of the divergent-thinking tests. In Torrance's second study, all the children in two elementary schools in Minnesota were given the Torrance test battery multiple times over the years 1958–1965. Other measures, including IQ scores, were also obtained. The study focused on 400 children who had been given the divergent-thinking tests for three consecutive years over grades 5–8, because multiple measures provide the most reliable estimate of creative-thinking potential.

In 1980, 22 years after the study was begun, the students, now approximately 28 years of age, were contacted, and 220 participated in a follow-up study, in which they were asked about creative achievements, such as inventions, published scientific articles, awards for creative work, and so forth. Each participant also listed his or her most creative achievements, which were rated on overall creativity by three judges. Plucker (1999a) used multiple-regression analysis to examine the predictive power of the Torrance tests over 22 years, and the results provided support for the tests' usefulness. The verbal test score predicted creative achievement, and it did so more strongly than intelligence did. The figurative component of the divergent-thinking score did not successfully predict later creative achievement, however. From these results Plucker

concluded that the Torrance tests do possess predictive validity and that such tests provide useful information about people's creative potential.

Validity of Divergent-Thinking Tests: Conclusions and a Remaining Question

We have now reviewed several studies on the validity of divergent-thinking tests as measures of creative-thinking capacity, and it should now be clear why it is difficult to draw firm conclusions in this area. Studies can be brought forth to support a whole range of seemingly contradictory conclusions, ranging from (1) divergent-thinking scores have little or no validity as even short-term predictors of creative achievement, to (2) divergent-thinking scores are valid predictors of people's future creative accomplishments, even over many years. At present, the most reasonable conclusion may be that the relationship between divergent-thinking scores and creative achievement is complicated and that simple conclusions may not be possible. Divergent-thinking scores may predict creative achievements in only some people, and then in only some circumstances. The validity of the divergent-thinking scores may be related, for example, to the general intelligence level of the individuals being tested (Runco, 1991) as well as to the specific types of achievements that are being measured. Plucker's (2003) reanalysis of Torrance's (1974) longitudinal predictive-validity data using multiple-regression methods indicates that the divergent-thinking tests have predictive validity in that sample. However, in several other studies that have reported negative results, Plucker's methods are not available to rescue the validity of the divergent-thinking tests, because the researchers reporting negative findings did use multiple regression when they carried out their original analyses.

In their often-cited review of the validity of divergent-thinking tests, Barron and Harrington (1981) drew the following conclusion: "Some divergent thinking tests, administered under some conditions and scored by some sets of criteria, do measure abilities related to creative achievement and behavior in some domains" (p. 447). That very conservative statement—which, as Brown (1989) noted, does not instill great confidence in researchers who might be thinking about using those tests—still seems to be valid 25 years later. The criterion/predictive validity of the RAT has been subject to less investigation than that of divergent-thinking tests, but overall the results do not support the predictive validity of the test (see Brown, 1989, and Mansfield & Busse, 1981, for review).

A Remaining Question: What Do Divergent-Thinking Scores Mean?

If we assume for the sake of discussion that some divergent-thinking tests in some circumstances are valid predictors of creative achievement, that still

leaves us with the question of why that should be so. Divergent-thinking scores might be correlated with later creative achievements for any of a number of reasons. It might be that divergent-thinking scores predict later creative achievement because divergent thinking forms part of the creative thought processes, so possession of divergent-thinking skill might make it more likely that one would produce creative responses in various situations. However, as noted earlier in the discussion of the face validity of divergent-thinking tests, results from the case studies presented earlier in this book, as well as from laboratory studies of problem solving (e.g., Fleck & Weisberg, 2004, 2006), provide support for the conclusion that the creative-thinking process is not as Guilford (1950) assumed it was.

Most important, if the conclusions from the case studies and laboratory research are accurate, the first stage of the creative process does not entail production of large numbers of possible responses, as Guilford proposed. In addition, as discussed earlier, creative responses do not seem to be based on remote associations (consider again Picasso's *Guernica* and *Minotauromacy*; Watson and Crick's adoption of Pauling's helical idea; Edison's carbon- and platinum-filament electric lights; and the Wright brothers' conception of the airplane as a bicycle with wings). If those analyses are correct, divergent thinking is not a critical component of the creative process. This conclusion leaves open the question of why divergent-thinking tests might in some cases predict later creative achievement. This question will be dealt with in the next chapter.

The Generality versus Domain Specificity of Creative-Thinking Skills

As noted earlier, one critical assumption underlying the development of tests to measure creative potential is that creativity is a general trait of people. That is why researchers assume that they can use responses on an unusual-uses-for-a-brick test to predict creative production in areas such as literature, poetry, painting, and so on. However, here too there is controversy in the literature, because research results are contradictory concerning whether creativity is a general trait. First of all, it is notable that one can find very few people who make significant contributions in multiple creative domains, especially domains that are very different in subject matter. For example, it is very rare to find a creative scientist who also makes significant contributions to any of the arts. Such negative findings would seem to indicate that creativity is relatively domain-specific, but there is one problem in interpreting the finding that people are usually creative in only one domain. As we saw in Chapter 4, it takes many years of dedication

to reach world-class levels in any domain (the 10-Year Rule). We also saw in Chapter 5 that the 10-Year Rule is relevant to creativity, which means that we might not be able to find people who are creative in more than one domain due to time constraints. That is, there might not be enough time available for a person to develop the expertise needed to be creative in multiple domains. Creativity might be a general trait, but exhibiting that generality might be limited by constraints of time and effort rather than anything intrinsic to the creative process. If so, then we must turn elsewhere for evidence concerning the generality versus specificity of creativity.

However, before we move on, one further point should be noted. The finding that creative achievement depends on domain-specific expertise that takes years to acquire, if valid, by itself casts doubt on any theory that assumes that creative achievement depends on general creative-thinking skills. The finding of the necessity of domain-specific expertise for creative achievement, on its face, raises problems for the notion of generality of creativity skills, since the 10-Year Rule indicates that specific skills are crucial in creative achievement.

Baer (see Baer, 1998, for review) has taken a different approach to assessing the possible generality of creativity, by asking ordinary people, ranging from schoolchildren to adults, to produce creative products in a variety of domains, such as poems, short stories, collages, and mathematical puzzles. The products in each domain were then rated for creativity by judges. Results from several studies indicated that performance across domains was not related; that is, the person who wrote the best poem did not necessarily construct the best collage. Baer concluded that creative ability is specific in nature. Indeed, creative production in Baer's studies was extremely domain-specific: Even the domains of poetry and fiction, which one might think would be related, were not. The best poets did not produce the best stories. Baer noted that this result raises problems not only for theories that assume that creativity is a general trait, but also for Gardner's (e.g., 1993) theory of multiple intelligences. Gardner assumed that linguistic intelligence, which would encompass poetry and fiction, was one category of intelligence. Baer's finding that performances in those domains were independent does not support Gardner's assumption. From these results, which are based on ratings of products that people produce, one would conclude that creativity is a domain-specific trait.

Baer (1998) also used training in divergent-thinking skills in an attempt to examine the general versus specific nature of creative-thinking skills. In one study, seventh-grade students were taught divergent-thinking skills that were related to poetry (e.g., the students practiced producing words that rhymed with a given stimulus word). The trained students and a nontrained

control group then wrote poems and short stories, which were evaluated by judges. The training had a very specific effect: The poetry-writing skills increased for the trained group compared with the control group, but the story-writing skills did not. This is evidence that training in skills potentially relevant to creative thinking has effects only within the domain to which the training is directed. One does not seem to get general increases in creative thinking from such training.

An opposite conclusion concerning the generality versus specificity of creative thinking comes from another set of studies, which collect data using questionnaires—such as that in Table 9.6—that ask people to list their past creative accomplishments (for reviews, see Plucker, 1999b, 2004). When one analyzes data from such questionnaires, one finds that there is a general tendency toward creative accomplishment across domains: People who list accomplishments in one field tend to list accomplishments in other fields as well. Plucker (1999b) carried out research in which he reanalyzed data from earlier studies (e.g., Runco, 1987) as well as collecting new data, and he has found evidence for generality in people's responses to questionnaires. In addition, Plucker carried out a study in which people provided both questionnaire responses and descriptions of their most creative achievements in several different domains for judges to evaluate. In this dual-method study, Plucker found evidence for generality from the questionnaires and for domain specificity from the judges' ratings of the concrete products. A similar conclusion arose from Plucker's reanalysis of data from the study by Runco (1987), in which questionnaire responses and creative products were also judged. As a result of those various analyses, Plucker (2004) has concluded that there is a "method effect" that affects the conclusion of generality versus specificity in creative achievement. Traditional psychometric methods, such as questionnaires, produce evidence for generality; newer measures based on specific creative performances, such as the consensual assessment technique, produce evidence for domain specificity.

Assuming that Plucker's (2004) "method effect" conclusion is valid, it leaves us with the question of why such an effect might be found. Plucker does not provide any specific reasons for why it might occur, although he notes that the consensual assessment technique is subjective in nature, since it is based on judges' ratings of creative products. This might indicate that Plucker believes that there is an inherent weakness in such studies. However, in the study that he reports, in which both questionnaire responses and judges' ratings were obtained for the same group of people (Plucker, 2004), the reliabilities of the judges' ratings were higher than that for the responses on the questionnaires. That finding seems to indicate that there is not an inherent weakness in the consensual-assessment technique. In addition,

one might raise the question of whether judges' ratings of the creativity of products are any more subjective than people's answers to questions concerning how many times they have written poems, for example. While it is obvious that frequency of poems *could* be measured objectively—that is, one could videotape a person's life and then go over the tape and count every time the person writes a poem—that is not how those data are collected. If we ask a person to report frequencies of various activities, then a subjective element is inevitably added.

In a related vein, Baer (e.g., 1998), as might be expected from the earlier discussion, has argued that evidence for generality of creative achievement arising from questionnaire studies might be due to factors not related to creativity at all. He takes the position opposite to Plucker and raises questions about subjective factors not related to creativity that might affect people's responses to questionnaires about their creative accomplishments. There might be some aspects of the strategies that a person could use in responding to a questionnaire that might be critical here. For example, as seen in Table 9.6, questionnaires sometimes ask about awards that people have earned for their creative works. However, the term *award* is not usually specifically defined, so it may be that some people are more likely than others to credit themselves with creative achievement simply because of the vagueness of some of the terms involved. Other people might be more reluctant to do what they might see as blowing their own horn. Similarly, if one is asked whether one has taken lessons in painting, say, does spending a couple of evenings in an adult-education drawing class count as lessons?

Thus, aspects of people's response styles, such as how likely they are to give themselves credit for some accomplishment, might affect conclusions concerning the generality or domain specificity of their creative achievements. Some people might report creative accomplishments across a wide range of areas because they tend to feel positively about their own accomplishments. More reticent people might report fewer activities. That pattern of responses would tend to support the conclusion that creativity is a general trait, because people might report creative achievements across the whole set of domains or in none of them. However, a conclusion of generality might not be warranted by the actual achievements of the respondents. In the next chapter, I will examine another noncreativity factor that might contribute to findings of generality of creative achievement.

As this discussion has shown, there is some controversy as to whether creativity is based on general or specific skills. Evidence indicates that the method through which creative achievement is assessed plays a large role in one's conclusion concerning this issue. We have examined several possible reasons for the controversy. In addition, evidence from the case

studies of creative thinking presented elsewhere in this book, including evidence concerning the 10-Year Rule and expertise in creativity, supports the premise that domain-specific skills underlie creativity. Additional evidence concerning this question will be discussed in Chapter 11, in the context of the discussion of confluence models of creativity.

Testing Creativity: Conclusions

The review in this chapter has indicated that serious questions can be raised about the divergent-thinking tests that have been used in a wide range of studies. Those tests have demonstrated mixed levels of discriminant and predictive validity. Questions can also be raised about the face validity of divergent-thinking tests, based on reservations about Guilford's divergent-thinking analysis of the creative process. Similarly, questions can be raised about Mednick's (1962) postulation of flat versus steep associative hierarchies in creative versus noncreative thinking. In sum, empirical and theoretical questions can be raised about the premise that divergent thinking is the basis for the capacity to think creatively. This is indirect support for the "ordinary-thinking" perspective. In the next chapter, we examine the hypothesis that a unique set of personality characteristics (the "creative personality") play a role in determining whether a person will be creative.

This chapter has focused on development of the divergent-thinking tests by Guilford and others. However, Guilford's analysis of the components of the creative thought process was more complex than the distinction between divergent and convergent thinking. Indeed, Guilford proposed a complex model of cognition—the structure of intellect model—based on many factors. In recent years, that model has received much less interest than has the role of divergent thinking in creativity, which is why that aspect of Guilford's research has been discussed here. Mumford (2001) has recently presented a review of the wider range of Guilford's thinking vis-à-vis creative thinking in an attempt to make more researchers aware of the potential value in the broad range of Guilford's ideas. It is too early to determine if Mumford's effort will result in a renewal of interest in aspects of Guilford's research that have more or less been put aside.

CHAPTER

10

The Psychometric Perspective, Part II

The Search for the Creative Personality

As noted in Chapter 9, one important component of Guilford's (1950) analysis of creativity was that creative production was a function of two aspects of an individual: the cognitive abilities already described (i.e., those centering on divergent thinking) and relevant personality characteristics. Thus, determining who would function creatively required two sets of measurements, the cognitive measurements (see Table 9.2) and the measurement of personality characteristics using personality inventories (see Table 9.4). As articulated by Guilford, one's personality can be conceived of as a set of *traits*, which are relatively permanent aspects of our beliefs and behavior that serve to distinguish us from one another. So, for example, people differ in how *outgoing* or *extraverted* they are, in *honesty*, and in whether they are content to let others make decisions for them (i.e., if they are willing to be *subordinate* to others or if they want to be in a position of *leadership* and *responsibility*). In addition, some people are comfortable making decisions based on *intuition*, or their gut feelings, without much evidence, while others depend on logic and analysis based on evidence carefully obtained from the world. Some are very *conscientious* in following rules, while others are more ready to go outside rules as needs require.

Based on Guilford's (1950) theorizing, the question of interest becomes whether there are any personality traits that distinguish creative individuals from their non- or less-creative peers. In addition, researchers have tried to analyze how any discovered differences in personality might be related to differences in creative achievement; that is, researchers have attempted to

understand how differences in personality characteristics might contribute to differences in creative achievement. Following Guilford's lead, numerous studies attempted to measure the personality characteristics of creative individuals. As an example of the scale of this work, Feist (1999) reviewed studies that have examined personality characteristics of creative artists and scientists, and the summary tables in his article list 44 articles that have compared the personality characteristics of artists and nonartists and 35 that have compared more- and less-creative scientists. Furthermore, those numbers are conservative, since Feist reviewed only studies that met several selection criteria, so there are more studies in the literature.

Creative versus Comparison or Control Groups

Studies of the creative personality have generally focused on two sorts of "creative" people: (1) individuals who have achieved career success in some creative field, such as successful architects or research scientists, as nominated by their peers or by experts in the domain; and (2) "ordinary" individuals who have scored highly on tests of creative-thinking capacity (i.e., on divergent-thinking tests). As we saw in Chapter 9, one can question the strategy of using performance on divergent-thinking tests, by themselves, as an index of creativity (Brown, 1989; Hocevar & Bachelor, 1989). Performance on divergent-thinking tests is not always a good predictor of creative accomplishments in real life. Therefore, if one is interested in assessing the "creative personality," it seems more prudent to choose creative people through methods such as peer or expert nominations and then have them fill out personality inventories. In this chapter, I will concentrate on studies, as reviewed extensively by Feist (1999), that have examined personality characteristics of individuals who have been designated as creative on the basis of their having achieved success in the arts and sciences.

Studies examining the artistic personality have tested a wide variety of artists, ranging from visual artists (painters, sculptors, and architects), to writers and poets, to performing artists (musicians, singers, dancers, and actors). Some studies also tested art students (Getzels & Csikszentmihalyi, 1976). A criterion for inclusion in Feist's (1999) review was inclusion of a control group of nonartists (for the studies of scientists, the control groups were noncreative scientists). Feist's motivation for choosing studies with different control groups in the arts versus the sciences was based on differences he perceived in the arts versus the sciences as professions. People working as research scientists can carry out their work with differing degrees of creativity but can still maintain careers as scientists. If one then compared more- and less-creative scientists based on their eminence in their fields,

one would have real differences in creativity between the groups, and so one could make meaningful comparisons. For artists, in contrast, one could argue that all practicing artists are creative, so choosing a group of artists who were not well known to use as a control group for comparison with artists of acknowledged creativity would result in two groups that were creative to more or less the same degree, so there might be no important differences between them in personality. This reasoning leads to the necessity of a control group of ordinary nonartists for studies of the artistic personality.

Creative Personality in the Arts and in the Sciences

Table 10.1 presents examples of personality characteristics that typically have been found in creative artists and scientists. As can be seen, there are similarities but also differences in the personality profiles across the two domains. Feist (1999) divided the traits typically found into social versus nonsocial aspects of personality. The results for the artists supported several of the stereotypes that our society holds. First, artists rated themselves as

Table 10.1 Summary of personality characteristics of the creative personality of artists and scientists

Trait category	Artists	Scientists
Nonsocial	Openness to experience Fantasy oriented Imagination Impulsivity Lack of conscientiousness Anxiety Affective illness Emotional sensitivity Drive Ambition	Openness to experience Flexibility of thought Drive Ambition Achievement
Social	Norm doubting Nonconformity Independence Hostility Aloofness Unfriendliness Lack of warmth	Autonomy Introversion Independence Dominance Arrogance Hostility Self-confidence

Source: Feist (1999).

being more open to experience and to fantasy and imagination than did nonartists. Artists also conform less to society's norms and expectations than control individuals, in several ways: They are impulsive; not conscientious; nonconforming; and independent. This set of characteristics fits the "job description" of an artist in our society, which is questioning and rebelling against society's norms. Artists are also driven and ambitious, and are not particularly friendly people. Related to their lack of sociability is their tendency to be introverted. In addition, there is evidence that artists have tendencies toward anxiety and affective illness, as we saw in Chapter 7. As noted in Chapter 7, Ludwig (1998) reported that the rate of mental illness in creative professions varies according to the rational versus emotional basis of an artistic or scientific subfield. Individuals in fields that rely more on emotional or subjective modes of expression show greater rates of psychopathology. In summary, the personality of the artist emerging from those studies is an individual who is imaginative and open to new ideas, driven and anxious, and not social.

Creative scientists, like the artists, rate themselves as open to experience. They are also flexible in their thinking, which fits the idea that creative individuals in the sciences have to go beyond what they know. However, one interesting finding noted by Feist (1999), but not summarized in Table 10.1, is that outstanding science students seem *not* to be flexible in their thinking. So there may be differences between experienced versus beginning scientists on that dimension. That is a very interesting finding, because it raises important questions about cause-and-effect relationships between personality and creative achievement, which will be discussed later in some detail.

The creative scientists, like the artists, are ambitious and driven, and they want to achieve more than their noncreative peers do. These scientists were also arrogant, hostile, dominant, and, perhaps not surprisingly, self-confident. They, like the artists, were not social; rather, they were autonomous, aloof, and independent. To summarize the personalities of the scientists, one sees overall similarities to the artists in the scientists' drive and ambition, as well as in their openness to new ideas and their lack of sociability. It is also notable that different aspects of the scientists' ambition and drive were related to different aspects of their career success. In a study by Helmreich, Spence, Beane, Lucke, and Mathews (1980), scientists who reported that they were motivated to work hard because they enjoyed challenging and difficult tasks—who were intrinsically motivated—had produced many publications, and their work was cited frequently by other scientists. In contrast, those scientists who reported that they enjoyed competing with and bettering others also produced many publications, but

their work was cited less by other scientists. Assuming that the quality of the competitive scientists' work was the same as that of the intrinsically motivated individuals, then the lack of citations may mean that the individual who is driven to be superior to others is ignored because he or she is seen as having a negative impact on the field.

Questions about Method in Studies of the Creative Personality

The results summarized in Table 10.1 are taken from summary tables from the original research studies, and at this point we are not able to discern details of the methods used to collect the data. Sometimes when one goes back to the original studies exploring the relationship between personality characteristics and creativity, one discovers potential problems with method that should at least be thought about before the results are accepted (Brown, 1989). Two potential problems worth discussing here involve questions about significance levels in studies carrying out multiple tests, and, second, the question of the appropriate comparison group to use in studies of the creative personality in science versus art.

Multiple Tests and Significance Levels

When one carries out statistical tests, the inferences one draws concerning the relationships among the variables one is studying depend on, among other things, the level of significance (the probability level, or α [alpha] level) that one chooses. As we all know, most studies use $\alpha = .05$ as the basis for concluding that a significant relationship obtains between two variables, and studies of the creative personality are no different. When you set the probability of rejecting the null hypothesis at a particular α value, you are taking a chance that you will make an error and that you will conclude that a significant difference exists between your groups when it did not; the chance of making such an error (a Type I error) is equal to the α value that you chose for your statistical tests. When one carries out multiple tests, the chance of finding a significant difference is a function of the number of tests that one carries out. That is, the probability of committing a Type I error increases with the number of tests one carries out. So, for example, if one carries out 10 tests, each of which uses $\alpha = .05$, the chance of finding a significant difference by chance alone in one of those tests, even if no differences exist among the groups one is examining (that is, the probability of making a Type I error), is .50.

In order to deal with the possibility of finding significant differences when they do not exist, researchers often use various correction techniques that

adjust the significance level to take into account the number of tests they are planning to carry out. In some studies examining the creative personality, investigators carry out many statistical tests without, as far as one can tell, taking any steps to deal with the possibility of Type I error. I have seen papers in which 50+ tests are carried out and no correction is made. One or two significant findings are reported, and the results are accepted as valid. Thus, some of the findings summarized in Feist (1999) may be spurious, the result of Type I errors due to multiple tests having been carried out. The basic problem with such errors is that it is impossible to know whether they have occurred. One might say that the consistent pattern of results across studies can alleviate qualms about Type I errors, but in response one might question whether, if all the results were collected using flawed methods, an overall pattern should be accepted. We will discuss this issue again shortly, when we consider one specific study of the creative personality.

The Question of the Appropriate Control Group

As noted earlier, many of the studies that have investigated the artistic personality have used a comparison group of ordinary individuals—that is, people who are not engaged in art in any way. Questions can be raised about that choice of control group for studies searching for distinguishing characteristics of artists' personalities. If one compares the personality characteristics of artists who have achieved eminence with those of a control group of ordinary people (i.e., nonartists), the two groups differ in two ways: eminence versus lack of it, and artists versus nonartists. Therefore, any differences in discovered personality characteristics could be the result of either the eminent/noneminent difference or the artist/nonartist difference. One cannot confidently conclude that one has isolated the personality characteristics of eminent (creative) artists using such a design. Although it may be hard to do, if one hopes to isolate the personality characteristics that might contribute to innovation in the arts, one needs to compare the innovative artistic group to a group of noninnovative artists. In his review, Feist (1999) included only results from comparisons with the nonartist control group and ignored any other comparison groups that might have been included in the study, so one can raise questions about any conclusions that are drawn from those studies.

There are two studies that have attempted to include "noncreative" artistic comparison groups, and the results raise interesting questions concerning the creative personality in art. In an early study of the creative personality, MacKinnon (1962) compared the personality characteristics of eminent architects (Architects I), as nominated by professors in schools of architec-

ture, with noncreative architects. There were two control groups, each of which was matched for age, sex, education, and location of practice with the Architects I group: a group of noncreative architects (Architects III), who were obtained from a directory of architects; and a group of noncreative architects each of whom at some point had worked for at least 2 years as an assistant to a member of the eminent group (Architects II). The Architects II group is potentially of significance, because it was composed of architects who had not achieved eminence but had come into contact with those who had. Therefore, comparing their personalities with those of the Architects I group might be especially illuminating, given the foregoing discussion. MacKinnon made an assessment of the eminence of the various groups of architects by determining how many articles had been published by or about each architect in the years preceding the study, and found clear differences among them, with the Architects I group much higher than the other two, who were closer to each other, with the Architects II group in the middle. The architects in the three groups were also rated for creativity by members of the profession, and again clear differences were found.

The results concerning personality revealed first of all that the personalities of the Architects I differed from those of the Architects III group in ways consistent with the results reported by Feist (1999). However, when the eminent architects were compared with their former assistants, the differences in personality were much less. For example, on the 16 scales of the California Personality Inventory, the Architects I and II groups differed on only 1. This result indicates that there were more similarities than differences in the personality structures of the creative architects and their noncreative (or less-creative) former assistants. Such a finding raises questions about differences in personality between more- versus less-creative individuals, at least in that study, and also about the role of personality characteristics in creative accomplishment.

There is one other potentially important point that should be made about the methods used in MacKinnon's (1962) study of the personality characteristics of creative architects. The Architects I group, after being designated, was invited to visit the Institute for Personality Assessment and Research at the University of California at Berkeley for a weekend-long assessment. The staff at the institute gave those architects the tests and also made assessments of their personalities on the basis of their personal interactions with them. The Architects II and III groups were sent a packet of materials and were asked to fill out the various scales at their leisure at home. This difference in procedure had one definite effect: scales that depended on administration by a staff member could not be given to the Architects II

and III groups. More important, perhaps, might those procedural differences have produced differences in the scores on the various scales that all the groups were able to complete? We have no way of knowing, but it is possible that the Architects I might have been affected by several days of interaction with other people whom they knew as being outstanding members of their profession. Thus, one can raise the question of whether this study should be included in reviews of studies of the creative personality, because of those differences in methods. This example is only one of a number that could be cited that raise questions about the methods used in investigations of creative personality (see Brown, 1989, for review).

The study of problem finding in art students by Getzels and Csikszentmihalyi (1976), already discussed in Chapter 9 in the context of the predictive validity of divergent-thinking tests, is also relevant to the question of the role of personality factors in creative achievement. Getzels and Csikszentmihalyi measured the personality characteristics of their participants so they could examine the relationship between those characteristics (as demonstrated in art school) and career success. As you recall, the fine-arts students were followed over the first 7 years of their careers in order to examine if any of the various measures obtained when they were in art school predicted later career success. After 7 years there were already some clear differences in career success among the artists. Some had dropped out of the art world, while at least one artist had had a solo show, and one of his paintings had been purchased by a museum. Getzels and Csikszentmihalyi found, however, that none of the personality characteristics measured in art school predicted career success, which raises questions about the role of the supposed creative personality in creative achievement.

One point to be noted about this negative conclusion is that all the fine-art students, including those who had had no career success, were relatively extreme in personality characteristics when they were tested in art school. It might be possible that the lack of prediction based on the personality characteristics was due to those relatively extreme scores and that if the study had had a wider range of personality scores there might have been a relationship between personality and career success. However, keeping this caution in mind, it is nonetheless true that this study did not find a significant relationship between personality characteristics and creative achievement, and this negative finding is consistent with the lack of strong findings in MacKinnon's (1962) study of architects.

Thus, for the reasons we have seen, questions of several sorts can be raised about the study of the creative personality: both about the methods used and about the weak or nonexistent findings reported by several studies.

A Model of the Role of Creative Personality in Creative Achievement in Science

Let us put aside for the present the questions that can be raised concerning studies of the creative personality, and look further at research that has attempted to specify the relationship between creativity and personality. We have seen that researchers have found that creative individuals in the arts and in the sciences differ from their noncreative or less-creative peers in consistent ways. Those differences are assumed to play an important role in bringing about or paving the way for creative achievement. A study of the relationship between personality characteristics and the creative process was carried out by Feist (1993). He assessed personality characteristics of male scientists of differing levels of creative achievement and developed a model to summarize the relationship between personality and creative success. Feist contacted 205 scientific researchers—physicists, chemists, and biologists—at first-rank university campuses in California, asking them to participate in an examination of the relationship between personality characteristics and creative achievement in science. Of the 205, approximately half agreed to participate, which is a high number for studies of this sort.

The participants were interviewed and were also asked to fill out personality questionnaires. In addition, Feist's (1993) research assistants listened to transcripts of the interviews and rated the personalities of the scientists on a standard personality measure. A number of measures of creativity were also used. First, each scientist who participated in the study was asked to rate the work of each of the other scientists in his or her discipline on its historical significance and its creativity, assuming that the scientist was familiar with the other person's work. In addition, two objective measures of creative productivity were used: (1) how many publications the person had produced, and (2) how many times the person's work had been cited by others. Presumably, if other people refer often to a person's work, they view that work as creative and valuable.

The findings of the study are summarized in Figure 10.1. It turned out that the ratings of historical significance and creativity were very similar for each scientist, so the two ratings were summed to produce a single score of the person's *eminence*; an eminent scientist is one who is considered important by other members of the field. A high rating in eminence was related to several factors, including high productivity (see the arrow from productivity to eminence in Figure 10.1). This leads to the question of what factors were related to productivity. The productivity of the scientists was related to two aspects of their personalities. First, the most productive scientists had what Feist called an *arrogant working style*: They were

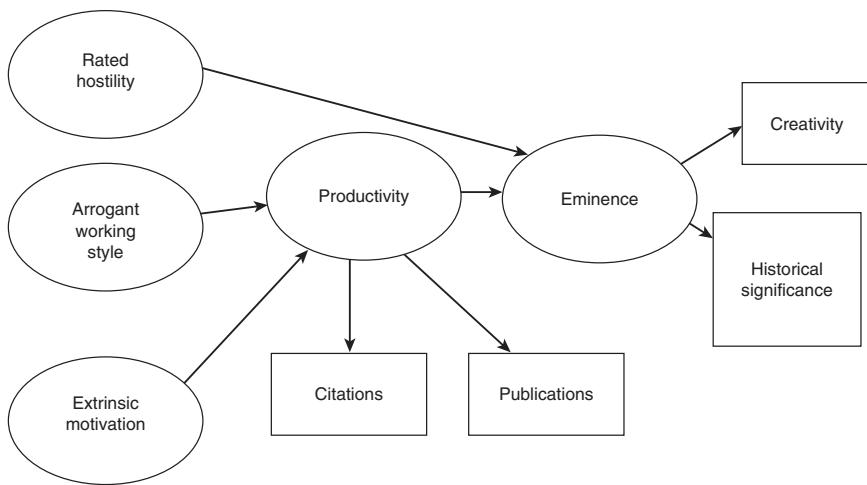


Figure 10.1 Feist's model of scientific eminence

Source: Adapted from Feist (1993, Fig. 1).

vain and competitive, and they did not want others to set goals for them. Productivity was also related to the scientists' being *intrinsically motivated* in their work: The more productive scientists were more likely to say that they worked not because of external rewards (fame, money, prizes, etc.) but because they gained pleasure from work (see also the discussion in the next chapter of Amabile's [1996] model of creativity). As is also shown in Figure 10.1, the eminent creative scientists were rated on the basis of the interviews as being more hostile.

To summarize, Feist's model paints the following picture of the factors that are related to eminence in science: (1) being productive, (2) being intrinsically motivated, (3) being competitive, and (4) setting one's own goals. The next question is how we interpret those findings. Feist assumes that the personality characteristics of the scientists are causally related to their creative achievement. An individual's possessing certain personality characteristics is assumed to make it more likely that he or she will produce creative work. So, for example, being flexible in thinking is assumed to contribute to the production of creative ideas (based, once again, on the divergent-thinking, remote-associates view of creative thinking). However, determining whether personality characteristics play a causal role in creative accomplishment is a difficult task, as will be demonstrated in the next section.

The Question of Personality as a Cause of Creativity

One of the reasons for researchers' interest in specifying the personality characteristics of creative individuals is because it is assumed that those

characteristics are causally related to creative accomplishment. That is, it is assumed that the personality characteristics that distinguish eminent creative scientists from their less-creative colleagues have played a role in making those scientists creative. Feist's (1993) model, presented in Figure 10.1, assumes a causal connection between personality characteristics and creative productivity (and therefore between personality characteristics and eminence, assuming that eminence is a result of creative accomplishment in the field). If we were to interpret Feist's model from this perspective, for example, we would conclude that having an arrogant working style helped or played a role in the scientists' achieving eminence. At the risk of oversimplification, Feist's results tell us to advise young people to become arrogant—if they are not arrogant already—if they hope to become great scientists.

Correlation versus Causation in the Study of the Creative Personality

However, there is a basic difficulty in assuming a causal connection between personality characteristics and creative achievement from the studies summarized in Table 10.1, and from Feist's (1993) study that produced the model in Figure 10.1: Those studies are *correlational* studies—that is, they have not manipulated any variables but only report relationships among variables that they measured—and correlational studies do not allow one to make inferences about cause-and-effect relations between variables. What those studies tell us is simply that variable X goes with variable Y; that is, higher levels of creative achievement in science (or in the arts) are associated with—go with—certain personality characteristics. However, simply demonstrating a correlational relationship does not tell us which, if either, of the two variables in the relationship is the cause and which is the effect. Although it might seem reasonable to assume that the personality characteristics were critical in bringing about the differing levels of creative achievement in the various groups, it is equally possible from a logical and statistical point of view that the opposite relationship holds.

For example, while it may seem reasonable to conclude from Feist's model that the creative scientists that he studied became eminent because of their arrogant working style, it is just as reasonable on logical grounds to conclude the exact opposite: that they developed an arrogant working style because they saw themselves as successful. They might have learned that their ideas were usually better than other people's, and that might have led them to be dismissive of others and of their ideas. Thus, perhaps the differences in creative achievement were the cause of the differences in personality. Furthermore, it is also possible that both eminence and the personality characteristics were the result of some third variable, and that

- A. Personality influences creativity**
Arrogant working style \Rightarrow creativity and eminence
- B. Being creative influences personality**
Creativity and eminence \Rightarrow arrogant working style
- C. Some other factor influences both creativity and personality, which are not directly related**

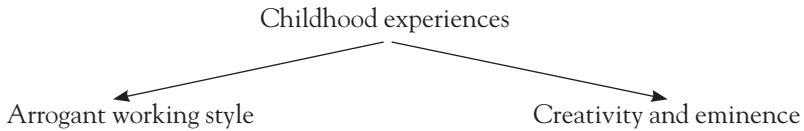


Figure 10.2 Possible relationships between personality and creativity

eminence and personality are not related directly at all. As an example, perhaps certain experiences in childhood affect independently both one's personality and one's creative capacity. In such a scenario, there would be no direct connection between personality and eminence; the correlation would be brought about as the result of the effects on both of childhood experiences. Thus, finding a correlational relationship between personality characteristics and creative achievement could mean one of three things, as outlined in Figure 10.2.

Similar possibilities of multiple interpretations exist regarding Feist's (1993) finding that eminent (creative) scientists are seen as being hostile. First, being hostile might lead one to become eminent, which would mean that the personality factor is the cause of eminence. However, the reverse could just as well be true: Perhaps being eminent leads one to hostility. For example, as one becomes known in one's field, one might become concerned that one's work is being criticized and undermined by others, which might make one hostile. Still another possibility is that there is no causal relationship between hostility and eminence. Perhaps people who suffered some trauma early in life tend to grow up hostile *and* creative. In this hypothetical case there is no causal link between hostility and creativity, even though the two are correlated.

Establishing Personality as a Cause of Creativity: The Logic of Cause and Effect

As long as we simply examine correlational relationships, we are unable to establish causal links between the variables in which we are interested—in this case, between personality characteristics and creativity. As noted by

Feist (1999), in order to establish a causal link between two variables, one must demonstrate the following (Rosenthal & Rosnow, 1991). First, the two variables must go together; they must be correlated. Second, there must be *temporal precedence of cause versus effect*; the proposed cause must come before the effect. Third, in order to conclude that A causes B, we must be able to *rule out all other possible causes* of B. Let us examine how well studies of the creative personality meet those three criteria.

Correlation of Personality Characteristics and Creative Achievement

The first criterion in establishing causation is that the two variables that one believes are causally related must be correlated: Cause must be found where effect occurs. If the two variables are never found together, then one cannot be the cause of the other. Let us say that I want to test the hypothesis that liking tuna fish increases creative achievement. I measure the food preferences of a large group of scientists who are rated as highly creative and also those of a comparison group of less-creative scientists. The results of my study indicate that the creative group does not like tuna fish any more than the comparison group does. Since the hypothesized cause (liking tuna fish) and the hypothesized effect (increased creativity) have not been found to go together (I have not found them to be correlated), liking tuna fish cannot be the cause of the increased creativity in the scientists I tested. Thus, demonstrating a correlation between two variables is a necessary first condition for establishing a causal relation between them. The requirement that cause and effect go together is met by the studies in Feist's review (Feist, 1999; see also Barron & Harrington, 1981). We have seen that certain personality characteristics are associated consistently with artistic success, and a partially overlapping set of personality characteristics is associated with scientific success.

Temporal Precedence of Cause versus Effect

If A is the cause of B, then not only must A and B go together, but the two must occur in a specific order in time: A must occur *before* B; there must be temporal precedence of cause versus effect. So, in order to show that some personality characteristics had a causal role in determining creative achievement, one would have to show that those personality characteristics were in place *before* the individual embarked on his or her career. That is, one must carry out a *prospective* or *longitudinal* study, in which one examines relationships among variables over time. If one can establish that one variable was present before another, then one has gone beyond simple correlations and progressed one step further toward establishing causality between the variables in question.

The requirement that the proposed cause must precede the effect is not met by the studies cited by Feist (1999). None of those studies were prospective studies, so we cannot conclude that the personality characteristics were present before the creative individuals achieved their success. As an example of this problem, consider again Feist's (1993) study of the personality characteristics of eminent scientists (see Figure 10.1). Feist concluded that, among other things, an arrogant working style contributed to their achieving eminence. However, the personality measurements were obtained from the already-mature scientists, that is, after they had achieved eminence. Therefore, we do not know if their arrogant working style is the cause or effect of their eminence, or whether the arrogant working style and eminence might both be results of some other cause.

As noted earlier, in order to determine the causal links among personality characteristics and creative performance, one has to carry out a prospective or longitudinal study, in which one begins with young people, before they are eminent scientists (Feist, 1999). One would measure the personality characteristics of those people and then follow them *over the course of their lives* to see who produces outstanding creative work. One could then go back and look at the personality characteristics that the creative individuals possessed when they were just beginning, and compare them with the characteristics of the young people who did not go on to outstanding creative achievement. Assuming that one found consistent differences in early personality characteristics between the people who turn out to be creative versus the noncreative individuals, it would support the idea that the characteristics that were found earlier only in the creative group played a role in their developing into creative individuals. Since Feist's (1993) study was not longitudinal, the results, as he notes, do not allow us to draw any conclusions concerning the causal role of personality in creativity. Almost all of the numerous studies carried out on the creative personality are not longitudinal, so their results tell us nothing about causality. In addition, those few studies that have looked over time at the relationship between personality characteristics and creativity (e.g., Feist & Barron, 2003; Helson, 1999) have typically not begun with very young people and followed them over their development into possibly creative adults. In those studies the data collection began when the participants were in college, or even later. By that time in most people's lives it is likely that they are already set on the creative/noncreative path, so it is too late to determine the personality characteristics that preceded creativity.

One study that measured personality characteristics and did follow individuals longitudinally was the problem-finding study of art students by Getzels and Csikszentmihalyi (1976), which has already been discussed several times. As noted, the researchers measured the personality character-

istics of art students when they entered art school, before any of them had a chance to establish creative achievements as artists, and then followed them through the early years of their careers, when some established reputations as creative artists and others did not. Geztels and Csikszentmihalyi then examined the personality profiles obtained years before, to see if there were any characteristics that the more creative group possessed that the less-creative group did not, and they found that there were essentially no personality characteristics measured early in art school that predicted later creative success. A second piece of evidence, mentioned earlier, that raises questions about a causal relationship between personality and creative achievement is the finding noted by Feist (1999) that successful science students are less flexible than are successful scientists (Davids, 1968; Smithers & Batcock, 1970). If one can assume that those students will become successful scientists, that finding indicates that flexibility might be a result of the process of developing as a mature successful scientist, rather than a causal factor in bringing about that success.

A related finding concerning the question of cause versus effect of personality characteristics of scientists was reported by Dunbar (1995), who carried out an intensive investigation of the creative process in scientific research by studying activities in several world-class microbiology laboratories. Dunbar was taken into the laboratory communities, attended laboratory meetings, and met and talked with the scientists in each laboratory about their ongoing research. In the present context, one interesting discovery from his studies is that when scientists were faced with experimental results that did not fit their hypotheses, older scientists were more likely to accept the results and modify or discard their hypotheses than were younger scientists. The latter were more likely to assume that the unexpected data were due to experimental error and so could be ignored; the original hypothesis could then be maintained unchanged.

Dunbar noted that the more experienced scientists explained their tendency to drop or modify a hypothesis in the face of conflicting data as being the result of their predictions having been wrong many times before. The senior scientists learned to be flexible through their experiences with being wrong. The younger investigators, who had not yet learned that they would often be wrong, assumed that their hypothesis was correct and the data were wrong. This finding can be taken as further evidence that young scientists' personalities may change significantly as they progress through their careers, and the personality characteristics of the mature scientist might not be the same as those that he or she possessed as a beginner in the enterprise.

Thus, for reasons we have seen, one cannot take for granted that the personality characteristics of the mature individual must have always been

that way and therefore must have preceded and contributed to his or her creative achievement. Given the lack of prospective studies in Feist's (1999) analysis, one can raise questions about any cause-and-effect conclusions concerning personality characteristics and creative accomplishment. The logic of those cause-and-effect conclusions may appear reasonable; that is, it may seem reasonable that personality characteristics play a role in causing creative achievement. However, correlational results do not support such conclusions. There is one more component to establishing cause and effect, to which we now turn.

Eliminating Other Possible Causes

If we are to conclude that A is the cause of B, we must be able to rule out all other possible causes for B. We must be able to point to A alone as the possible cause of B. Even if it were found that creative adults possessed some unique set of personality characteristics when they were children, one still could not conclude that those characteristics played a part in causing the adult creativity. In order to establish Factor A as the cause of Behavior B, not only must A be present before B occurs, but the presence of A must be the only possible cause of B—all other possible causes must be eliminated. For example, even if we found that creative adults were hostile as children, that might not mean that early hostility was the cause of adult creativity. Once again, perhaps early childhood trauma made the individuals both hostile in childhood and creative as adults. One way to eliminate other possible causes is to carry out an experimental study, with relatively large groups of participants randomly assigned to experimental and control conditions. In that way you can be confident that the two groups are identical on all variables except the variable that you are hoping to establish as the cause of some behavior.

The criterion that an experimental manipulation be carried out is also not met by the studies reviewed by Feist (1999). That criterion is very difficult to satisfy in this context, of course, since one cannot carry out an experimental study to examine personality characteristics. We cannot randomly assign personality characteristics to people; people bring personality characteristics with them into the laboratory. For ethical as well as practical reasons, an experimenter cannot randomly select a group of young people and turn them into hostile individuals, say, to see if they become creative as adults and compare them with another randomly chosen group not given hostile personalities. On the other hand, it might be possible to make people more open to experience through some sort of intervention, which might lead to increases in creative achievement. It may not be impossible to carry out experimental manipulations of personality, just difficult. However, at present there are to my knowledge no studies available that meet this criterion.

Personality and Creativity: Conclusions

This discussion has made clear that specifying the “creative personality” and its role in creative achievement turns out to be a very difficult research enterprise. At this time, as Feist (1999) notes, we can do little more than speculate about the personal characteristics, if any, that will contribute to a person’s becoming successful in a creative field. On a positive note, numerous studies have found that certain personality characteristics are related to creative achievement in the arts and sciences. However, interpreting that relationship is difficult for several reasons. First of all, there are weaknesses in method in some of those studies. Second, very few studies have examined prospectively the relationship between personality characteristics and creative achievement, and the limited results available indicate that personality characteristics may change as an individual develops in a creative career, which raises questions about the contributory role of adult personality characteristics. Finally, there is the difficulty if not the impossibility of carrying out experimental manipulations of personality variables, which limits the causal conclusions that one can draw from studies of the creative personality.

Is It Futile to Search for The Creative Personality in the Arts and the Sciences?

A basic assumption underlying the research reviewed in this chapter is that there is a single set of psychological characteristics that we could call “the creative personality” that is waiting to be discovered (or perhaps two creative personalities: one in the arts and one in science). However, a number of researchers have raised questions concerning whether such a simple situation should be expected (Abuhamdeh & Csikszentmihalyi, 2004; Helson, 1999; Ludwig, 1998). When one examines the numerous and diverse environments in which artistic or scientific creativity can be expressed, it seems unlikely that a single set of personality characteristics, or even two overlapping sets of characteristics, will be relevant to all of them. As one example of this diversity, consider an architect, who must exhibit his or her creativity within constraints set by a client, restrictions set by construction materials, and regulations set by governments. Surely the personality characteristics needed to succeed in such an environment are different from those that would be important in a painter who spends time in isolation before an empty or partially completed canvas, trying to bring to realization a new work of which he or she has only a glimmer of an idea and which may have nothing to do with the representation of external reality. In both of those hypothetical cases, artistic creativity may be expressed, but surely the people involved would be very different

psychologically. One might also expect that, even within the domain of painting, different personality characteristics are involved in the creation of Mondrian's precise, nonrepresentational, geometrically based abstractions versus Pollock's poured paintings, also nonrepresentational, but built out of swirling streams of paint.

As discussed in Chapter 7, Ludwig (1998) has reported that aspects of psychopathology differed within subdomains of the sciences and the arts according to the rationality involved in the domain. Although Ludwig was concerned with psychopathology, it seems reasonable that his conclusions would be more broadly relevant and would lead to the expectation that non-pathological personality characteristics would also vary across subdomains in the arts and in the sciences. Further support for this view can be seen in Sass's (2000–2001) discussion in Chapter 7 concerning the schizotypal personality and artistic creativity. Sass has proposed that people with that personality, who are typically aloof, nonsocial, slightly eccentric, and unemotional, will be drawn to postmodern art, with its ironic slant on modern society. In this view, the "artistic personality" will change as the dominant artistic style changes, because the stylistic changes may result in different types of people being drawn to an area of creative activity. From this perspective, the conclusions from one time period concerning the artistic personality will not necessarily transfer to another period. A similar conclusion can be drawn from a historical study of changes in the status and societal position of artists in Western culture (Becker, 2000–2001). Until the Renaissance, the artist was looked upon more or less as a skilled craftsman and was not expected to produce works of originality or question society's values. The Renaissance job description would probably draw a different type of person from those who are attracted to the arts today, when the artist is expected to produce original works and be a rebel.

Thus, even if we put aside for the present the difficulty in determining cause-and-effect relationships between personality characteristics and creative achievement, there is still the question of whether the search for "*the* creative personality" (or the *two* creative personalities, one in the arts and the other in science) is a misdirected one. Gruber (1981) has proposed that each creative person is unique and that there is no single personality configuration, or small set of such configurations, that describes the creative personality. That claim may be a bit strong; probably the personalities of creative people are not as diverse as are creative people themselves—that is, there probably is not a unique personality configuration for each creative person. However, there is reason to believe that there are at the very least numerous creative personalities, and it is probably true that even people working within the same subfield of the arts or the sciences can approach their work from very

different perspectives, meaning that their personalities would probably be different. Therefore, looking for simple relationships between personality characteristics and creative achievement may be a fruitless task.

Creativity and the Need to Be Original: A Reexamination of Divergent Thinking and Creativity

In Chapter 9, questions were raised about the relationship between divergent thinking and creative thinking, and it was concluded that divergent thinking might not be a component of creative thinking. That left us with the question of why a positive correlation is sometimes found between performance on divergent-thinking tests and creative productivity (see review in Chapter 9). One possibility is that divergent thinking and creative productivity are the products of a common cause. If so, it might be possible to explain a positive relationship between divergent-thinking performance and creative achievement without assuming that the former is a critical skill underlying the latter. Recent work in personality theory by Joy (e.g., 2004) may allow us to do that. Joy has recently proposed that people differ in the *need to be different*, and this personality characteristic affects their behavior in all situations, including those in which creativity is possible.

Joy (2004) proposes that the need to be different arises from people's experiences with receiving rewards for producing novel behavior versus replicating or staying close to things done or advocated by others. To the degree that a person has had a wide range of experiences in which he or she has been rewarded for not conforming to what others have done, there will be a tendency for that person to approach new situations with novel behaviors. This tendency might be seen in an overall bohemian or nonconforming approach to life, as well as in specific responses to situations in which varying degrees of novelty are possible, as when someone is faced with a divergent-thinking test. From this perspective, one reason that some people produce novel—"divergent"—outcomes on divergent-thinking tests might be that they want to be different. Joy (2004) has developed a scale to measure this hypothesized need, consisting of pairs of adjectives, some of which are shown in Table 10.2. For each pair, individuals are asked to choose the description that they would value more if it were to be applied to themselves, assuming that both were possible. This scale has been shown to be reliable.

In several further studies, Joy (2004) has examined correlates of the need to be different. In one study, it was shown that scores on the need-to-be-different scale correlate with peer ratings. Participants were given two descriptions of people, one of whom was middle-of-the-road in opinions, appearance, relationships, and so forth, and the other of whom was described

Table 10.2 Need-to-be-different scale

In each pair, choose the word that you <i>value more highly</i> . That is, in each pair, choose the word that labels how you would rather be.	
1. productive	creative*
2. ambitious	original*
3. misfit*	uninteresting
4. congenial	independent*
5. individualistic*	cooperative
6. inconsistent*	unimaginative
7. interesting*	responsible
8. nonconforming*	disciplined

Source: Adapted from Joy (2004).

Note: Items with asterisk indicate need to be different.

as different from others in dress, in musical and artistic tastes, in suggesting new and unexpected ideas, and so on, and were asked to place their peers in one category or the other. People who rated themselves as high on the need to be different were more frequently chosen by their peers as fitting the “nonconforming” description. The opposite was true for people who scored low on the need to be different. Need to be different was also found to be positively correlated with the personality characteristic of openness to experience, which was mentioned in the context of the artistic and scientific personalities and will be discussed in more detail in the next section.

The importance of the need to be different in the present context is that it is correlated with divergent-thinking scores, as well as with ratings of creativity of drawings produced by people. Joy (2004) examined several divergent-thinking measures, including word associations, unusual uses, and items that ask the individual to predict what would happen if certain changes in society came about, such as conquest of disease or elimination of prisons in favor of a system restitution for victims (Wilson, Guilford, & Christenson, 1953). The various divergent-thinking scores and the creativity ratings for the drawings were all correlated with ratings on the need-to-be-different scale. Those results have implications for the understanding of the relationship between divergent thinking and creativity. As noted earlier, the evidence is mixed concerning the criterion and predictive validity of divergent-thinking tests as measures of creative potential. However, even if it is ultimately agreed by researchers that those tests are useful as predictors of creative achievement, that leaves us with the question of why that connection might obtain.

The basic assumption behind the development and use of the divergent-

thinking tests as measures of creative-thinking potential is that divergent thinking is a component of the creative-thinking process. As we have seen, that assumption can be challenged, based on the results from the case studies and experimental studies (Fleck & Weisberg, 2004, 2006). If divergent thinking is not a component of the creative process, that raises the possibility that both creative achievement and divergent thinking are the result of a common cause, and that is where the need to be different becomes relevant: Perhaps creative achievement and creativity-test performance are correlated because both are related to the need to be different. That is, a person high in the need to be different will tend to produce novel responses on divergent-thinking tests and will also tend toward creative accomplishments in his or her life's work, but, contrary to the assumptions of Guilford and those who follow his theorizing, the two scores are not directly related in a cause-effect manner. This take on the relationship between divergent thinking and creativity assumes that the person's need to be different shapes how he or she approaches the divergent-thinking task (as well as how he or she approaches life tasks), and therefore divergent thinking is not to be looked upon as some basic skill that underlies creative thinking.

Personality, Cognition, and Creativity Reconsidered: The Question of Openness to Experience and Creativity

The results discussed so far provide at best weak support for the view that there is a close relation between personality and creativity. However, there is a stream of research that brings together ideas from a wide range of areas and presents a coherent picture of the relationship between personality and creative process that is at odds with that negative conclusion. This alternative picture provides an impressive integration of a broad range of experimental findings, and makes some unexpected connections across areas that might have been thought to be unrelated. This work is worth discussing in some detail, because it has captured the interest of a number of researchers and because it holds out the promise of bringing together a wide range of research.

The analysis centers on the personality trait of *openness to experience*, which we have already informally come into contact with in the discussion of the personality traits typically found in creative scientists and artists (see Table 10.1). That trait is one of five personality traits that have been emphasized in recent years through the development of the Five-Factor model (or “Big Five” model) of personality (Costa & McRae, 1985; see Table 10.3). Several studies have demonstrated that openness to experience is related to creativity in both artists and scientists, as we have seen

Table 10.3 Five-Factor model of personality

Trait	Examples of relevant items
Neuroticism+	Anxious, defensive, depressed, emotional, excitable, guilt-prone, insecure, worrying
Neuroticism-	Adjusted, calm, conforming, good impression, guilt free, stable
Extraversion+	Achieving, active, talkative, outgoing, social
Extraversion-	
Openness to experience+	Original, curious, comes up with good ideas
Openness to experience-	Has few artistic interests
Agreeableness+	Likes to be helpful; kind
Agreeableness-	Finds fault with others
Conscientiousness+	Does a thorough job; perseveres
Conscientiousness-	Can be careless

Note: “+” designates items positively responded to; “–” designates items on each scale *less frequently* checked by high scorers.

in the discussion earlier in this chapter (Feist, 1999). A person open to experience tends to check descriptive items such as “original, comes up with good ideas” and “curious” as being self-referential, while checking “has few artistic interests” *less frequently* than average. Given the content of those items, one might conclude that it is not surprising that one finds that openness to experience is related to creativity. Studies examining the possible relationship between openness to experience and creativity have found positive connections between that personality trait and numbers and ratings of creative achievements, as well as between openness and scores in divergent-thinking tests (e.g., King, Walker, & Broyles, 1996).

Costa and McCrae (1985) made distinctions among several different kinds of openness, depending on the type of experience that was the focus.

- Openness to *fantasy* refers to a willingness to explore one’s inner world and to let one’s mind wander.
- Openness to *aesthetics* refers to an appreciation for artistic expression.
- Openness to *feelings* involves a willingness to accept one’s emotions, both positive and negative.

- Openness to *actions* refers to willingness to try new activities.
- Openness to *ideas* is intellectual curiosity and willingness to consider new ideas.
- Openness to *values* refers to a willingness to examine the fundamental values on which one bases one's life.

The more interesting aspect of the research goes beyond simply examining the relationship between personality variables and creativity ratings, and involves the relationship between openness, creativity ratings, and cognitive processes. As we have seen, it has been proposed by numerous researchers, beginning with Poincaré (1913) and leading to the present (e.g., Feist, 1993; Koestler, 1964; Martindale, 1989, 1995; Mednick, 1962; Simonton, 1988, 1999), that creative individuals are able to produce novel ideas because they are able to make connections among ideas that are not made by noncreative individuals. One of the many examples of this view that we have discussed is Mednick's (1962) concept of the flat associative hierarchy of the creative individual and the steep hierarchy of the noncreative. Related to this notion of associative structure, it has also been hypothesized that the creative individual is able to spread his or her attention more widely over ideas, so that more ideas in memory can be activated at the same time (Martindale, 1989). This *spread of activation* would make it more likely that two heretofore unrelated ideas would come into contact—through being activated at the same time—which might result in a new synthesis. This is one way to understand Mednick's flat hierarchies: as the result of broadening of attention.

Taking this logic one step further, it has been hypothesized that creative individuals might also be able to spread their attention more widely when dealing with external stimuli, and therefore would be sensitive to a wider range of stimuli (Martindale, 1989, 1995). This wide range of sensitivity might allow a wider range of external stimuli to come into contact with whatever the person is thinking about at a given time, which might also increase the chances of a novel combination of ideas being developed. If the person is thinking about a problem, for example, the solution to the problem might be stimulated by an external event. The creative individual, with a wider spread of attention to external events, might be open to an influence from that event; the noncreative thinker, in contrast, with a narrow focus of attention, might not even be aware of the potentially relevant event.

Those ideas have been subjected to empirical testing in several ways. One series of studies (e.g., Peterson, Smith, & Carson, 2002) has focused on the phenomenon of *latent inhibition*, which is outlined in Table 10.4. Latent inhibition is seen when a stimulus previously ignored in one situ-

Table 10.4 Outline of latent inhibition task

Phase 1: Person hears a long list of nonsense syllables (30 syllables repeated 5 times) and is told to keep track of how many times one of those syllables (e.g., BIM) appears. At the same time, occasional bursts of white noise are heard in the background. Nothing is said about the white noise. White noise occurs approximately 20 percent of the time.

Syllables (person's count)	White noise
WUG	
DIF	XXX
BIM (1)	
FIP	
JUR	
GUJ	XXX
BIM (2)	
KIP	
PUZ	
RUW	
QOB	XXX
LUR	
WAZ	
BIM (3)	
.	
.	XXX
.	
MUR	

Phase 2: Nonsense syllable/noise tape played again. This time there are yellow disks presented on a screen. Appearance of the disks coincides with the white noise. Person's task is to determine which auditory stimulus signaled the appearance of the disks. The dependent measure is how long it takes the person to determine that the white noise signals the appearance of the disks.

Example results	
Experimental condition	Number of syllables to solution
Control (only goes through Phase 2)	10
Latent inhibition (Phase 1 followed by Phase 2)	30

ation becomes relevant in a new situation. Learning to respond to that stimulus takes longer than learning to respond to a stimulus that has not been previously ignored. That result indicates that processing of the previously ignored stimulus was inhibited, or interfered with, during the initial phase of the experiment. The inhibition is *latent*, or hidden, because it is not seen until the situation is changed so that the previously ignored stimulus becomes relevant. Latent inhibition has been taken as evidence that focusing attention on one object rather than another is an active process, which requires that the to-be-ignored object be actively pushed out of attention. The processes involved are assumed to assist in the individual's dealing most efficiently with relevant versus irrelevant stimuli in the world. That is, when a stimulus in the past has been irrelevant to our ongoing activities, our processing systems are constructed so that less attention will be allocated to it in the future.

The relationship between latent inhibition and creativity comes from the hypothesis that creative individuals are more open to external stimuli. That is, if creation of new ideas involves connecting ideas that might originally seem far apart psychologically, then the process of focusing attention might be inimical to creative thinking, because focusing might limit the breadth and number of stimuli that are potentially available for combination. If that is so, it might mean that more-creative individuals, who are more able to allocate their attention over a wide range of stimuli, are less likely to carry out active inhibition of irrelevant stimuli when attending to some stimulus that is relevant to the task they are currently carrying out. Thus, more-creative individuals might be less likely to show latent inhibition than would less-creative people: More-creative individuals, when placed in the situation outlined in Table 10.4, should learn to respond to the previously irrelevant but now relevant stimulus more quickly than do noncreatives. At its most extreme, creative individuals might learn to respond to the previously ignored stimulus as quickly as to a new one that had not been previously ignored. Predictions of this sort have been upheld: Undergraduates designated as more creative as the result of their reports on creative-achievement checklists demonstrate less latent inhibition in situations like that in Table 10.4. In addition, people who are designated as open to experience also show less latent inhibition and are also found to be more creative, which closes the circle (Peterson et al., 2002).

Eysenck's Theory: Psychoticism and Creativity

Eysenck (e.g., 1993, 1995) has proposed a theory of creativity closely related to the ideas just outlined, based on the idea that creative persons

are more likely to possess a certain cluster of personality characteristics, including the following: aggressive, emotionally cold, egocentric, impersonal, impulsive, antisocial, and without empathy. The basis for this cluster of personality characteristics is the trait of *psychoticism*, an inherited tendency toward the development of psychopathology as a result of exposure to, among other things, situations of high stress. It must be emphasized that the person who is high on psychoticism is not suffering from psychopathology; he or she is within the normal range of behavior, although such a person may impress an observer as being odd or eccentric. There is in such a person an underlying tendency to *develop* psychopathology, but he or she is not suffering from mental illness. The critical component of Eysenck's theory is that psychoticism not only predisposes an individual to development of psychopathology, it also provides a basis for creativity. The person high in psychoticism has a wide horizon of responding to situations, much like Mednick's (1962) flat associative hierarchies, which results in that person's producing unusual responses to situations. This, in Eysenck's view, provides the foundation for creative ideas.

Eysenck brings forth different sorts of evidence (1993, 1995) in support of this view. First, the links that we have discussed in Chapter 7 between genius and madness are consistent with the psychoticism theory, since, as we have seen, high levels of creative achievement have been found in the normal relatives of people suffering from psychopathology. Such a conclusion is consistent with the notion that the genetic tendency toward psychopathology is related to creativity. In addition, studies we have reviewed earlier in this chapter have indicated that creative individuals often show personality characteristics associated with psychoticism, such as introversion and emotional coldness. Finally, studies have indicated that people who score high on a psychoticism scale that Eysenck developed also provide unusual responses on a word-association test (Eysenck, 1993). This result supports Eysenck's notion that psychoticism is related to a wide horizon of responding and breaking away from usual responses. Eysenck assumes that this breaking away from the usual responses is critical to the production of creative ideas. Eysenck proposes overinclusive or "allusive" thinking, one of the characteristics of thinking in psychopathology, as the basis for creative thinking. He also posits attentional deficits and a lack of latent inhibition as characteristics of thinking in psychopathology as well as in creativity. Thus, Eysenck's theory is another variant on the view just outlined that assumes that creative thinking depends on breaking away from the past, and that the looseness of the thought processes in people high in psychoticism is able to support such processes.

Openness to Experience and Creativity: Summary and Critique

This stream of research built on the remote-association view of creativity ties together an impressive array of findings, some of which are the result of unexpected predictions coming from the theory. Martindale (1989) presents a stimulating review of a wider range of research that links creativity to cognitive and personality traits related to primary-process thinking (see Chapter 7) as well as to attentional and inhibitory processes. It should be noted, however, that questions can be raised about this research. First of all, one can raise the question of whether postulating openness to experience as an explanation of creativity adds anything to our understanding of creativity. As presented earlier (see also Table 10.3), many of the items on the openness scale seem to be asking about creative experiences and accomplishments, although perhaps in a somewhat indirect way. It may not be surprising—or particularly informative—to find that a person who checks “is original, comes up with new ideas” and does not check “has few artistic interests” also reports having produced more creative accomplishments than average, assuming that the person is reasonably accurate in assessing his or her own characteristics and accomplishments. Martindale has noted that the items on the openness scale are almost synonymous with creativity, so it is not surprising that openness correlates with creative production.

In response to such challenges to the usefulness of the openness scale as an independent assessment of creativity (another example of the question of discriminant validity), King and colleagues (1996) have attempted to show that openness is more than simply another way of saying “I am creative.” King and colleagues concluded that openness and creativity are not identical, because the relationship between openness and creativity is not uniform, which implies that the two are not the same. King and colleagues found that creative achievement is seen in people high in openness only when they are also high in creative-thinking potential, as measured by divergent-thinking tests. Since people high in openness but low in divergent thinking are not high in creative achievement, it seems that openness and creativity are not identical, although they may overlap.

A different set of questions about the latent-inhibition research and the underlying remote-associates theory of creativity comes from some of the findings concerning creative thinking presented earlier in this book and reviewed earlier in this chapter. Most important, as I have noted before, we have seen evidence from case studies (see Chapters 1 and 5), as well as from laboratory research (see Chapter 6; see also Fleck & Weisberg, 2004, 2006), that the creative process does not work by associating remote ideas. In examining Picasso’s creation of *Guernica*, Watson and Crick’s discovery of the double helix of DNA, the Wright brothers’ invention of the airplane,

and Edison's invention of the electric light, as well as undergraduates' solutions to insight problems of several sorts, we have not found evidence that the thinker works by initially developing ideas based on remote associative connections. Rather, the process works in a top-down manner, in which knowledge works to direct the thinker to potentially relevant ideas based on the structure of what the person knows about the situation he or she is facing. If that conclusion is valid, it raises the question of how we are to understand the results that demonstrate a negative relationship between creativity and latent inhibition. Assuming that the latent-inhibition and creativity results just presented are valid, then we are left with a set of results that lacks an overriding theoretical explanation. On the other hand, if one assumes (contrary to the results from the case studies, etc.) that the creative process works through the bringing together of remote ideas, the results make sense. We thus seem to be at an impasse.

One way out of this impasse is the possibility that the results from the case studies are not valid and that the conclusions I have drawn from them concerning the creative process are therefore incorrect. One possible objection to the case studies as data relevant to the creative process is that the kinds of information they are based on—artists' early sketches and sketchbooks, scientists' and inventors' laboratory notebooks—might be produced relatively far into the creative process, and so tell us little about how the process actually works. When an artist fills a sketchbook with sketches, for example, he or she may have already made most of the decisions concerning the work to which the sketches are related. Therefore, those sketches might not be as close to the beginning of the creative process as I assumed earlier. Perhaps the more free-associative or primary-process components of the creative process have already taken place before an artist or scientist sets anything down on paper (perhaps before he or she even experiences any ideas at all at a conscious level). That conclusion would mean that the study results that demonstrate a relationship between openness, creativity, and latent inhibition could be taken as supporting a wide-ranging theory linking the creative personality and creative thinking. At this point, there is no way to determine whether the case studies are valid as descriptions of the creative process, although I obviously believe that they provide useful information concerning creative thinking. Thus, each person is free to make his or her own choice between theoretical points of view.

Divergent Thinking and the Creative Personality: Conclusions

The psychometric stream of research on creativity—examining divergent thinking and assessing the creative personality—has produced hundreds of

studies over the past 50 years (for reviews, see in Runco, 1991, and Sternberg, 1999). The psychometric viewpoint has thus been valuable in stimulating much research. In addition, Guilford's assumption that the capacity for creative thinking is present in all of us to at least some degree helped tie the study of creativity to other areas of mainstream psychology, such as the studies of cognition and of personality. However, Guilford's basic idea, that creative thinking is based on divergent thinking, has not received strong support from studies of real-world creative thinking. Studies of the creative personality, likewise, have not provided strong evidence of causal effects of personality variables on creativity. On the basis of these negative results, one can draw the conclusions that creativity might not be based on some special sort of thinking and that creative people might not possess some special set of personality characteristics.

On the other hand, some researchers have recently carried out studies linking together (1) the personality characteristic of openness to experience, (2) creative accomplishment, and (3) the cognitive process of latent inhibition. That research might lead the way to a coherent picture of the relationship among personality, cognition, and creativity. At present we are not able to resolve the apparent conflict between those perspectives, so we will have to wait for advances in theory and research to clarify the relationship between personality and creativity.

CHAPTER

11

Confluence Models of Creativity

In the last two chapters, we broadened our focus beyond studies of creative thinking and examined the psychometric perspective on creativity, which has concentrated on testing for creative capacity as well as developing models that relate personality characteristics to creative achievement. As we saw in the discussion of the role of personality characteristics in creativity, researchers such as Eysenck (1995) have proposed broad conceptions of personality that have resulted in wide-ranging theories of creativity. A number of researchers have gone still farther beyond the psychometric perspective as outlined in the last two chapters and have proposed what have been called *confluence* models of creativity, which assume that the confluence, or coming together, of many factors is critical for creative achievement to come about (Sternberg & Lubart, 1995). Different theorists have brought into consideration many aspects of the creative person and have also gone beyond the person to examine social and environmental factors that might contribute to the creative process.

Outline of the Chapter

In this chapter, I will examine three influential confluence models of creativity, those of Amabile (1983, 1996), Simonton (e.g., 1998, 1999, 2003), and Sternberg and Lubart (1995, 1996). As I present the general aspects of each confluence model, as well as research relevant to it, I will note points of commonality and difference among the various models. I

will also present a critique of each model based in part on the database that we now have available concerning creative production. At the end of the chapter, a general critique of the models will be presented. Some of the components of the confluence models to be presented in this chapter have been anticipated in earlier chapters, during discussion of specific topics. One example is the role of unconscious processes in creativity, and another is the role of insight in problem solving. I believe that it is nonetheless useful to present each of the models in integrated form, which allows the sweep of the ideas and the breadth of proposals to become clear.

The Social Psychology of Creativity: Amabile's Componential Model

Amabile (1983, 1996) initiated her work in creativity from the perspective of social psychology, in which she included the influence on the creative process of external social-environmental factors. At the time when Amabile began her work, the study of creativity was dominated by the psychometric perspective, as discussed in the last two chapters. Researchers were concentrating on determining the personality characteristics of creative individuals and using psychometric tests to measure creative potential. Those approaches concentrated on the individual, essentially in isolation from others. Little attention was paid to factors outside the individual that could influence his or her creative performance, although there was evidence that factors that Amabile classified as social-environmental influences could affect creative performance. Some of those factors have already been discussed in Chapter 9. It was known, for example, that features of the environment could affect performance on tests of personality and creativity (Barron & Harrington, 1981). Performance on an unusual-uses divergent-thinking test is affected by the instructions given to the participants: People perform differently if they are told to be creative on the task. Performance is also influenced by the label that is given to the task: People perform differently when an unusual-uses exercise is labeled a creativity test as opposed to a word exercise. Similarly, when people are filling out the Adjective Checklist (see Table 9.4, p. 456), a measure of the creative personality, their responses change if they are told to fill it out as a creative person would. Finally, the environmental atmosphere in which divergent-thinking tests are administered—formal (a traditional testing atmosphere) versus playful—can sometimes affect people's performance. Those influences require that one go beyond the individual in order to understand creativity, which implicates social-psychological factors in any complete theory of creativity.

Amabile (1983) also discussed reports by creative individuals of negative

influences on their creativity brought about by social-environmental variables. As one example, winning prizes for literary accomplishment can result in a person's ceasing to work; also, critics' responses to one's work—both negative and positive responses—can greatly diminish creative productivity. In the traditional literature on creativity, such factors are looked upon as "confounding variables" that muddy the waters and interfere with our understanding of creativity. For example, if instructions influence people's responses on creativity tests, then one will see researchers considering carefully how to control the instructions given to participants to maximize the chances of obtaining a pure and valid measure of each person's creative potential. In contrast, Amabile (1983, 1996) interpreted the influence of external factors on various aspects of creativity as evidence that a complete understanding of the phenomenon of creativity required that we deal with social factors and their influence, and not try to control for them in our research designs. Amabile's model was a pioneering attempt to look more broadly at creativity and to place it in a social context.

Amabile's Definition of Creativity

In defining creativity, Amabile (1983, Chap. 2) noted that most definitions of creativity either implicitly or explicitly include a subjective element—the notion of value, discussed in Chapter 2. She emphasized that, even when we use creative products as the basis for determining who is creative, those products must have been judged as being of value by some reference group. Similarly, if we emphasize the process in determining whether a person is creative, the creative process is only so labeled when it produces an outcome that is valued by some reference group. Thus, a subjective element is intrinsic in evaluating products as creative, and is therefore intrinsic also in the definition of creative outcomes and the classification of people as creative. Amabile begins with the definition of creativity as the production of some product that is novel and judged to be of value by some reference group of individuals, but she adds to it that the product must come about through the use of heuristic, rather than algorithmic, methods. If one uses algorithmic methods—specific procedures, such as the rules of addition—to carry out some task, the outcome is not creative. If a child solves an addition problem using those rules, then, even if the child has not solved that specific problem before, in Amabile's view no creativity is involved.

Concerning this definition of creativity, I have already discussed in Chapter 2 what I see as problems with using value as a criterion for calling something creative. I do not need to emphasize that point again here, except to reiterate that incorporating value in the definition means that

the criteria for classifying a person or a product as creative could be shifting constantly as values change, which would leave researchers in a constant state of uncertainty. Considering the issue of the heuristic versus algorithmic basis of the creative product, I would also voice an objection here. I believe that one should consider the hypothetical child's response to the addition problem just cited to be creative, although perhaps minimally so. The output of the child qualifies as goal-directed novelty, which in my view means that it qualifies as creative. Since that child did not solve that particular problem in the past, the child cannot simply run off some complete solution that is retrieved from memory. The novelty of the situation requires some adjustment of the child, so in my view that would entail creativity, although, as noted, it might be close to the lower bound. I believe that the crucial aspect in calling some product creative is that the individual in producing that object has had to adjust his or her behavior in some way. From this perspective, applying an algorithm to a new situation involves creativity, at least minimally. For the most part, this distinction will not matter in considering Amabile's research, so I will not emphasize it here, although there might be some situations that she would put aside where I would see outcomes worthy of consideration as creative.

Amabile (1983, Chap. 2) also assumed that one can find a continuum of creativity, from the collages, drawings, stories, or poems that might be produced by ordinary people during laboratory exercises to the masterpieces that fill our museums and have changed our lives. Her research shows that experts are able to reliably rate the creativity of this wide range of accomplishments, so creativity must be present throughout that entire range of products. Products differing greatly in creativity—that is, differing in their novelty and influence as far as the bigger picture is concerned—are, in Amabile's view, brought about by the same processes. She also noted that creativity research centering on divergent thinking and the creative personality had been strongly criticized in recent years, which she took as a reason to focus more on creative products as the basis for studying creativity, although she noted that the traditional psychometric measures might still be useful in certain contexts.

Measuring Creativity

Amabile (1983) used her definition of creativity, with its emphasis on the subjective judgment of some reference group, as the basis for development of the *consensual assessment technique* as a measure of creativity. That technique, with which we are already familiar (e.g., Getzels & Csikszentmihalyi, 1976), uses judges who are expert in the domain to rate the creativity of products that the participants create. Thus, Amabile concentrated on assessment

of the product rather than the person or the process. As already noted, in Amabile's view studies of the creative person or the creative process must first of all rely on subjective evaluation of the creative product in order to determine whom to study, so concentrating on the creativity of a person's output seems a reasonable place to begin. In addition, tasks like constructing collages out of provided materials or writing very simple poems require no complex skills, so essentially everyone can produce something to be rated. Moreover, those sorts of tasks are ones in which creativity is found in the real world, so the tasks have validity at that level. The consensual assessment technique has been used in a large number of studies, both in Amabile's laboratory (Amabile, 1996) and elsewhere (e.g., Baer, Kaufman, & Gentile, 2004; Dollinger, Urban, & James, 2004), and it has been found to be reliable, although it is sometimes labor intensive, as when multiple judges must rate stories written by numerous undergraduates. However, Amabile believes that usefulness of the measure is worth the labor, and other researchers have followed her lead.

Amabile's Componential Model of Creativity

As noted, Amabile (1983, 1996) incorporated her studies of the social psychology of creativity within a conceptualization of creativity as a whole. Her original model of creativity (1996) is presented in slightly revised form in Figure 11.1A. Creativity is a process consisting of five stages (1–5 at the top of the model), which are presented sequentially, although the individual can go through them in varying orders once the process has begun. The creative process is initiated either when a person identifies a problem to work on (as when a poet decides to compose a poem about a recent emotional experience) or when a problem is presented from the outside (as when an artist is commissioned to paint a portrait). The second stage entails the activation in memory of information potentially relevant to the problem, including any algorithms that might be applicable to it. However, in order for a creative outcome to emerge, the individual must be engaged in a task in which there is no algorithm available, so that he or she must use heuristic methods to devise a new method that is applicable to the problem. In the third stage, information from memory, as well as relevant information from the environment, is used as the basis for generation of a possible response that might serve as the beginning of a solution to the problem. The generated response is evaluated and communicated to others at stage 4, which can, at stage 5, result in solution of the problem or a recycling through the earlier stages in order to deal with inadequacies of the proposed idea. In addition, if no candidate responses have been generated, the person might give up.

The aspect of Amabile's (1996) model that distinguishes it from other

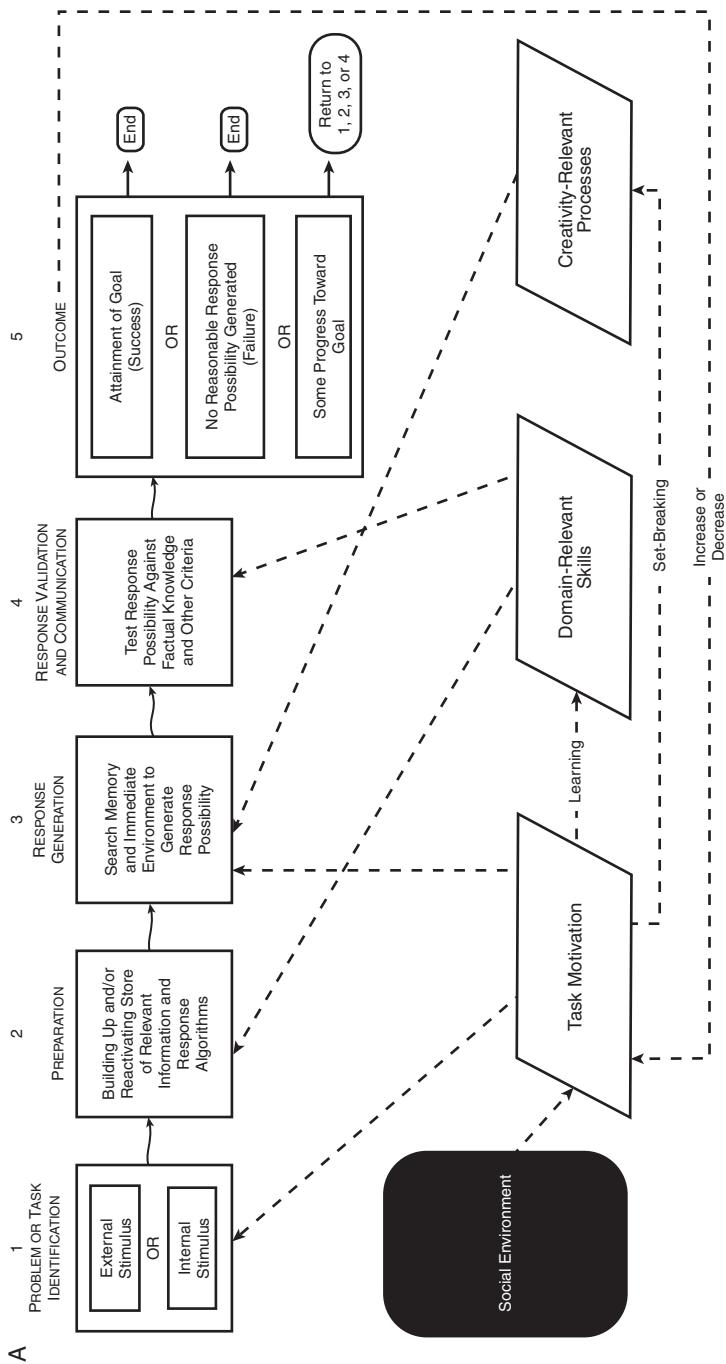


Figure 11.1 Amabile's componential model of creativity: A, Overview; B, Details
 Source: For figure 11.1A, Amabile (1996). For figure 11.1B, adapted from Amabile (1996, Fig. B).

Confluence Models of Creativity

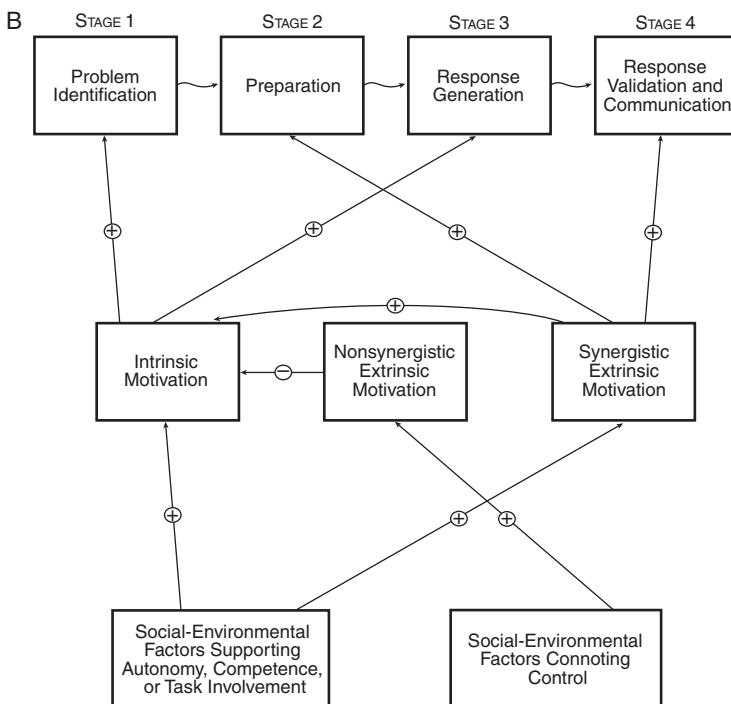


Figure 11.1 (continued)

work in creativity is its emphasis on the effects of the social environment on creativity, as noted at the bottom of the diagram. The social environment works most crucially on the motivation of the individual to carry out the task. Amabile emphasizes that creative outcomes are most likely to occur when the person is *intrinsically motivated* to carry out some task—when he or she carries out a task for its own sake rather than for some extrinsic goal. Amabile (1983) proposed the intrinsic-motivation *hypothesis* in the original model and elevated it to the intrinsic-motivation *principle* in the newer version (1996). Thus, in the two examples of problems initiating the creative process just outlined, the poet, who is intrinsically motivated to write, should produce a more creative product than the painter, who is working on commission.

General Aspects of Creativity: The Creativity-Relevant Processes

Intrinsic motivation is critical in the creative process because it influences the use of *creativity-relevant processes* (see the bottom of Figure 11.1A), which are general processes that can enhance a person's creativity regardless of domain (Amabile, 1983, pp. 72–73). In Amabile's view, the difference

between a product that goes significantly beyond what has been done before and one that does not—that is, the difference between a good or acceptable outcome versus a creative outcome—is the result of the utilization of creativity-relevant processes. If the individual possesses domain-relevant skills, he or she will produce something acceptable, but without the participation of the general creativity-relevant processes, the outcome will not be creative. Amabile (1983, pp. 72–73) lists many examples of such processes, which can be grouped into three areas.

First is a cognitive style characterized by an ability to deal with complexity and to break set during problem solving. “Set” refers to the tendency to continue behaving in a previously useful way that might no longer be optimal. It is “thinking within the box.” Specific facets of this set-breaking cognitive style include the ability to break perceptual set, such as when one is able to perceive that a box holding tacks can be used as a shelf for a candle (the now-familiar Candle problem; see Figure 6.1B, p. 284). Closely related is the ability to perceive things differently from the way others do, which can also play a role in the use of accidental events in the external environment in one’s creative endeavors. Similar to breaking perceptual set is the ability to break *cognitive set*, which involves abandoning unsuccessful strategies and searching in a new direction. A related process is keeping one’s options open as long as possible and suspending judgment concerning the value of one’s ideas until one has gathered multiple ideas, some of which might seem useless at first glance. This maximizes the chances that one will be able to find a novel—and therefore creative—approach to the situation. Use of wide rather than narrow categories in dealing with objects in the world can also foster creativity. Such a pattern of classification might allow the person to see relationships and connections among objects that might not be seen by others, which could lead to creative responses. Finally, creativity is fostered by the ability to break out of performance scripts—that is, well-used algorithms—and to produce the changes in one’s routine actions that will result in novel—that is, creative—outcomes. Many, if not all, of those components of the creative cognitive style are variations on one basic process: breaking away from the assumed constraints of past experience in order to produce new ideas. If one examines all those skills, one becomes aware that all of them involve not relying on one’s knowledge but rather going off in a different direction. This is a view that is familiar from discussions in earlier chapters, especially the discussion in Chapter 4 of expertise in creativity. I will return to this issue in the critique at the end of the presentation of Amabile’s view.

The second creativity-relevant skill, which works on a more general level than cognitive style, involves knowledge of heuristics for generating new

ideas: taking a different perspective on a problem, for example, or adopting an open or playful attitude to the problem. Such an approach in turn may also encourage risk taking, which may increase the creativity of the outcome. Here, too, we see an emphasis on breaking with the past. Finally, the third creativity-relevant skill is a working style conducive to creative production. Components of this working style include the ability to concentrate effort for a long period of time as well as the ability to abandon unproductive strategies and put aside problems on which one is making no progress. Also relevant to the creative work style are persistence in the face of difficulty, willingness to work hard, and a high overall level of productivity.

Amabile also cites personality factors as playing an important role in creative production, also through their influence on the creativity-relevant skills (Amabile, 1983, p. 74). Some of those personality factors are a high degree of self-discipline, the ability to delay gratification, a tolerance for ambiguity, and perseverance in the face of frustration and lack of success. Other personality factors are independence of judgment, a high degree of autonomy, an internal locus of control (i.e., the person works under his or her own direction rather than taking orders and direction from others), a high level of self-initiated striving for excellence, and, perhaps most important, independence in thinking and an absence of dependence on social approval. Finally, as noted already, there is a willingness to take risks. Those characteristics are related to the characteristics of the creative personality discussed in Chapter 10.

Although Amabile's model of creativity involves components of several different sorts—domain-specific process, more general creativity-relevant processes, and task motivation—the most influential aspect of the model has been its emphasis on motivation. The next section will focus on this.

Intrinsic Motivation and Creativity

A person is *extrinsically* motivated to carry out some activity when that activity serves as a means to the attainment of something else—for example, monetary reward or the positive recognition of the product that will result from the activity. A person is *intrinsically* motivated, in contrast, when he or she will carry out the activity for its own sake and for no other purpose. Amabile's original model (1983) assumed that extrinsic motivation is always detrimental to creative production. Subsequent research indicated that extrinsic goals can foster creativity if the person sees the attainment of those goals as informative in some way (Amabile, 1996, Chap. 4). As seen in Figure 11.1B, the influence of intrinsic versus extrinsic motivation through the creativity-relevant processes occurs at the third stage of the creative cycle, during which the person is generating a possible response.

Amabile (1996; Ruscio, Whitney, & Amabile, 1998) uses the concept of a person working through a maze to illustrate how motivation affects the creative process. Using an algorithmic approach to solving a problem is equivalent to taking a straight-line path in a maze directly from the entrance to the exit. However, in this hypothetical maze there are other possible exits, but these can be reached only through the use of heuristic methods, which allow deviation from the straight path and entail taking some risk, because the path to the exit is not apparent. The motivation of the individual is critical in determining which sort of method he or she chooses, as Amabile notes:

We propose that extrinsically motivated individuals, because they are motivated primarily by some task-extrinsic factors, will be more likely to rely on common, well-worked algorithms that they have learned for doing a particular task. . . . By contrast, intrinsically motivated individuals, because they enjoy the task itself and the process of searching for a new solution, will be more likely to explore the maze, attempting to find their way to one of the more novel exits. (Amabile, 1996, p. 122)

This passage makes clear the importance that Amabile places on intrinsic motivation in setting in motion the processes that are critical in producing a creative outcome. However, as she notes in discussing the double helix (1996, p. 11–14; see discussion in Chapter 1 and elsewhere in this book), in some cases creative accomplishments have been brought about by individuals who seem to be motivated by extrinsic factors (e.g., Watson and Crick's desire to "beat Pauling at his own game" [Watson, 1968, p. 32] and perhaps to win a Nobel Prize). Amabile believes, however, that situations in which extrinsic factors play a large role in highly creative outcomes are relatively rare.

In discussing how extrinsic factors might interfere with people's creativity, Amabile (1983, p. 100) considers two different sorts of explanations, which are not mutually exclusive. First, the presence of some sort of external factor during some task—such as the expectation or hope of getting a reward, or the expectation that others will evaluate one's work—might serve to distract the person from the task at hand. The individual in such a situation might spend more time thinking about the reward or evaluation and less time considering the task and the available elements. This explanation assumes that the external factor has a negative effect because it takes away some of the person's processing or working-memory capacity, so he or she cannot focus fully on the demands of the task itself. The second explanation is that concern with external factors such as reward or evaluation may change the way in which the individual approaches the task. Most particularly, as was

made clear in the quotation just presented, the presence of a possible reward, for example, may make the person less likely to take risks, since he or she might believe that taking risks lowers the chances of receiving the reward. If creativity of an outcome depends on taking risks, then this strategy will result in lowered creativity. These two explanations are, as noted earlier, not mutually exclusive: The presence of an external reward, for example, could both be a distraction and result in the person's changing his or her strategy for approaching the task.

Studies of the Creative Process

One set of studies evolving out of interest in the effects of intrinsic versus extrinsic motivation on creativity examined the role of an expected evaluation of one's product on its creativity. The literature on intrinsic motivation makes the prediction that performance on a heuristically based task—that is, one that demands creativity—will suffer from the person's expectation that his or her product will be judged by others. Several early studies demonstrated that expectation of evaluation did have negative effects on artistic and verbal creativity (Amabile, 1979; Amabile, Goldfarb, & Brackfield, 1982). In an examination of artistic creativity (Amabile, 1979), undergraduates were asked to create collages, using a set of standardized materials, including more than 100 pieces of paper in different sizes, shapes, and colors (all of which were presented in the same arrangement for each participant), glue, and a 15" × 20" piece of white cardboard on which the collage was to be constructed. In order to study verbal creativity, undergraduates were asked to create simple haikulike five-line poems. In both those situations, as noted earlier, no high levels of domain-specific skills are needed; the person creates a concrete product that can be judged for creativity; and the situations are not very different from those in which creative activity takes place in our culture. The students in the evaluation conditions were told that their work would be judged by experts in the area and that the judges would report their evaluations to the experimenters, who would also send them to the participant. Thus, not only was there the possibility of evaluation, but the outcome would be known to someone beside the evaluator and the participant.

The results from those studies were clear in supporting the prediction from the intrinsic-motivation hypothesis: Creativity scores were lower in the groups who were expecting evaluation. In addition, the results held across domains: Evaluation interfered with creativity in creation of both collages and poems. More recent research (summarized in Amabile, 1996, Chap. 5) has made things a bit more complicated, as Amabile and others have gone on to examine more subtle aspects of the relationship between

creativity and expectations of evaluation. However, the general conclusion, that expectation of evaluation will lower creativity, has held up.

A second set of studies growing out of Amabile's model (1983) has examined the influence of reward on creativity. As noted, the model predicts that if one carries out an activity that can be done creatively in order to receive a reward, the level of creativity will be negatively affected. This prediction has also been supported. In one early study (Amabile, Hennessy, & Grossman, 1986), children were asked to construct collages using the basic design just discussed. One group of children was told that if they agreed to carry out the collage task they could play with a Polaroid camera. All the children agreed to make the collage for the chance to use the camera. After agreeing, the children first played with the camera and then constructed the collage. This reversal in what might be the expected order of the tasks has interesting implications for our understanding of how reward might affect creativity, which will be discussed shortly. A second group was given the opportunity to play with the camera before constructing the collage, but nothing was said about the use of the camera being dependent on an agreement to make the collage. This group simply was exposed to two activities in succession, with no explicit connection between them.

Results indicated that the children who received the reward produced collages that were rated less creative by judges. In addition, as just noted, the fact that the reward activity—playing with the camera—was carried out *before* the creative activity tells us something about how reward might affect creativity. As noted earlier, reward might negatively affect the creative process because the person who is working for a reward might be distracted by the thought of the upcoming reward, and such a distraction might make it harder for him or her to concentrate on the creative task. This explanation is not relevant to the study of Amabile, Hennessy, and Grossman (1986), since the children had already received the reward when they were constructing the collage, so the upcoming reward could not have been a distractor. This indicates that the reward might have affected the children's motivation for carrying out the task, resulting in their carrying out the task to receive the extrinsic reward. That might have affected how the children approached the task, as Amabile (1983) proposed in her analogy of creativity as working through a maze. A number of other studies have supported the finding that reward can interfere with the creativity with which a task is carried out (Amabile, 1996), although, as with the question of evaluation, the pattern of results has become more complicated as researchers have examined more subtle aspects of the possible influence of reward on creativity. The overall conclusion—that carrying out a creative activity in order to receive a reward will have a negative effect on creativity—seems valid.

There is another set of findings, however, that contradicts the hypothesis that reward will interfere with creativity (e.g., Eisenberger & Selbst, 1994). In those studies, performance on divergent-thinking tasks has been found to be affected by reward. In the basic design, people are given reinforcement for some aspect of creative production on divergent-thinking tasks: for example, fluency (number of responses), flexibility (number of different categories of responses produced), or originality (rarity of responses). Results indicate that the reinforced aspect of the responses increased and that each of those aspects—in this example, fluency, flexibility, and originality—could be influenced separately through reinforcement. Those results would seem to raise problems for Amabile's intrinsic-motivation principle, but she concludes that divergent-thinking tasks are *algorithmic* tasks, not heuristic-based creativity tasks. According to this interpretation, the results from studies of divergent thinking are not relevant to questions about creativity. The reason Amabile assumes that divergent-thinking tasks do not involve creativity is that those tasks are highly structured and the participant essentially knows how to do well on the task. Since the strategy for successful performance on divergent-thinking tasks is known, there is not a heuristic component, which would require the individual to construct the solution strategy.

A further aspect of reward must be considered when dealing with creativity: the interpretation of the reward by the individual carrying out the task (Amabile, 1996, p. 175). An individual may interpret a reward as information that he or she has exhibited competence in carrying out the task. If the reward is seen as being *informative*, rather than being the *reason* for which the task was carried out, then the task might still be intrinsically motivating to the person. If so, then the person might approach the task creatively.

In another examination of the negative versus positive effects of reward on creativity, Amabile (1996, p. 173) reports a study in which an attempt was made to "immunize" children against the negative effects of reward. The children were first given exposure to a video in which other children talked about their schoolwork in terms that emphasized its intrinsic-motivational aspects. For example, they said that they worked hard not for grades (i.e., not for an extrinsic reward) but because they liked to learn new things. A control group saw a video in which children talked about food preferences, which was not relevant to intrinsic versus extrinsic motivation. The videos were then discussed in groups by the children, in order to enable the children to "internalize" the intrinsic-motivational message. This procedure was designed to give one group of children—the immunization group—a way of approaching reward that would protect them from reward's negative influences on creativity. The two groups of children were then given two tasks to carry out, one of which was presented as a reward (as in some of the

studies already discussed, the reward task was done first). The second task was a creative task. In this experiment, the children in the immunization group actually exhibited a higher level of creativity in the reward condition, while the control group's creativity decreased under reward. In addition, the immunized group reported more intrinsic motivation in their response to the creative task. Thus, it seems to be possible to counteract the negative effects of reward on creativity, but it involves training and practice. Some creative people have found through their own experience that they must immunize themselves against the detrimental effects of reward, like the poet Anne Sexton. Amabile (1996, p. 174) reports that Sexton learned not to take part in discussion of the monetary details in negotiation of a book contract: Instead, she had her agent attend to those details. Sexton said that she was interested in money, but first she wanted to write good poems, and she wanted to maximize the chances of that happening by not dealing with reward.

Amabile and her colleagues have also carried out nonexperimental investigations of the effects of reward on creativity, mainly in organizations (summarized in Amabile, 1996, pp. 174–175). Interview studies indicate that rewards have a negative effect when people feel that they are being rewarded as an inducement to carry out some work. On the other hand, when people feel that the organization rewards creative work, the reward will have a positive effect on creativity. One example of rewarding people for creativity is to allow them to choose the next project they will work on and/or the team with which they will work.

A particularly interesting study examined the effects of external constraint, rather than reward, on creativity (Amabile, Phillips, & Collins, 1994; cited by Amabile, 1996, p. 175). Professional artists were asked to submit randomly chosen works that they had done over the past 7 years, 10 of which had been commissioned and 10 of which were noncommissioned. The artists also filled out a questionnaire that asked about the conditions under which each work had been produced as well as the artist's feelings about the work, including its creativity. The works were then rated by artist judges who were blind to the conditions under which each painting had been created. Results indicated that the works produced on commission were rated as less creative than were the noncommissioned works. In addition, among the commissioned works there was a negative correlation between the ratings of creativity and the artist's report of being constrained by the commission. On the other hand, the commission had a positive effect on creativity (as rated by the artists producing the work) if the artist perceived the commission as *enabling*, that is, as providing the opportunity for the artist to carry out interesting work.

As these different studies show, the effects of reward on creativity can be

either positive or negative (Amabile, 1996, p. 175). If the reward is salient to the person and if he or she believes that the reward is constraining, then its influence will be negative. On the other hand, reward can have positive effects in several ways, among which are the following. If the reward is not salient and the person also has an intrinsically motivated orientation to the task, it will have a positive effect on creativity. Also, a reward seen as informative or enabling will also be positive in effect. Thus, extrinsic factors can sometimes work in conjunction with intrinsic ones to positively affect creativity. Amabile (1996, p. 118) uses the term *motivational synergy* to describe the process whereby extrinsic motivation can combine with intrinsic motivation in a positive way.

Increasing Creativity

On the basis of her model, Amabile (1996, Chap. 9) discusses ways of increasing creativity. First of all, because her research has demonstrated that extrinsic constraints can have a negative impact on creativity, those factors should be minimized if possible. Teachers, for example, should talk less about grades in the classroom, and when they talk about grades they should emphasize their informational aspect: that grades provide information that can lead to higher levels of skills. The study on immunization discussed earlier demonstrated that one can reduce the effects of potential external constraints by changing the ways in which those events are perceived by the individuals in the situation, which is another way to potentially affect creative activity. One can also increase the synergistic influences of external factors, by ensuring that reward and recognition serve to inform the individual about his or her competence and how to improve it rather than simply serving in the evaluation of performance. Amabile also proposes that creativity-relevant skills can be improved if parents and teachers model independent and intrinsically motivated activity. Creative and playful exploration of activities should also be encouraged.

Summary and Critique

Amabile (1983, 1996) has developed an influential model of the creative process, which began with a unique emphasis on the possible role of social-environmental factors in creativity. In addition, she and her colleagues have carried out an impressive set of studies, both experiments in the laboratory and nonexperimental studies in real-life settings, to provide data relevant to the model. A most impressive aspect of Amabile's work is the evolution of her theoretical views to confront new facts that have arisen from those studies, as can be seen when one compares the 1983 and 1996 versions of her model.

In critiquing Amabile's model, one can raise specific questions about two related points: the issue of creativity as a general skill and the question of creativity-relevant processes versus domain-relevant skills. In addition, questions can be raised about the specific creativity-relevant skills that are postulated in Amabile's model. Finally, questions raised in Chapter 10 concerning the cause-and-effect relationship between creativity and "the creative personality" are also relevant here.

Is Creativity a General or Domain-Specific Process?

Amabile (1996) proposed that creativity depends on a number of general processes, most if not all of which are directed at breaking away from responses based on the past. One can raise several sorts of questions concerning the generality of creative processes. First, as documented in Chapter 5, the evidence concerning the 10-Year Rule and the possible importance of expertise as a causal factor in creative achievement casts doubt on the premise that creativity involves general skills. In addition, a number of studies, some of which were reviewed in Chapter 9, raise empirical problems for the notion of general creative skills. Baer (1998) has shown that there are only weak correlations among creative performances across different domains, which he takes as evidence for domain-specific skills in creativity. In addition, when Baer exposed schoolchildren to creativity training he found that the skills developed by such training are relevant to very narrow domains. For example, giving children practice in finding words that rhyme with a given word provides assistance in writing poetry but not in writing prose.

Amabile and colleagues (Conti, Coon, & Amabile, 1996) reviewed the combined results of several studies carried out in Amabile's laboratory that had examined creativity across several dimensions. Amabile (1996) interpreted those results as providing evidence for the general nature of creative performance. Individuals were given several different creativity tasks to carry out. In the domain of creative writing, the participants were asked to write three short stories, each in response to a different picture. The first picture was a drawing of an area in the woods with what appeared to be an abandoned boat in the center. The second was a drawing of a writer's desk, and the third was a picture of a blank page. In a separate activity, the participants were asked to write a short story about two characters they had previously read about in a learning passage. Participants also engaged in three art activities: making a collage out of paper shapes, making a drawing using only straight lines, and using sponges of different shapes to paint a picture.

Table 11.1 presents the results from the analysis and shows the correlations between performances within the various domains. As can be seen, there are relatively large correlations within each of the domains (that is,

Confluence Models of Creativity

Table 11.1 Results of study of Conti, Coon, and Amabile
examining generality of creative accomplishment

	Boat Picture (1)	Desk Picture (2)	Blank Page (3)	Story Mean (4)	Learning Story (5)	Collage (6)	Drawing (7)	Painting (8)	Art Mean (9)
1	X	.64**	.43**	.86**	.47*	.36	.33	-.07	.27
2		X	.50**	.87**	.46*	.19	.31	-.22	.12
3			X	.75**	.21	.35	.31	-.13	.23
4				X	.43*	.35	.36	-.16	.25
5					X	.12	-.22	.09	.00
6						X	.43**	.27*	.77**
7							X	.15	.73**
8								X	.66**
9									X

Source: Conti, Coon, and Amabile (1996).

Notes: *Italic* indicates correlations within domains. **Boldface** indicates correlations across domains.

* $p < .05$.

** $p < .01$.

within writing or art; see correlations presented in *italics* in the upper left for writing and the lower right for art). The correlations across domains (across writing and art), presented in **boldface** in the upper right of the table, are much smaller and are not significant, and several are negative in value. Therefore, I would conclude from those results, contrary to Amabile, that there are not creativity skills that bridge domains (see also Kaufman & Baer, 2002). Concerning the presence of weak correlations across domains, which might be taken as pointing to generality of the creative process, I would hypothesize that those weak relationships across domains might be due to factors like motivation (the person's general willingness to work on projects demanding creativity), which might cross domains and result in some generality of results.

Breaking Away from Experience as a Creativity-Relevant Skill

As noted earlier, many of the creativity-relevant skills proposed by Amabile (1983, 1996) center on methods of breaking out of constraints presumed to develop from experience. Based on the case studies discussed in several places in this book, one can raise the question as to whether such processes

are relevant to most situations that require creativity. For example, if Picasso had broken with the past, there would be no *Guernica*. A similar claim can be made about Watson and Crick and the double helix, and Edison and the light bulb. Interested readers can consider each of the other case studies as well to see if the creative product came about as the result of a strategy of abandoning the past.

Questions of Causality

Amabile's confluence model (1996) assumes that personality traits play critical causal roles in creative production. However, as noted in Chapter 10, there are difficulties in making claims about causal roles of personality variables in the creative process, because it is very difficult to isolate such variables so that one can study their effects independent of possible confounds. In addition, as noted in that chapter, a number of studies have presented evidence that personality factors can be influenced by creative accomplishment, which means that the causal relationship between personality and creativity may be in the opposite direction from that postulated by most theories, Amabile's model included.

Amabile's Confluence Model: Conclusions

Amabile (1983, 1996) has developed an important research program concerning creativity and has developed a model that attempts to deal in broad terms with the wide range of phenomena related to creative production and creative people. Her model and her innovative research have stimulated others to investigate factors beyond the creative thought process, and the results have pointed to the importance of motivational and environmental factors in creativity.

Economic Theory of Creativity: Buy Low, Sell High

The second confluence theory of creativity to be examined is the "investment theory" of creativity of Sternberg and Lubart (e.g., 1995, 1996, Lubart & Sternberg, 1995). Sternberg and Lubart use an economic metaphor based on investment in the stock market to organize thinking about creativity (see also Rubenson & Runco, 1992). Success in investing in the stock market depends on *buying low* and *selling high*. The savvy investor looks for potentially good stocks that are at present low in value. He or she invests in those stocks, and when they go up, as the investor predicted, they can be sold for a profit. Similar concepts can be used to describe the activity of a person engaged in a creative enterprise. Like a stock that is valued low by investors, a new idea produced by a creative thinker is usually not valued highly

by others. The person who produces the innovation, however, obviously values it; that is, he or she has “invested” in that idea or product. Since the innovation is not yet valued by others, the creator has “bought low.”

In the process of carrying out research on creative individuals, Sternberg and Lubart noted one commonality in all of them: They were willing to go against the grain. In economic terms, the creative person is one who is willing to buy low in the realm of ideas, with the hope of selling high (1996, p. 683). This investment in a not-yet-popular idea requires, in Sternberg and Lubart’s words, the “guts to defy the crowd” (1995, p. viii). Such courage on the part of an individual is the result of the confluence of six resources, to be discussed shortly. Once the creator/investor has bought low, he or she must sell high, so the task becomes one of convincing others of the value of the innovation, be it a scientific theory, a painting or style of painting, an invention, or some other type of innovation. In selling a new theoretical idea, for example, a scientist can attend meetings at which other scientists can be exposed to the new theory, through formal talks as well as informal discussions, both of which can increase the likelihood that others will come to accept it.

In defining creativity, Sternberg and Lubart (1995, p. 12) subscribe to the already-familiar view that a creative product is novel and appropriate. Where an appropriate product meets the demands of the situation. It is very similar to “value.” Specifying that creative products be appropriate (and valued) serves to rule out the inappropriate novel responses of some psychologically disturbed people to given stimuli. Sternberg and Lubart add the additional criteria that the creative product be of high quality and of importance. Those last two criteria are not necessary for something to be creative—novelty and appropriateness are necessary and sufficient—but quality and importance can add to the creativity attributed to an object. A product of high quality is one that is well executed. An important product is one that has wide scope and can stimulate further work and more ideas. Thus, a novel and appropriate product that is also of high quality and wide scope is one that is maximally creative. The ability to produce such outcomes is a skill or talent that can be developed, according to Sternberg and Lubart (1995, p. vii): In their view, we all possess the required skills to some degree, and we can all increase our creative ability.

According to their model, the creative person is able to produce creative outcomes through buying low and selling high. Such a person rejects conventional ideas and comes up with fresh ones. Sternberg and Lubart (1996) note that the conception of the creative person as defying the crowd is broadly held in our society. In an earlier study, Sternberg (1985) asked laypeople to list what they considered to be the essential attributes of a person who is

highly creative. The participants listed such features as willingness to take a stand, nonconformity, and a tendency to question norms. In addition, professionals in various fields, such as artists, scientists, and businesspeople, all emphasized that the creative individual in their profession went against conventional thinking, and took risks, and followed through on the consequences of taking those risks.

Heuristics for Buying Low

Sternberg and Lubart (1995, pp. 80–87) provide some rules of thumb for buying low in the market of ideas—that is, heuristics for determining whether to invest one's intellectual capital in some idea. First of all, be wary of an idea that is popular. If everyone is doing it and you decide to work in that area, you will be buying high rather than low. So the first rule in trying to establish one's own creativity is not to work in an area in which much work is already being carried out. You can tell that you are buying low if people think you are at least slightly crazy when you present your idea to them, or if you feel a bit uncomfortable with the idea. One possible drawback to investing one's time and effort in an unpopular idea is that many unpopular ideas are unpopular because they are bad ideas, not because no one has yet discovered their value. Therefore, the person who wants to buy low in the market for ideas must have a way to differentiate good ideas from bad ones. Sternberg and Lubart provide several questions that can assist in making that differentiation. First, is there any evidence to support your idea? Even though others may not accept your idea at first, there may still be evidence available that supports it. On the other hand, since your new idea will overthrow conventional wisdom, is there any evidence that current beliefs are incorrect? Even though most people may accept conventional wisdom now, there may still be evidence against it; finding such evidence would raise one's confidence in one's new idea. You can also consider the aesthetic appeal of the new idea; a good new idea may possess an aesthetic appeal that a bad new idea will not have. This taste in ideas is something that can be developed in young researchers through their exposure to teachers and mentors.

Resources Needed for Creativity

The investment theory proposes that creativity on the part of an individual requires the confluence of six distinct resources: intellectual abilities (i.e., intelligence, broadly conceived), knowledge, styles of thinking, personality characteristics, motivation, and the environment (Sternberg & Lubart, 1995, Table 2.3).

Intellectual Skills

Working from Sternberg's theory on the structure of intelligence (e.g., Sternberg, 1985), Sternberg and Lubart (1995, Chap. 5) analyze intelligence into component sets of skills—synthetic, analytic, and practical—each of which plays a role in creativity. *Synthetic intelligence*, which is concerned with generating ideas, is critical in creativity, because it underlies a person's ability to see a problem in a new way or to redefine a problem. Such a redefinition will allow the thinker to go beyond convention. Sternberg and Lubart cite a number of important creative thinkers, including Einstein, who emphasized the importance in creativity of formulation of problems. Sternberg and Lubart (1995, pp. 100–108) present examples of tests that they have developed to assess people's abilities to redefine problems (see Table 11.2). In one type of exercise, the person is given analogies to solve, but each problem is preceded by a false presupposition that the person must accept as true and factor into his or her reasoning. An example is the following analogy problem (Sternberg & Lubart, 1995, p. 105):

Assume that goats are robots. CHICKEN is to HATCHED as GOAT is to:
BORN FARM BUILT FACTORY

Given the information that is to be assumed, the correct answer is BUILT; without that information, the correct answer is BORN. The critical question is whether the person will be able to adopt the new information and work with it, and, if so, how difficult it will be to do so. In another type of problem used by Sternberg and Lubart, numerical problems are presented in which new operations are defined, and the critical question is whether the person can adopt them and calculate correctly from them (see panel B of Table 11.2).

An especially important set of skills in problem redefinition and solution is what Sternberg and Lubart call *insight* skills—selective encoding, selective comparison, and selective combination—which were proposed initially a number of years ago by Davidson and Sternberg (e.g., 1986; Davidson, 1995) in the narrower context of the analysis of solution of insight problems. Sternberg and Lubart (1995, pp. 109–124) propose that the same processes can lead to development of creative ideas—that is, to buying low in the market of ideas. *Selective encoding* is seen when a person who is trying to solve a problem recognizes the potential importance of a piece of information that is not immediately obvious. This insight can lead to a new conceptualization of a situation. An example of a selective-encoding insight is a person's realization that the tack box in the Candle problem can be used as a shelf to hold the candle on the wall (see Chapter 6, Figure 6.1B, p. 284).

Table 11.2 Examples from Sternberg and Lubart
assessments of problem redefinition ability

A. Novel analogies

In solving these analogies, assume that the statement given before the analogy is true. Then solve the analogy, taking this assumption into account.

- PIGS climb fences.

GOLDFISH is to BOWL as PIG is to:

PEN CAGE DIRTY GRACEFUL

- DIAMONDS are fruits.

PEARL is to OYSTER as DIAMOND is to:

MINE TREE RING PIE

- TOASTERS write cookbooks.

SPATULA is to UTENSIL as TOASTER is to:

WRITER APPLIANCE BREAD BOOK

B. Novel numerical operations

In each problem, you will employ unusual mathematical operations in order to reach the solution. There are two unusual operations: graf and flix. First read how the operation is defined. Then decide what is the correct answer to the question.

There is a new mathematical operation called graf. It is defined as follows:

$x \text{ graf } y = x + y$, if $x < y$
but $x \text{ graf } y = x - y$, if otherwise.

There is a new mathematical operation called flix. It is defined as follows:

$a \text{ flix } b = a + b$, if $a > b$
but $a \text{ flix } b = a \times b$, if $a < b$
and $a \text{ flix } b = a + b$, if $a = b$

- How much is $4 \text{ graf } 7$?
(a) -3 (b) 3 (c) 11 (d) -11
- How much is $4 \text{ flix } 7$?
(a) 28 (b) 11 (c) 3 (d) -11
- How much is $13 \text{ graf } 5$?
(a) 5 (b) 18 (c) 13 (d) 8
- How much is $3 \text{ flix } 7\frac{1}{2}$?
(a) $10\frac{1}{2}$ (b) $21\frac{1}{2}$ (c) $22\frac{1}{2}$ (d) $4\frac{1}{2}$

Novel analogies answers: 1. Cage; 2. Tree; 3. Writer

Novel numerical operations answers: 1. c; 2. a; 3. d; 4. c

Source: Adapted from Sternberg and Lubart (1995, Table 5.1 and Fig. 5.3).

In the broader realm of creativity, selective encoding is seen in Alexander Fleming's discovery of penicillin (Sternberg & Lubart, 1995, p. 111–114). Fleming had been growing bacteria in vitro when he noticed that some of the bacteria had been killed by mold that had developed as the result of airborne spores' being deposited in the dish. Rather than disposing of the contaminated colonies and starting again, as most other scientists would have done, Fleming concentrated on the organisms that had destroyed the bacteria. As the result of a selective-encoding insight, he began the work that resulted in the discovery of penicillin.

Selective comparison insights in problem solving and creative thinking occur when an individual brings information from the past to bear in the current situation. Such insights usually involve analogical transfer, as discussed in Chapters 3–5, in which information from the past is applied to a new situation with which it shares structural components. Sternberg and Lubart (1995, p. 115) discuss Kekulé's "snake dream" of the structure of benzene as an example of a selective-comparison insight. Kekulé brought together two realms—chemistry and snakes—that would not usually be connected, and that juxtaposition resulted in a creative advance. The final type of insight, *selective combination*, occurs when an individual finds, while examining information that is available to everyone, an organization among that information that no one else sees. An example is Darwin's development of the theory of evolution. According to Davidson and Sternberg (1986), the information available to Darwin was available to anyone else who was knowledgeable in the area. Darwin succeeded in developing a theory because he was able to see how to fit the pieces of the puzzle together, an insight that had eluded other thinkers—except, of course, Alfred Russell Wallace, who developed the same theory independently of Darwin.

The second class of intellectual skills, *analytic intelligence*, is concerned with problem solving in its broadest scope, ranging from "problem finding" to solution. Sternberg and Lubart (1995, Chap. 5) propose that analytic intelligence plays a role in problem recognition and definition, the process in which the person decides in the first place that he or she is faced with a problem. They discuss the findings of Getzels and Csikszentmihalyi (1976) concerning the importance of preliminary work to a creative outcome, which was discussed extensively in Chapter 3. A related skill is that of determining how the problem is to be represented, which plays a critical role in determining the relative ease or difficulty that a problem will present to the individual. If a person thinks about the now-familiar Socks problem as one of probability, success will not result (see Table 11.3A). Similarly, if one takes a linear approach to the Lilies problem (see Table 11.3B), the incorrect answer will result. Sternberg and Lubart present testimonials from

Table 11.3 Two insight problems

A. Socks

You wake up early to go to work. It is still dark, and you do not want to disturb your partner by turning on the light. You know that you have five pairs of blue and four pairs of black socks in your drawer, but the socks are not separated into pairs. What is the fewest socks you have to take out of the drawer in the dark so that you will be certain of having a matching pair?

Solution: Three socks

B. Lilies

Water lilies double in area each day. On the first day of summer, there is one lily on the lake. Sixty days later, the entire lake is covered. On which day is the lake half covered?

Solution: Day 59

eminent individuals that demonstrate the importance of visual strategies in creative thinking, which they take to indicate that verbal strategies are not relevant to all problems. This should make us aware of the possibility of multiple ways of approaching any problem.

Analytic intelligence also plays a role in the individual's formulation of a specific strategy for approaching a problem, as well as in the allocation of resources during solution. Sternberg and Lubart (1995, p. 139) suggest that divergent thinking can play a role in formulating a strategy. For example, divergent thinking is demonstrated when a person faced with writing a poem first lists all the possible topics he or she can think of. Sternberg and Lubart note that, in their research, less-creative individuals tend to quickly converge on a single solution to a problem, whereas more-creative people think about more strategies before deciding on one and reformulate that strategy during the solution attempt. The final role of analytic intelligence in problem solving is evaluative: The thinker must be on the lookout for errors and ready to revise early versions of creative products to deal with inadequacies that might be found in them. It is better that you correct early versions of a poem, for example, than that a critical reader or editor reject the poem because it has not been developed enough.

Finally, *practical intelligence* is needed in the choice of a problem to work on; one must pick a problem that others will find interesting. Practical intelligence is important here because one of its components is the ability to communicate to others the value of what one has done. All creative endeavors, ranging from research in the pure sciences to developing a creative advertising campaign, depend for their success on the creator's ability to convince others of the value of the ideas involved. In addition, the abil-

ity to deal effectively with the inevitable criticisms that any new idea will receive is a facet of practical intelligence.

Knowledge and Creativity: A Double-Edged Sword

Knowledge is different from intelligence, because knowledge is the raw material on which the intellectual processes operate. Concerning the role of knowledge in creativity, Sternberg and Lubart (1995, Chap. 6) take a position already familiar to us from the discussion of expertise in creativity in Chapter 4 and 5. They are advocates of the *tension view* and conclude that knowledge plays two conflicting roles in creativity. First, it is necessary that the person know the area in which he or she is working, because one cannot create something new if one does not know what has been done. Also, knowledge can aid in the production of works of high quality, which, as we have seen, can play a role in influencing people's judgments of creativity. Knowledge, in the form of a person's past practice, can also free the person's mental resources to concentrate on new ideas rather than basic skills. It should be noted that those functions of knowledge are minimally positive: The knowledgeable person will not waste time in the repetition of what others have done, will produce high-quality work, and will have resources available for concentration on the production of new ideas. Sternberg and Lubart do discuss the positive role of knowledge and expertise in high-level performance, such as in playing chess. However, in that context they emphasize the importance of Mednick's (1962) flat associative hierarchies in the generation of new ideas (see discussion in Chapters 8 and 9), so even here they are moving away from assuming a positive role of expertise in creativity.

More important, in Sternberg and Lubart's view, knowledge can play a decidedly negative role in creative thinking, because it can keep a person trapped in old ways of thinking, thus blocking creativity. Support for the possible negative influence of knowledge on creativity comes from demonstrations of fixation of various sorts in problem solving, such as *functional fixedness*, as exemplified in the Candle problem by participants' inability to see the tack box as a potential shelf for the candle (Duncker, 1945; an alternative interpretation of this problem was given in Chapter 6; see also Fleck & Weisberg, 2004). Similar conclusions come from a study by Frensch and Sternberg (1989) in which bridge players of different levels of expertise were asked to play versions of bridge in which the normal rules were changed in various ways. Results indicated that the more-expert players had more difficulty in adapting to conceptual changes, which altered the basic structure of the game. In the context of bridge playing, they were not able to adapt to changes in the world. This result is analogous to real-world situations that

demand that new ideas be developed: The expert will be at a disadvantage. Accordingly, Sternberg and Lubart (1995, p. 161) note that it is not always the world-class expert who has the best ideas; sometimes a person who is a newcomer to a field will think in new ways because he or she has not yet been co-opted by the standard ways of looking at things.

Similar conclusions about the potential negative effects of knowledge on creativity were drawn by Simonton (1984, Chap. 4) from a study, already briefly discussed in Chapter 4, in which he analyzed the higher-education levels of eminent creative individuals born between 1450 and 1850; his sample included Galileo, Darwin, and Shakespeare. The tension view would lead us to expect that too much knowledge might be a bad thing. Indeed, Simonton found that the individuals who are now most recognized for their creative accomplishments were those whose formal education was in the middle range in terms of years of study, equivalent to their being about half-way through modern undergraduate training. Those lacking formal higher education altogether and those with the most higher education achieved less in the way of lasting recognition.

Further emphasizing the broad potential negative effects of knowledge on creative thinking, Sternberg and Lubart (1995, Chap. 6) point out that the expert is not the only one who can be caught in the web of stale knowledge and expectations when a fresh viewpoint is demanded. One could say that we are all experts in various ways; that is, we are all “experts” concerning aspects of our lives, so we all are subject to entrapment by our knowledge. Therefore, we must be ready to deal with that problem when it arises, as it inevitably will. One can fight entrapment in a number of ways. First, one can vary one’s usual routines, so that one’s entrenchment in intellectual ruts is lessened. Second, one can invite feedback from others concerning how one could do things differently. Finally, one can actively seek to learn new things, which would force one out of one’s habits.

Thinking Style and Creativity

Sternberg and Lubart (1995, Chap. 7) also assume that general styles of thinking play a role in determining whether a person will be creative. Thinking style, which is different from the thinking abilities, is the way in which one chooses to think. Sternberg (1986) has proposed an analysis of intelligence in which there are different ways one can approach problems. Creativity is fostered by a *legislative* style, which is characterized by a preference for thinking in novel ways of one’s own choosing rather than following rules set by others (which would be an *executive* style) or taking a judgmental attitude toward situations (which would be a *judicial* style). A person with an executive style might take up a writing project but would

be most comfortable providing exposition of others' ideas. A person with a judicial style might write a critique of someone else's ideas. Both of the latter projects might involve creativity, but it would not be buying low and selling high, since no new ideas would be produced by the primary person.

Thinking styles are not all-or-none; one's overall style is typically a blend of styles. A creative person might benefit from having judicial tendencies in addition to a predominantly legislative style, because such a person might effectively critique his or her own ideas as a project was taking shape. Sternberg and Lubart (1995, Chap. 7) also note that the legislative style cannot work alone in bringing about creative production: If the person does not possess the relevant knowledge, he or she will not be able to go beyond the present state of things (again, knowledge plays a minor role, at best). In addition, a *global* style, which is characterized by a greater interest in larger issues than in details, also plays a role in creativity, since it affects the person's determination of which questions are important and worth working on.

Creative Personality

Sternberg and Lubart (1995, Chap. 8) note that many people who possess the potential to be creative never actually produce anything creative. Possessing the relevant intellect, knowledge, and thinking style is only part of the picture: In order to actually produce creative work, one needs to possess personality characteristics that maximize the likelihood that one will utilize that potential. Sternberg and Lubart critique theoretical analyses of creativity that concentrate on the cognitive processes involved and do not consider personality as part of the mix. Such views assume that a complete understanding of the creative thought process will allow us to understand creativity. Those views are, according to Sternberg and Lubart, critically lacking, because studying cognitive processes alone will not enable us to understand how a person can be productive in a creative manner over a lifetime.

Sternberg and Lubart (1995, Chap. 8) emphasize a number of personality characteristics that have been found to be associated with creativity. One critical characteristic is a willingness to persevere in the face of obstacles. Sooner or later, all people who would buy low and sell high will encounter obstacles. If you have decided to go against the crowd, then there is no doubt that many in the crowd will oppose what you have to say. The worst ideas will be subject to criticism from the crowd, but so will the best ideas. The best ideas will radically break with the past and therefore will by definition leave many people and their ideas behind. Furthermore, problem situations that demand creativity may be difficult, so producing the solution may require a

long period of commitment. The obstacles faced by the person who would buy low can be external—the opposition of the crowd or the difficulty of the problem he or she is facing—but they can also be internal, like one's own entrenched way of thinking. In this situation too perseverance can play a positive role, because the more times one approaches a recalcitrant problem, the greater the chances that a new approach might develop.

Since there will usually be opposition to new ideas from the establishment, anyone who hopes to succeed in the creative arena must also be willing to take risks. A number of studies have demonstrated that people's willingness to take risks (e.g., their willingness to gamble on a highly valued outcome) is correlated with performance on divergent-thinking tests as well as responses to creative-attitude scales. The creative person must also show a willingness to grow. If not, he or she will become a one-hit wonder and never produce anything beyond the first crowd-defying idea. As Sternberg and Lubart (1995, Chap. 8) note, if one hopes to metaphorically buy low and sell high over the course of a career, one must be ready to move on after one has succeeded in forging an unpopular idea into one that others accept.

The creative person must also be willing to tolerate ambiguity; that is, he or she must be willing to deal with situations in which it appears that no closure may be forthcoming in the near future. Someone who demands that situations be resolved within short periods of time may produce something that is inadequate in various ways, because he or she did not tolerate the ambiguous situation long enough for additional information to become available. Sternberg and Lubart (1995, Chap. 8) discuss Pauling's production of his triple helix as an example of the negative consequences that can befall one who cannot tolerate ambiguity, or at least one who could not tolerate ambiguity in that situation. As noted in Chapter 1, Pauling was basing his work in part on early X-ray photos of DNA, which were not precise enough to allow him to accurately determine some parameters of the molecule, so his model, which was similar to the triple helix of Watson and Crick, was incorrect in several ways. If Pauling had been willing to tolerate the ambiguity of not formulating a model for a bit longer, he might have seen Franklin's more precise photos, which might have led him in the correct direction.

We are already familiar with the trait of openness to experience, which Sternberg and Lubart (1995, Chap. 8) emphasize as critical in some people's being able to consistently come up with new ideas. People who are open to experience will constantly be seeking out information and stimulation from the world, and thereby will maximize the chances that they will have available information that might be relevant to their problem. Finally, in

order to produce creative work, one must also have confidence in oneself and the courage of one's convictions, so that one can stand up to the establishment.

Motivation

In order for the characteristics described so far to be effective, the individual must be motivated to do creative work. Like Amabile (1983), Sternberg and Lubart (1995, Chap. 9) discuss the possible roles of intrinsic and extrinsic motivation in creativity, with an emphasis on intrinsic motivation. However, also like Amabile, they conclude that extrinsic motivators can play positive roles as well as negative ones in creative endeavors. Ochse (1990) has reviewed the literature on motivation in creativity and summarized a wide range of motivating factors that have been reported by creative people:

1. To obtain mastery or to overcome ignorance
2. To achieve immortality through one's work
3. To make money
4. To prove oneself, to oneself and to others
5. To attain recognition
6. To attain self-esteem
7. To create a thing of beauty
8. To discover an underlying order to things

Of those factors, 1, 7, and 8 are intrinsic; 2, 3, and 5 are extrinsic; and 4 and 6 might be either intrinsic or extrinsic. On the basis of these results, and also Amabile's (1996) recent work, it seems that both intrinsic and extrinsic factors can be important in motivating creative accomplishment. As was noted in discussing Amabile's more recent analysis, the informational aspects of motivating factors can also influence their effectiveness.

The Environment

Finally, the environment can play a critical role in creativity, because the environment can stimulate, encourage, and reward innovative thinking, which will increase the chances that an individual will engage in such activities. In addition, the environment can be a source of obstacles that the creative person must overcome. As Sternberg and Lubart (1995, Chap. 10) note, some researchers have concluded that obstacles in one's life, such as early loss of a parent, may be positively related to creative achievement, so those external obstacles might be critical in fostering creativity.

An Empirical Examination of the Economic Model

A study by Lubart and Sternberg (1995) examined the relationships between creativity and the various resources discussed in the economic model. Forty-eight adults participated. They were given creativity tasks of different sorts, as well as tests to measure the intellectual processes postulated to be relevant to creativity. The participants also filled out self-report measures designed to obtain information about their knowledge, intellectual styles, personality traits, and motivation resources. There were four types of creativity tasks.

1. Writing a short story in response to a topic chosen by the participant from a list provided by the researchers (examples: “beyond the edge” and “the octopus’s sneakers”).
2. Drawing a picture in response to a topic chosen from a list (examples: “hope” and “rage”).
3. Creating a television commercial about a product chosen from a list (examples: “the IRS” and “bow ties”).
4. Solving a scientific problem from a list of problems (example: “How could we detect the presence of aliens among us?”)

The topics from which participants chose had been selected to allow freedom of creative expression. Each participant performed each task on the list two times and participants were encouraged to “be imaginative” and “have fun.”

The researchers chose intellectual tasks to measure general intelligence as well as the three insight processes—selective encoding, selective comparison, and selective combination—that they assumed to be crucial to the redefinition of problems and thus to the production of new ideas. Knowledge was assessed with a biographical questionnaire, which asked participants how often they engaged in activities related to the creativity tasks (e.g., writing poetry) and unrelated activities (e.g., working on social problems). Questionnaires were also used to assess thinking styles. Personality characteristics were measured with personality inventories of the sort discussed in Chapters 8 and 9. Finally, the participant’s motivation for creative work was assessed with a scale that asked such things as how well the person felt that he or she was described by such statements as “I would like to write a short story to challenge myself.” The statements assessed motivation across a range of areas, including those represented in the creativity tests, and also examined intrinsic and extrinsic motivation. The creative products were rated for creativity by 15 peers of the participants, not by experts. Lubart and Sternberg (1995) used peers as raters because they felt that peers would

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be the most likely judges of the creative products of those individuals in real life, since the participants were ordinary people, who volunteered from the community to participate in the study. No criteria for creativity were supplied; raters were asked to use their own definitions of creativity. The raters were able to reliably rate the creativity of the products; that is, the ratings of a given set of products were consistent across raters.

The results of the study, like those of Amabile's (1996) model of the creative process, indicated that there was only a weak relationship among the creativity ratings of the products across the various domains (see Table 11.4). This result provides additional evidence that there may be some factors that influence creativity across domains but also that each domain has its own specific factors. Lubart and Sternberg (1995) attribute the positive relationships across domains to the possibility that the intellectual processes (the insight processes, for example) are generally relevant, which would produce positive relationships across domains. Interestingly, Sternberg

Table 11.4 Testing the buy-low/sell-high model

	Creative Performance Domain				Overall
	Drawing	Writing	Advertising	Science	
A. Correlations across creative performance domains (N = 48)					
Drawing	.85	.32*	.31*	.23	
Writing		.89	.41**	.62***	
Advertising			.81	.44**	
Science				.87	
B. Correlations of resources with rated creative performance (N = 48)					
Intellectual processes	.51***	.59***	.50***	.61***	.75***
Knowledge	.35*	.37**	.33*	.41**	.49***
Intellectual styles	-.08	-.28	-.51***	-.28	-.39**
Personality	.25	.25	.26	.32*	.36*
Motivation	.28	.34*	.61***	.34*	.53***
Combined resources	.61**	.63***	.73***	.66***	.83***

Source: Adapted from Lubart and Steinberg (1995).

Note: In panel A, the diagonal elements give the alpha coefficient interrater reliabilities.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

and Lubart conclude that personality characteristics are probably domain-specific. So, for example, one might be a risk taker when creating an advertisement but not when attempting to solve a scientific problem.

Lubart and Sternberg (1995) also found that there was not a very strong correlation among the creativity scores within each domain. That is, the two stories produced by a given person were positively correlated, but the correlations were only moderate in size: Even if a person's first story was highly rated, the second one might not be. The two products in each category were produced in sessions that took place on average 2 days apart, so that might have contributed to the lack of high correlations among products within each domain.

Table 11.4B presents the correlations among the summary scores for each of the postulated resources and creative performance in the various domains. Summarizing across all the creativity domains, as shown in the last column of the table, all the resources were significantly related to performance, which would lead one to conclude that the Sternberg and Lubart model was strongly supported. However, looking more closely at the entries in the table raises some questions about the strength of that support. The model predicts that each of the resources should be significantly related to creative performance, but that was not uniformly the case: The relationships between resources and creativity varied across domains. In the drawing domain, only the intellectual processes were significantly correlated with creativity. In writing, intellectual processes, knowledge, and motivation were significantly related to creativity, but intellectual styles and the personality measures were not. In the domain of advertising, motivation, intellectual styles, and knowledge were significantly related to creativity, but personality was not, which demonstrates some of the variability across domains. Finally, in science, all the resources save intellectual styles were significantly related to creativity. The notes in the table provide the details. Considered as a whole, this study found some support for the specific predictions of the economic model, although not all the resources followed the predictions from the model. However, this study does demonstrate how one can examine the possible role of different resources in creative accomplishment.

Critique of the Economic Perspective

The buy-low/sell-high model of creativity is, like the other models of creativity discussed in this chapter, one of broad sweep. Sternberg and Lubart (1995) incorporate a wide range of processes and factors in their discussion. However, this sweep of ideas may be accompanied by a lack of precision concerning some of the concepts in the model. In addition, the empirical support for the model is weak in some areas. I will first critique

two general aspects of the buy-low/sell-high view and will then turn to more specific issues.

Is the Buy-Low/Sell-High Model Prescriptive or Descriptive?

One general question that can be raised in response to Sternberg and Lubart's (1995, 1996) model concerns its status as a theory of creativity: Is the economic theory *descriptive* or *prescriptive*? That is, do Sternberg and Lubart believe that all outstanding creators buy low and sell high, which would mean that they are describing the way the creative process usually works? Or do they think that ordinary people who learn to buy low and sell high will become creative (or more creative)? Under this latter interpretation, the buy-low/sell-high view would be prescriptive: It prescribes what people *should* do if they want to be creative.

It seems that the model is at least in part descriptive, because Sternberg and Lubart (1995, p. viii), say that the buy-low/sell-high interpretation—that is, the idea of the creator's going against the grain—resulted from their research on creative individuals. In addition, they provide examples of creative achievements that seem to fit various aspects of their model. However, it is worth exploring the general applicability of their view as a description of the behavior of creative individuals. If we apply this model to our case studies, Picasso is perhaps the most obvious candidate for the buy-low/sell-high model. He changed his style significantly several times over his career—most significantly, in the context of this discussion, when he and Braque created Cubism around 1912. In addition, this idea was “sold” to other artists, and after Cubism became common Picasso then moved on to other styles. So this aspect of Picasso's career fits the economic model. It is interesting to note, however, that Picasso's later style shifts did not have effects on other artists comparable to that of Cubism. Few artists can be found who adopted Picasso's later styles as a hallmark of their work. This raises a question as to whether Picasso can be accurately described as following the buy-low/sell-high strategy beyond the example of Cubism, since he did not buy low and sell high as regards his later styles. For example, the creation of *Guernica* does not seem to fit the buy-low/sell-high pattern, since it did not defy the crowd in either style or content: On the contrary, *Guernica* was accepted as a masterpiece immediately upon its completion.

In other examples, discussed earlier in this book, an individual produced a significant creative advance that did not seem to be based on buying low and then stayed within that sphere for the rest of his career, and therefore did not sell high. When Calder developed his abstract style of sculpture, for example, there was no uproar in the art community. He did not have to defy the crowd: His mobiles were accepted immediately by all. In addi-

tion, Calder maintained that style without significant change for the rest of his life, so we see no selling high (Marter, 1991). The Beatles also do not conform to the buy-low/sell-high view. As we saw in Chapter 5, their early work consisted largely of covering hit songs by others, so we could call that buying *high*. In addition, their groundbreaking works—*Rubber Soul*, *Revolver*, and *Sgt. Pepper's Lonely Hearts Club Band*, produced during their middle period—were hailed as masterpieces immediately.

As for Watson and Crick, did they buy low and sell high? When they started their research, they adopted Pauling's orientation toward model building and his helical idea, which could be described as buying *high*, since those ideas had already been successful. Once they had produced the double helix, it was accepted with little struggle (see Olby, 1994). So Watson and Crick seem to not have bought low. As for the question of selling high, or moving on to new ideas, Watson has stayed within the molecular biology that the double helix spawned and has served as the director for the Human Genome project. So he did not sell high. Crick stayed within molecular biology for a significant period of time, carrying out research on the implications of the double helix and becoming the most eminent researcher in the field (Olby, 1994). He then went on to study neuroscience, where he did try to buy low and sell high, advocating an orientation to the analysis of the brain and nervous system that deviated significantly from the accepted view, at least in his own estimation (he and a collaborator titled one book *The Astonishing Hypothesis: The Scientific Search for the Soul*). However, his ideas have not had an effect in that area remotely comparable to that of the double helix in molecular biology.

Moving beyond the case studies covered in this book, the Impressionist painters also seem at first glance to follow the buy-low/sell-high pattern, but here too questions can be raised about the fine points of the correspondence. The Impressionists can indeed be described as buying low: When they first produced works in that style, the paintings were ridiculed and described as being unfinished (Rewald, 1973). The style gradually became accepted, and painters around the world adopted it. Some of the original group of Impressionists went on to different styles (e.g., Renoir and Pissarro). However, Monet, perhaps the leading Impressionist, never changed his style, and the basic Impressionist philosophy can be seen in his last works. Thus the buy-low/sell-high description does not fit Monet, who was the leader of the Impressionists. So again we can raise a question as to how well the buy-low/sell-high perspective describes creative activities in real life.

We can see from these case studies of seminal creative achievements in the real world that the generality—and, accordingly, the validity—of the buy-low/sell-high model as a description of the creative process is question-

able. On the other hand, the buy-low/sell-high view might be meant to be a prescription for how to become creative. If so, then questions about its generality might not be critical to its validity. That is, it might be the case that eminent creators do not behave according to the buy-low/sell-high description, but that model still might be useful as a prescription of how to become creative. However, Sternberg and Lubart (1995, 1996) provide no evidence that trying to buy low and sell high will increase the chances of one's achieving creative eminence. If the buy-low/sell-high model is prescriptive, then, there is no evidence either for or against it.

Choosing an Area in Which to Be Creative:

Is Buying Low All That Is Involved?

An additional critical point about Sternberg and Lubart's (1995) general orientation is that they do not mention motivational factors when they introduce the buy-low/sell-high perspective. That is, they do not provide any discussion of *why* a person should consider doing creative work in some area, other than that he or she will be able to buy low there. Given the discussion by Sternberg and Lubart of the importance of motivation in creative production, we would expect them to propose that it would be important that one should choose an area, all other things being equal, in which one has some intrinsic interest. As their model is currently presented, however, one gets the feeling that the only issue is whether one can make a mark in the area because it is ripe for buying low. Surely there is more to motivation than that. As it is presented, the buy-low/sell-high model seems relatively opportunistic: Find an area in which others are not working and make it your own. Surely a more positive motivation should also be involved: Find some area that (1) is of *interest to you*, and (2) *in which you would be willing to invest the time and effort required to develop new ideas*, and (3) *in which others are not working*. Then you might have a maximal chance of buying low and selling high.

Questions about Specific Aspects of the Buy-Low/Sell-High Model

I will conclude this critique of the buy-low/sell-high model with a consideration of a number of more specific issues. First, as we saw in reviewing the study by Lubart and Sternberg (1995), support for the specifics of the model was lacking in several areas. Second, Sternberg and Lubart (1995) emphasize the importance in creative thinking of the "insight skills" developed by Davidson and Sternberg (1986), but one difficulty with incorporating those "insight skills" in a model of creative thinking is that we are not given by either Davidson and Sternberg or Lubart and Sternberg much beyond labels and examples of the various skills. To take an example

from the analysis of problem solving, we are not given details on how and why a person working on the Candle problem might suddenly “selectively encode” the tack box as a potential solution object and change his or her approach to the problem. What factors make a person suddenly notice the presence of the box and decide to use it in a solution? As we saw in Chapter 6, there may be complex processes underlying such a decision, but Sternberg and Lubart (1995; see also Davidson & Sternberg, 1982b; Davidson, 1995) provide little detailed information on what they think might be occurring. Similar questions can be raised about the application of the purported insight processes to creative thinking more broadly conceived. No in-depth analysis is provided, for example, of the postulated “selective encoding insight” of Fleming (Sternberg & Lubart, 1995, pp. 111–114), which resulted in the discovery of penicillin. Here, too, we are not told anything about how or why he was able to come to the realization that something of importance had occurred in the dish where the bacterial culture had been destroyed. As long as we have no specifics about underlying processes, we are left with little more than a new label for a phenomenon, which does not greatly increase our understanding of creative thinking.

Finally, Sternberg and Lubart (1995, Chap. 6) place heavy emphasis on the negative consequences of knowledge on creative thinking. That orientation is obviously very different from that of this book, which assumes that expertise is critical in creative advances, numerous examples of which were given in the case studies discussed earlier, among them *Guernica*, the double helix, and Calder’s mobiles. Thus, we must wonder whether the basic thrust of the buy-low/sell-high model might be in the wrong direction.

The Darwinian Theory of Creativity

Perhaps the most widely influential of the recent confluence models of creativity is the Darwinian view of Simonton (e.g., 1988, 1995b, 1999, 2003), which is built on the theorizing of Campbell (1960). Aspects of Simonton’s theory and its development out of Campbell’s (1960, 1974) ideas were discussed in Chapter 8, in the context of the role of the unconscious in creativity. In this chapter, I will consider broader aspects of Simonton’s theory.

Simonton’s theorizing has found a receptive audience both within psychology (e.g., Eysenck, 1993) and without (e.g., Miller, 1996). His ideas are of broad sweep: His historiometric studies range from an examination of the influence of war and other conflicts on creativity, in which he considers 2,000 years of Western civilization, to studies of factors that influence the lasting reputations of Shakespeare’s plays. Although Simonton has gone

considerably beyond Campbell (1960), especially in his presentation of data relevant to the Darwinian view, it will be useful to begin again with a consideration of Campbell's theorizing, which will allow us to put Simonton's work into historical context and understand how he goes beyond Campbell. In addition, examining Campbell's theorizing will make clear the deep historical roots of this view.

Campbell: Blind Variation and Selective Retention as a Model of Creative Thought

Campbell (1960, pp. 380–381) was concerned with the general question of how humans can acquire knowledge. Most important for the present context is his view of creative thinking as an example of a knowledge acquisition process. The tremendous gain in knowledge over the course of development of our species has come about, he asserts, as the result of “breakouts” from the limits of available wisdom. If the expansions of our knowledge had simply resulted from *deductions*, constructed logically from what we already knew, they would not represent true advances. Since new knowledge must go beyond the limits of existing knowledge, Campbell concluded that any gains in knowledge must have come about as the result of processes that were blind as to the probable outcome: That is, the individual must not have known what to expect when he or she tried something new, either mentally or physically.

Campbell (1960) therefore came to the conclusion that underlying the development of human knowledge is a process analogous to true trial and error, in which the ignorant individual has no basis for choosing one possible response over another. This blind process can also be conceived of as analogous to the processes underlying evolution according to Darwin's theory of natural selection. In that theory, random (blind) mutations result in changes from one generation to the next in the genetic material and in its expression, and the organism has no say in or control over the occurrence of mutations. Campbell (1960) applies the same argument to creative thought: If thinking can bring about true innovation, then each of the “thought trials” through which the person thinks of possible new responses must also be blind, lacking in foresight. In other words, when the person begins to consider his or her response to some situation that demands creativity, he or she cannot build in any direct way on the past, and therefore cannot tell in advance what the creative outcome will look like.

Campbell (1960) proposed that the creative process involves three stages. The first stage is the blind idea-generation process. Once ideational variations are produced, there must be a set of criteria that determine which of those variations are worth preserving. Those criteria are provided by the

problem situation that the person is facing: Of the blindly produced ideas, those that will be preserved are those that solve the problem. Finally, there must be a mechanism whereby any selected ideas can be retained for future use. As Campbell (1960) noted, the first and last of these conditions seem to present a fundamental contradiction: The premise that blind variation is central to the production of new ideas means that there must be a breaking away from the variations preserved from earlier times. Thus, the creator is working within two contradictory sets of forces: the instinct to apply old knowledge to new situations and the need to reject old knowledge to create something truly new. This is another instance of the tension view of the relationship between knowledge and creativity (see Chapters 4 and 5).

Although it may be difficult to believe that Campbell (1960) viewed all creative thinking as the result of a truly blind process, the radical nature of Campbell's ideas is evident in his response to possible objections to his view. In response to the argument that his view ignores the so-called genius—the creative individual who by the force of intellect and/or personality is able to bring about insightful leaps—Campbell explicitly pushed such a person completely out of the picture:

Let a dozen equally brilliant men each propose differing guesses about the unknown *in an area of total ignorance*, and let the guess of one man prove correct. From the blind-variation selective-retention model, this matching of guess and environment would provide us with new knowledge about the environment, but would tell us nothing about the greater genius of the one man—he just happened to be standing where lightning struck. In such a case, however, we would ordinarily be tempted to look for a subtle and special talent on the part of this lucky man. However, for the *genuinely unanticipated* creative act, our “awe” and “wonder” should be directed outward, at the external world thus revealed. . . . [I]n comparing the problem-solving efforts of any one person; from the selective survival model it will be futile, in the instance of a *genuinely innovative achievement*, to look for special antecedent conditions not obtaining for blind-alley efforts: just insofar as there has been a genuine gain in knowledge, the difference between a hit and a miss lies in the selective conditions thus newly encountered, not in talent differences in the generation of the trials. (p. 391; emphasis added)

Thus, the person who makes a creative leap is no different from one who fails to do so: Both have blindly combined ideas, and one just happened to produce something that matched the demands of the world. In Campbell's view, our search for some critical characteristic of the person who is able to make a creative advance is based on “our deeply rooted tendency toward causal perception, a tendency to see marvelous achievements rooted in equally marvelous antecedents” (pp. 390–391).

Although Campbell's view may strike one as radical—and it strikes me that way—in his survey of the history of discussions of creative thinking in philosophy and psychology he found numerous individuals who had proposed similar views. Among them are Bain, Souriau, Mach, Baldwin, Pillsbury, Woodworth and Schlossberg, Thurstone, Tolman, Hull, Miller and Dollard, Craik, Boring, Humphrey, Mowrer, and many others, the most important of which in the history of psychology was Poincaré (1908, 1913). We have already extensively reviewed Poincaré's theory of creativity in Chapter 8 because of its important role in the development of theorizing on unconscious processes. Campbell paid particular attention to Poincaré because the latter's theory was based on the notion of ideas randomly permuting and colliding in the unconscious. This conception fit well with Campbell's idea that there is neither foresight nor conscious control over the creative process. Poincaré's report of the events of his sleepless night, when, as we have seen, he concluded that he had observed the workings of his unconscious, is particularly relevant (Poincaré, 1913, p. 387). As Poincaré noted: "It is rare for the blind permuting process to rise into conscious awareness; as a rule only the successful selected alternatives enter consciousness." As we see in this quotation, Poincaré himself used the term *blind* to describe the process that underlies the formation of mental combinations, as did others before Campbell.

Campbell (1960) also considers an objection to his view that focuses on the fact that there is a pattern even to the errors made by thinkers when they deal with some new situation. That is, as we have already seen extensively in the case studies discussed earlier, people respond to new situations in a structured manner; their errors do not produce what looks like a random pattern. Campbell asserts that any such pattern is the result of previously acquired knowledge, which may be applicable to the new situation. However, there had to be a time before there was any knowledge relevant to the current situation or to any others like it, and at that time the organism had to respond blindly. Furthermore, there might be response tendencies that have been handed down from one generation to the next through inherited mechanisms, so even naive organisms might know how to behave in a situation to which they had never been exposed. Here too there must have been a time in the history of the species in which an organism was forced to respond to a new situation blindly, with no foresight or knowledge inherited from its ancestors or acquired over its own life.

It should be noted that Campbell (1960, pp. 391–392) does not assume that there are no individual differences in creative capacity. One important difference among people would be the accuracy and detail of their representations of the external world. More detailed representations would make

available more information that could enter into the combinatorial process. Those differences are related to differences in intelligence, in Campbell's view. There are also differences in the number and range of the blind combinations of ideas that people will produce. Obviously, from this perspective, the more numerous and varied those combinations are, the greater the chances of stumbling onto the successful combination. Campbell notes that individuals who have been uprooted from traditional cultures, or who have been thoroughly exposed to two or more cultures, seem to have the advantage in the range of hypotheses they are apt to consider. For example, one sees a disproportionate number of children of immigrants among those who have produced seminal creative accomplishments. In addition, the more-creative thinker may be able to keep in mind at one time a wider range of criteria to use in judging the potential adequacy of combinations that are produced, which will allow him or her to focus on potentially valuable combinations among the large number that are produced.

Now that we have reviewed the main thrust of Campbell's (1960) ideas on creativity, we turn to Simonton's elaboration of the Darwinian view to see where he builds relatively directly on Campbell and where he goes beyond him.

Simonton's Darwinian Theory of Creativity

Simonton (1988, p. 388) begins with Campbell's (1960) proposal that three conditions are necessary for creativity. First, the solution of novel problems requires some means of generating ideational variation comparable to the random mutations that provide the material on which natural selection can operate. In Simonton's view (1995, p. 475), this generation of new ideas is brought about in the unconscious, as postulated by Poincaré. As we have seen, Campbell argued that this variation, to be truly effective, must be fully "blind." This term has resulted in criticisms of the theory (e.g., Sternberg, 1998), so Simonton provides other terms (which had also been mentioned by Campbell) to describe the process by which ideas are combined: *chance*, *random*, *fortuitous*, or *haphazard*. Second, once ideational variations have been produced, they are subjected to a selection process that retains only the very few that meet certain selection criteria. Those combinations are experienced in consciousness; all other combinations simply fade away. Third, the variations that have been selected must be preserved and reproduced by some mechanism.

Simonton (1988, p. 389) notes that Campbell (1960) built on a long tradition, which we just discussed. As one further example of a similar analysis of the creative process, here is a quotation from William James

(1880, p. 456, cited by Simonton, 1988), which can be looked upon as an early example of the Darwinian view.

The new conceptions, emotions, and active tendencies which evolve are originally produced in the shape of random images, fancies, accidental out-births of spontaneous variation in the functional activity of the excessively unstable human brain, which the outer environment simply confirms, refutes, or destroys—selects, in short, just as it selects morphological and social variations due to molecular accidents of an analogous sort.

James postulates a spontaneity and accidental or random quality in the functioning of the brain, which would generate novel ideas.

The Creative Process

According to Simonton (1988, p. 389) the creative process operates on “mental elements,” basic mental units that can be manipulated in some manner; examples are sensations, emotions, concepts, and recollections. The fundamental mechanism of creative thinking involves chance permutation of those elements. Here again there arises a potential misunderstanding, so Simonton elaborates on what it means to postulate “chance” permutations:

To claim that permutations are generated by chance is equivalent to saying that each mental element is evoked by myriad determinants. . . . [C]hance does not necessitate total randomness. We must merely insist that a large number of potential permutations exist, all with comparably low, but nonzero, probabilities. (pp. 389–390)

This view, as Simonton notes, has much in common with Mednick’s (1962) notion of the flat associative hierarchies of the creative individual, which holds that several responses, each with a low probability of occurring, are possible. The noncreative person, in contrast, possesses only a small number of strong responses to the situation, so only those stereotyped responses will occur.

The question now arises as to which of those randomly produced combinations will be selected and retained. Most of the combinations, as noted by Poincaré in his original discussion, are not worth retaining. Poincaré proposed that the individual’s aesthetic sensibilities played a role in selecting combinations for beauty or elegance. Simonton (1988, pp. 390–393) moves the mechanism from the unconscious sensibilities of the individual to the properties of the combinations themselves, and proposes that the “stability” of a new combination determines whether it will be retained. He assumes that the random permutations differ in stability, ranging from

what he calls *aggregates*, which are inherently unstable, to *configurations*, which are stable; the greater the stability of a combination of ideas, the greater the chance of its being selected. More stable combinations—the configurations—command greater attention in consciousness. Aggregates, because of their instability, fade away too quickly to rise above unconscious levels of processing. Confronting the question of why some combinations coalesce into configurations, Simonton (1988, p. 391) postulates that “certain elements possess intrinsic affinities for each other, a chance linkage of two elements can produce a stable pairing, and large clusters of elements can form themselves spontaneously into highly ordered arrangements out of utter chaos.” He notes the analogy proposed by Campbell (1974) to crystal formation, where a solution of sufficient saturation on cooling will suddenly—“spontaneously”—produce crystals.

In considering further the specifics of how configurations might be formed, Simonton suggests that sometimes two mental elements are structured so that their elements can line up in one-to-one fashion. When this occurs, chance permutation can produce an analogy between hitherto unrelated phenomena. This might be the mechanism behind Poincaré’s discovery of the analogies between the Fuchsian functions and the transformations of non-Euclidean geometry (see Chapter 8). Another example of such a discovered analogy noted by Simonton (1988, pp. 392–393) is the analogy between light and waves in science. In art, this process can result in a metaphor that unifies unrelated domains of experience. Simonton (1988, p. 393) also postulates that there might be a reinforcing aspect of forming configurations: “The mind derives pleasure from noticeable enhancements in mental order, where pleasure is merely the marking of an adaptive event. In other words, cognitive events that reduce mental ‘entropy’ . . . receive intrinsic reinforcement.”

Individual Differences in Creative Capacity

Simonton (1988, pp. 398–403) proposed that there are individual differences in creative capacity as postulated by the Darwinian view; here too we see traces of Campbell (1960). First of all, the broader the knowledge base possessed by a person, the more elements will be available to enter into combinations, which will increase the probability that a useful configuration will be formed. In addition, however, that knowledge must be organized in a way that will allow permutations of the elements. If the individual possess a tightly organized knowledge structure, then the elements will not be free to vary as the creative process demands. The ideal creative condition is a wide range of knowledge whose elements are only loosely associated, so that they are more available for permutation. Simonton (1988, pp. 400–401)

describes the different associative organizations as “intuitive” (when elements are loosely associated) and “analytical” (when elements are strongly associated). Thus, the “intuitive genius” possesses knowledge whose elements are linked by numerous loose unconscious associations; since fewer of those connections are habitual, they are relatively easy to break, so the elements can play a role in the permutation process. This looseness of associations can come about through cognitive and personality factors—for example, in a person with broad interests who is flexible, independent, and willing to take risks.

Simonton (1988, 1999) provides several sorts of evidence to support this view. As does Campbell (1960), Simonton provides introspections from historically significant figures that support the chance-combination process. One example is a comment from Einstein (Hadamard, 1945, p. 142) noting that “combinatory play seems to be the essential feature in productive thought.” Another example of combinatory activity was seen in Poincaré’s (1913) sleepless night, which we have already discussed several times. Simonton also emphasizes the influence of chance events in the environment, or serendipity, on the creative process. He notes that the well-known scientist Walter B. Cannon (1940) emphasized “the role of chance in discovery,” which can be seen when a researcher investigating one question stumbles on another, often totally unexpected, finding. A similar process occurs in the arts; Simonton (1995b, p. 469) cites the novelist Henry James (1908), who reported that he used language overheard in others’ conversations as the basis for stories. Thus, serendipity is a general process. Even more important, perhaps, serendipity is related to other aspects of people’s functioning that play roles in the creative process. Those people who make their minds accessible to chaotic combinatory play will also make their senses more open to the influx of fortuitous events in the outside world. In such individuals, both the retrieval of material from memory and the orientation of attention to environmental stimuli are unrestricted.

Simonton presents another comment by William James (1880, p. 456) as additional support for his view—the passage on the functioning of the “highest order of minds” that we have already encountered:

Instead of thoughts of concrete things patiently following one another in a beaten track of habitual suggestion, we have the most abrupt cross-cuts and transitions from one idea to another, the most rarified abstractions and discriminations, the most unheard of combination of elements, the subtlest associations of analogy; in a word, we seem suddenly introduced into a seething cauldron of ideas, where everything is fizzling and bobbling about in a state of bewildering activity, where partnerships can be joined or loosened in an instant, treadmill routine is unknown, and the unexpected seems only law.

James seems to be talking about a situation that fits Simonton's view: There is little permanent structure to ideas, and any idea can combine with any other, on a moment's notice, to produce something new.

Simonton (1995b) also notes that problem situations can be placed on a continuum according to the need for chance processes in their solution. At one end are problems like $489 \div 17 = ?$, which can be solved using algorithms and in which chance plays no part. However, in the less-defined problems that are important in scientific research or in art, chance plays a more important role, both in determining how the problem will be represented and in the solution strategy that will be undertaken:

As problems become more novel and complex, the number of potential representations and heuristics proliferate. For the kinds of problems on which historical creators stake their reputations, the possibilities seem endless, and the odds of attaining the solution appear nearly hopeless. At this point, problem solving becomes more nearly a random process, in the sense that the free-associative procedure must come into play. Only by falling back on this less disciplined resource can the creator arrive at insights that are genuinely profound. (Simonton, 1995b, pp. 472–473)

Simonton (1995b, p. 473) emphasizes Poincaré's early proposal that the most useful combinations of ideas come from domains that are far apart, which should make us aware of the possible dangers in applying knowledge and heuristics to problems. People can fail to create significant insights by excluding whole domains from the possible combinations, even when those domains are far from the problem being worked on and presumably irrelevant to it. History gives us many instances in which a seemingly irrelevant idea provided the critical component in a creative insight of the first magnitude. One such case is Guttenberg's invention of the printing press, which was stimulated by the sight of a wine press at a wine festival he attended while trying to determine how to print pages from moveable type. The wine press suggested to him how he could apply a strong uniform force over a wide area, which would meet his need to print a page. Simonton (1995b, p. 473) concludes that the more “offbeat” the connection that the thinker has made, the greater the role of chance in generating it.

As noted, those unexpected combinations can only be generated in the unconscious. However, there are times when the unconscious free-associative process is accessible to consciousness (Simonton, 1994a, pp. 476–477). First, when vivid imagery is involved, the person can sometimes have access to the combinatorial process. An example with which we are already familiar is Kekulé's observations of the snake-biting-its-tale image that gave him the solution to the problem of the structure of benzene

(see Chapter 2). Presumably, from Simonton's perspective, that image was constructed in Kekulé's unconscious, but he was able to observe it. Also, if there is no other task to distract the person, he or she may be able to become aware of the unconscious operations. The classic example is Poincaré's report of his sleepless night; since there was nothing else to distract him, he was fortunate enough to become aware of what he felt was the operation of his unconscious. Finally, the individual may be engaged in some activity that requires minimal active attention, such as walking, which can make him or her open to other thoughts. This happened when Poincaré was walking on the bluff above the seaside.

Thus, there is not a hard and fast line between unconsciousness and consciousness. At any given time, our core consciousness contains the central focus of our attention. However, at the same time, surrounding that core is a peripheral awareness of subliminal stimuli and partially retrieved memories. Still farther removed from core consciousness is unconscious processing. So, while one is engaged in some conscious activity, one may still have a vague sense that something is going on elsewhere in one's mind.

However, insights do not occur without groundwork first being laid by individual. First, there must be long-term preparation. The person who will produce insights must build a database; Simonton (1995b, pp. 479–481) cites the 10-Year Rule as evidence for the necessity of the database. As we have already seen, the elements in the database must be structured in a particular manner or else they will not allow the free-associative combinations to form. Simonton presents a passage from Price (1963, p. 107), who described the insightful scientist in the following way.

A scientist of high achievement . . . [has] a certain gift of what we may call *mavericity*, the property of making unusual associations in ideas, of doing the unexpected. The scientist tends to be the man who, in doing the word-association test, responds to "black" not with "white" but with "caviar."

This description raises the question of what factors make it most likely for the database to be organized as the creative process requires (Simonton, 1995b). First of all, some factors are supplied by nature. Some fortunate individuals are born with the tendencies to mavericity that Price emphasized. This is seen when creative individuals display thinking patterns that parallel those in psychotic populations. The creative individuals are not psychopathological, but they possess at a subclinical level certain tendencies that are helpful in creative thinking, what Simonton (1995b, pp. 480–481) has called "bizarre thinking tendencies," which include clang associations and overinclusive thinking. There is evidence that the (subclinical) psychopathology involved is genetic in origin. One sees similarities between

Simonton's theorizing and that of Eysenck, discussed in the previous chapter, who emphasized the role of the personality characteristic of psychoticism in the creative process.

However, experiential factors can also increase the likelihood that an individual will tend toward the free-associative processing of the creative thinker. Creative thinkers often experience childhoods that are more disrupted than those of more ordinary individuals, such as by the loss of a parent or other trauma. They also may be either ethnically or professionally marginal, which makes them likely to look at a situation differently from others.

Finally, there are short-term factors that play a role in determining whether the free-associative insight process will be carried out. Here Simonton (1995b, pp. 481–484) follows the stage view of creative thinking as developed by Wallace (1926) and Hadamard (1954) based on Poincaré's (1913) reflections on the creative process (see Chapter 8). There must first be a preparatory phase of preliminary work, followed by impasse and frustration. This negative state causes the person to break away from the problem, which initiates the incubation stage. The preparation stage, as Poincaré originally noted, serves to activate or *prime* certain ideas, which will then play a central role in the unconscious combinatorial process. In Simonton's view, the need for incubation is twofold. First, the solution to a difficult problem—the ones on which high-level creative individuals spend time working—will require a complex chain of associations. The incubation period provides the time in which that chain can be constructed. In addition, dealing with nondominant responses requires low levels of arousal, because strong associations are produced under high-arousal circumstances. Breaking away from the problem allows the person to perform activities that may reduce arousal, thereby increasing the likelihood that a chain of remote associations can be constructed. In Simonton's view, an example of an insight occurring during a reduced state of arousal is Poincaré's insight during his stroll on the bluff. In addition, Simonton (1995b, 2003) proposes that the critical function of the incubation period is that it allows external stimuli to play a role in stimulating the solution to the problem. Those stimuli can operate subliminally, so the person may not be aware of the stimulus that has played a critical role in the sudden awareness of the solution to a problem (Maier, 1931).

External Events and Chance Combinations of Ideas

In the development of Simonton's theory, one can see a change in the mechanisms he emphasizes as bringing about the combinations of ideas that provide the foundation for creativity. In his earlier presentations of his

theory, as just reviewed, Simonton (e.g., 1988) focused in detail on the role of *internal* factors in bringing about unexpected combinations of ideas. Those internal factors were related to the flat associative hierarchies postulated by Mednick (1962) to underlie creative thinking. In his more recent writings on the role of chance factors in the creative process, however, Simonton (1995b, 2003) has moved away from an emphasis on the structure of the individual's mental elements and how they enter into combination and has emphasized more the role of external factors that are truly out of the person's control—serendipitous environmental events—in producing truly chance combinations of ideas that turn out to be relevant to a problem being faced by the individual. This shift of emphasis can be seen in Simonton's discussion of the role of insight in creativity.

Opportunistic Assimilation and Insight

Simonton (2003) places much emphasis on the role of insight in creative thinking, and he incorporates into his theory the “opportunistic-assimilation” model of incubation and insight proposed by Seifert and colleagues (1995; see Chapter 8). As will be recalled from Chapter 8, early views of incubation, the most important being that of Poincaré (1913), proposed that during incubation the person continued working on the problem but on an unconscious level. The opportunistic-assimilation model is an attempt to explain how breaking away from a problem might facilitate solution without postulating unconscious processes. The model assumes that during incubation (when the person who is at an impasse breaks away from a problem and deals with other things both in thought and in action) failure indices set in memory point to the unsolved problem. During the incubation period, the individual is exposed to a random array of environmental and mental stimuli. One of those stimuli may set off activation in the individual's memory, which may result in the retrieval of the problem with a potential solution in an Aha! experience. (See Chapter 8 for a unified discussion of support for the opportunistic-assimilation view.)

The opportunistic-assimilation model fits very nicely with Simonton's orientation, because the external stimuli to which an individual is exposed at any given time are not systematically related to the problem(s) he or she is incubating in memory. This is a perfect example of a chance process that could produce new combinations of ideas. Simonton (2003) also assumes that the creative individual is more sensitive to external and internal stimuli than is the ordinary individual and so would be more likely to experience an insight after breaking off work on a problem. We are already familiar from Chapter 10 with personality differences that according to Simonton might result in such sensitivity: A personality characterized by openness to

experience would be more affected by stimuli. Simonton also notes that the finding that creative individuals are less subject to latent inhibition, which was discussed in the previous chapter (e.g., Carson et al., 2003; Peterson et al., 2002), might also mean that external stimuli have greater chances of coming into contact with unsolved problems in memory.

Application of Simonton's Theory to Creative Thinking

Simonton (e.g., 1998, 2003) has applied his theory to a wide range of phenomena across many domains. I will present some of the relevant results and will then use them as the basis for a critique of Simonton's theory.

Creativity in Science

Simonton (2003) has used his perspective to analyze a broad range of phenomena related to creativity in science. He has attempted to bring together several disparate views of scientific creativity that emanate from the cognitive and psychometric perspectives. He attempts to show that a large number of phenomena can be accommodated under his Darwinian view and that the other perspectives are really subsets of the Darwinian view. Simonton (2003, p. 476ff) proposes to analyze first what scientists do when they carry out their creative work so that we may understand how they did it. The critical foundation of creative accomplishment in science, according to Simonton's analysis, is *productivity*. Those scientists who produce the most important contributions, as evidenced, for example, by awards and honors and by listings in encyclopedias and other reference works, are those who produce the most contributions overall. Therefore, the critical issue in understanding outstanding creative work in science is understanding the productivity of scientists over their careers. Simonton also noted that this relationship holds in other creative domains also, as will be discussed shortly; the most influential artists, for example, are also those who are the most productive. In addition, there are large differences among scientists in total output over their careers; the large majority of contributions in any discipline are made by a small proportion of the active scientists in the discipline. Most scientists make only one or two contributions over their careers.

In order to explain the relationship among productivity, eminence, and individual differences in overall productivity, Simonton (2003) assumes that during his or her training, each scientist is exposed to the ideas that comprise the *domain*—the specific area of science in which he or she has chosen to work. As a result of the unique set of circumstances to which each person is exposed, each scientist-in-training acquires a different subset of those ideas. The size of the sample of ideas that the scientists acquire varies,

according to the normal distribution; some people learn more about their discipline than others do. Those ideas are then subjected to “free, relatively unconstrained, or quasi-random variation” (p. 478), which can result in creative combinations. Thus, Simonton takes the Darwinian view and applies it to the broad picture of scientific creativity.

Simonton also attempts to account for some smaller aspects of scientific creativity as well. For example, he applies the Darwinian view to the phenomenon of *multiple discoveries* (2003, p. 480), the independent discovery of the same phenomenon by more than one person. The classic example of a multiple discovery, interestingly, is the theory of evolution through natural selection, which forms the basis for Simonton’s theorizing. As has already been mentioned, Alfred Russell Wallace also discovered the theory, and his letter to Darwin that summarized his theorizing stimulated Darwin to bring his own work to publication. Simonton uses the chance-configuration idea to explain the overall frequency of known multiple discoveries in science, as well as their distribution across time (that is, some multiple discoveries occur at about the same time, while others are separated by years). As noted earlier, Simonton (2003, p. 486) also emphasizes the importance of *insight* in creative thinking, including scientific creativity. As noted, he relies on the opportunistic-assimilation theory of Seifert and colleagues (1995) as the basis for applying the Darwinian view to insight. In this perspective, insight occurs as the result of a period of incubation, but not because of unconscious processing: The person gives up work on the problem and, while he or she is doing other things, a serendipitous environmental event may stimulate solution to the problem.

Creativity in Art: Chance and Guernica

Simonton (1998, 2003) proposed the Darwinian view as a general theory of creativity, and he has accordingly applied it to the arts. Most useful in the present context, Simonton has applied his view to a creative act with which we are already acquainted: Picasso’s creation of *Guernica*. Examination of Picasso’s sketchbooks led Simonton to the conclusion that the painting developed out of a series of “false starts and wild experimentation.” Simonton provided no detailed analysis of Picasso’s sketchbooks to support his conclusion, perhaps because he felt that that conclusion would be obvious to anyone who simply looked at the sketches.

Equal-Odds Rule

One particularly important prediction from Simonton’s (2003) theory concerns the distribution of *masterworks* over a creator’s career. Campbell (1960) and Simonton propose that the creative process essentially begins

anew each time, since it is a random permutation process that produces the combinations of ideas that serve as the basis for creative responses. This analysis led Simonton to the prediction that there should be no increase in masterworks over a creator's career; in other words, thinkers should not demonstrate evidence of *learning* to produce high-quality output. This leads to what Simonton has called the *equal-odds rule*: The probability that a creative thinker will produce a work of importance (a "masterwork") in any creative domain should stay the same throughout a person's career. That is, creative thinkers should not become better at assessing the correctness or potential importance of their work. The equal-odds rule has been tested by Simonton in the domains of science and in music, among others, by examining the relationship over a creator's career between the overall production of works in a given period and the production of masterworks within that same period. According to the equal-odds rule, there should be a correlation between the overall productivity within a given period and the production of masterworks within that period: The periods in which the most works are produced are the periods in which the most masterworks (and the most forgotten works) are also produced. Furthermore, the proportions of masterworks produced in a given period of a creative thinker's career should stay constant over the person's career.

Critique

In embarking on a critique of Simonton's analysis of creativity, one may find oneself at a loss as to where to begin, because of the sweep of the ideas that he proposes. One is faced with, for example, analyses of creative production of a broad range of scientists across a wide range of disciplines, and Simonton provides what seem to be wide-ranging explanations of those broad phenomena. However, when I look closely at the phenomena Simonton examines, and what he provides as explanation, I find that something is lacking at the level of detailed analysis.

Looking at the Details

As noted earlier, Simonton (2003, p. 476) proposed to examine what scientists "actually do when they make bona fide discoveries" (emphasis added). When I read that phrase, I expected to see a detailed analysis of case studies of scientific creativity, such as the study of the development of the double helix presented earlier in this book, or Gruber's (1981) study of Darwin's creativity. However, in his analysis of what scientists "actually do," Simonton presents only group data, which summarize creative productivity and related phenomena across large numbers of scientists across many disciplines. One never finds a detailed analysis of the actual creative

processes involved in any particular discovery, and when I have carried out such analyses, I have found evidence for processes that are very different from the “free, relatively unconstrained” processes that form the foundation of Simonton’s Darwinian view (2003, p. 480). This discrepancy leads me to question the usefulness of the broad generalizations on which Simonton builds his theory. His theory may be too far from the data to capture the process underlying creative thinking. There is no doubt that Simonton has attempted to confront an impressive range of phenomena related to creativity, but he may have missed the trees for the forest. I am more interested in the trees—the nuts and bolts of the creative process—and I am left unsatisfied by the level of generality at which Simonton works.

The Role of Knowledge in Creative Thinking

Simonton (1988, 1995b, 1999), like the proponents of other confluence theories we have examined in this chapter, downplays the role of knowledge in the creative process. Indeed, he explicitly states that would-be creative individuals would be well served by a knowledge base that would support “wild associations” (1995b, p. 484) and “bizarre thoughts” (2005). As noted multiple times already, the case studies presented earlier provide no support for the idea that wild and bizarre associations are critical in the creative process. On the contrary, in all the case studies reviewed in this book, it has been possible in a straightforward way to understand the associative connections among the ideas used, and wildness did not seem to play a role. It is of course possible that my view of what a wild or bizarre idea is differs from that of Simonton, but, for example, the Wright brothers’ use of bicycles as the basis for a control system in an airplane does not strike me as wild or bizarre; thinking about bird flight in that context is also not wild or bizarre. Similarly, relating the bombing of Guernica to Goya and to *Minotauromacy* does not seem to me to be a wild or bizarre flight of thought. This issue is discussed further in the next section.

Blind Variation in the Creation of Guernica?

The fact that Simonton has applied his view to *Guernica* is, as noted earlier, of particular interest in this context. My analysis of the structure of the *Guernica* sketches (2004), presented in detail in Chapter 1, does not in my view support Simonton’s interpretation. In Chapter 1, I presented evidence that the overall structure of the painting was available from the earliest sketches, which indicates that no wild experimentation took place on the level of the overall structure. Each of the main characters in the painting was present in a majority of the composition sketches. Similarly, at the level of individual characters, one finds structure in the way they

were sketched: Picasso did not jump around randomly from one possible representation to another of a given character. The sketches of the women, for example, were highly structured in what they contained (see Figure 1.9). Finally, the external influences on *Guernica*—the works by Goya, among others—also demonstrate structure in Picasso’s creative process. The characters in *Guernica* that can be traced to Goya come from representations of the effects of war on innocent people, works that portray events similar in emotional tone to the event that stimulated Picasso to paint *Guernica*. For all these reasons, we have here a specific case where a detailed analysis of one creative achievement does not seem to support claims made by Simonton on the fine-grained level.

Questions about the Equal-Odds Rule

Simonton (2003) has consistently reported results that support the equal-odds rule across a wide range of domains, including musical composition. He asserts that the finding of equal odds of production of quality works over the careers of creative thinkers is strong support for the Darwinian view and for blind variation as the first stage of the creative process. However, results from two research projects have not supported the equal-odds rule. As briefly mentioned in Chapter 5, Weisberg and Sturdivant (2005) analyzed the career development of the four most eminent classical composers—Mozart, Haydn, Beethoven, and J. S. Bach—and found that the proportion of masterworks did not remain constant over any of their careers. The classification of a composition as a masterwork was based on the number of recordings available (see Hayes, 1989; Weisberg, 1994). For all the composers, as shown in Figure 11.2, the proportion of masterworks increased over their careers, which goes against Simonton’s equal-odds rule. In addition, there was some evidence of a falling off in masterworks later in the careers of all composers. The results in Figure 11.2 are summarized across all types of compositions; we are currently carrying out more detailed analyses of different types of compositions for each composer (e.g., symphonies, chamber music, pieces for solo instruments) to determine if the same pattern—an increase in masterworks over the first part of a composer’s career—is seen for the different types of compositions. Similar results were reported by Kozbelt (2004), who analyzed the career development of approximately 20 renowned classical composers and also found that many of them showed an increase in the proportion of masterworks over their careers.

The reasons for the discrepancies between Simonton’s findings and those of Weisberg and Sturdivant (2005) and Kozbelt (2004) are not clear. However, the fact that two studies have found the same pattern of results that conflict with Simonton indicates that there may be reason to question his

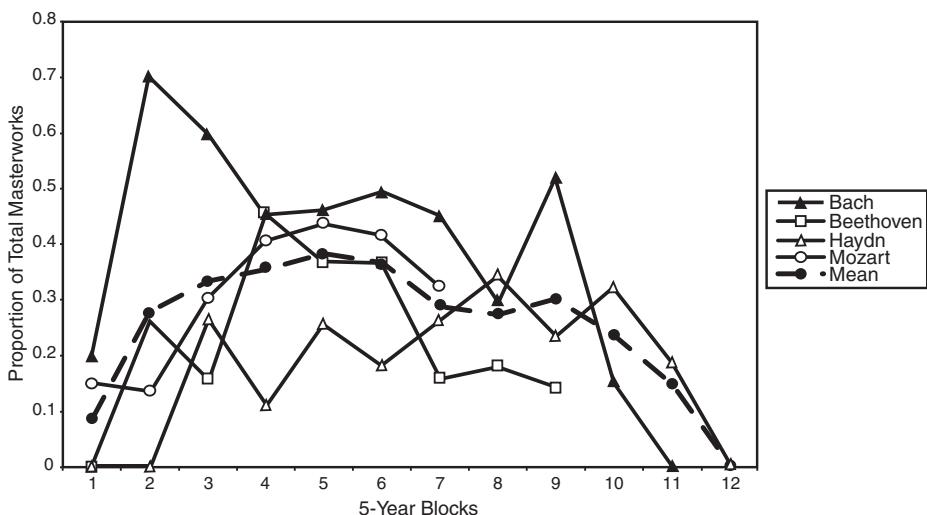


Figure 11.2 Proportion of masterworks per 5-year block of career for the best-known classical composers

Source: Weisberg and Sturdivant (2005).

conclusions. If so, it means that the equal-odds rule, one of the critical pieces of evidence in support of the Darwinian view (Simonton, 2003), may be on shaky ground.

Opportunistic Assimilation and Insight?

A final point of critique regarding Simonton's (2003) theory concerns his recent emphasis on the role of serendipitous environmental events in triggering insight during the incubation period, when a person has broken away from a problem. Simonton has adopted the opportunistic-assimilation theory of Seifert and colleagues (1995) as the basis for his explanation of insight. That theory was discussed in Chapter 8 in the context of the discussion of unconscious processes in problem solving. It was noted in that discussion that the results of the studies carried out by Seifert and colleagues do not support their own theory. In those experiments, people were given word problems to solve, and when they reached an impasse, they were then given another task to carry out, which involved word recognition. Unbeknownst to the participants, some of the words on the word-recognition task were the solutions to the as-yet-unsolved word problems. According to the model of Seifert and colleagues, presentation of those words during the word-recognition cover task should have resulted in the sudden realization on the part of the participants that they had solved one of those unsolved problems—an Aha! experience. However, such spontaneous Aha! solutions

were not reported by Seifert and colleagues, so I am assuming that they did not occur, which indicates that the opportunistic-assimilation mechanism postulated by Seifert and colleagues did not seem to be operating during problem solving in their study. As also noted in Chapter 8, independent support of the opportunistic-assimilation viewpoint is not strong at present (e.g., Christensen & Schunn, 2005). Therefore, Simonton may be mistaken in relying heavily on that mechanism to explain how serendipitous external events might play a critical role in stimulating insight.

To sum up, Simonton (e.g., 1988, 1995b, 1999, 2005) has constructed a broad-ranging confluence model of creativity, which is unique in its emphasis on the role of chance factors—both internal and external—in bringing about creative outcomes. The more revolutionary the outcome, the greater the role played by chance factors. While there is great sweep to Simonton's ideas, many different sorts of questions can be raised about the foundations of the theory. Fine-grained analyses of creative achievements do not support the critical role of chance processes in creativity. Furthermore, several pieces of evidence go against the equal-odds rule, one of the cornerstones of Simonton's model.

Confluence Models of Creativity: Summary

Each of the three confluence models discussed in this chapter attempts to integrate a broad range of phenomena in understanding creativity. The models have several components in common. First, and perhaps most important, all assume that the creative process functions to break away from the past, although the mechanisms postulated to bring about this break are different across the models. Amabile (1983, 1996) assumes that the use of general creativity-relevant processes and the influence of intrinsic motivation are critical in bringing about creative outcomes. Sternberg and Lubart (1995) assume that analytic intelligence, including the insight processes of selective encoding, selective combination, and selective comparison (Davidson, 1995; Sternberg & Davidson, 1982), plays a critical role in the reformulation of problems. Simonton (1988, 1995b, 2003), building on the theorizing of Campbell (1960) and Poincaré (1913), assumes that the random combination of ideas, sometimes brought about by serendipitous environmental events, is critical in the production of new ideas. From my perspective, all those models can be questioned on this ground, because, as noted numerous times, I believe that much evidence supports the claim that creative achievements do not come about through rejection of the past.

All of the confluence models that we have discussed also place emphasis on the causal role of personality factors in creativity. As noted in the last

chapter, the direction of causality in the creative personality is uncertain, and the researchers who developed the models discussed here have not presented any direct evidence that personality factors play a causal role in creative production. They simply assume, from the correlations typically found between creative achievement and personality factors, that the latter play a causal role in the former. However, it is also noted, especially by Amabile (1983, 1996) and Sternberg and Lubart (1995), that no one causal factor works alone in influencing creative achievement. A critical element in this confluence among factors in bringing about creativity is motivation, which Amabile was the first to emphasize, and which is explicitly or implicitly acknowledged by all researchers in the area, including those who developed the models discussed in this chapter.

Confluence models of the sort discussed here are no doubt the general shape of the ultimate theory of creativity that will be developed in psychology. However, some specifics of the dominant models of today may not withstand scrutiny, as demonstrated in this chapter.

CHAPTER

12

Understanding Creativity

Where Are We? Where Are We Going?

The centrality of ordinary thinking in creativity is the theme that has organized the presentation and review of research and theory in this book. The presentation and review have been two-pronged. The first half of the book focused on presentation of evidence that supports the ordinary-thinking perspective. Chapters 6–11 focused on a critical review of the research and theory that have been presented in support of various incarnations of the opposite view, the general idea that extraordinary processes—extraordinary cognitive processes and/or personality characteristics—must be invoked if we are to understand the creation of goal-directed novelty. In this chapter, I will review the evidence presented earlier to present a general overview and will also address some of the many questions that remain.

Outline of the Chapter

I will first review the case studies presented in Chapters 1 and 5 to examine the conclusions that can be drawn from them. I will demonstrate that each of them can be considered an example of problem solving, and the various types of problem solving involved in each will be examined. The analysis of the case studies provides strong evidence for the ordinary-thinking view. I then turn to a review of the results of the discussions in Chapters 6–11 of the various versions of the extraordinary-thinking view, results that have illuminated potential weaknesses in each of them. In addition, we will examine several additional issues: the structure of ordinary thinking in creativity, the use of

case studies in the study of creativity, and the status of the ordinary-thinking view of creativity as a scientific hypothesis. The chapter will conclude with a brief consideration of what makes a person creative.

Ordinary versus Extraordinary Processes in Creativity

We have examined several different variants on the general theory that creative achievements must be the result of extraordinary processes. The basic philosophy that underlies the extraordinary-thinking view is built on a negative conclusion: Ordinary thinking, which is based on the past and only moves beyond the past through incremental steps, is not able to support the great advances that emanate from the creative process. It follows from that negative conclusion that explaining creative thinking requires the postulation of thought processes that are structured in a different way from ordinary thought processes, because only the former would be able to overcome the limitations that theorists see as inherent in ordinary thinking. This general view is encapsulated in Mednick's (1962) concept of the flat associative hierarchies of the creative thinker contrasted with the steep hierarchies of the noncreative or ordinary thinker. Because they will play a significant role in the discussion in this chapter, Mednick's hierarchies are presented once again, in Figure 12.1.

As we saw in several early chapters, Mednick's (1962) ideas have been accepted explicitly by many modern researchers and implicitly by many others. His formulation of the difference between creative and noncreative individuals makes clear the general orientation that is common among the variants of the extraordinary-thinking view that we have considered in this book. Although the outward aspects differ across those various theories or points of view—for example, Amabile's (1996) theorizing versus Eysenck's (1995) versus Sternberg and Lubart's (1995) versus Simonton's (2003), or the notions of genius and madness or the unconscious—the basic motivating factor behind the development of those ideas is the core belief that ordinary thinking processes are not capable of bringing forth the sometimes amazing products of which human creative thinking is capable.

When the basic assumption underlying the extraordinary-thinking view of creative thinking is stated in this manner, it can be seen that there are two steps in the development of an understanding of the creative process. First comes an analysis of the thought processes underlying creative advances, since before going on to develop theories of the extraordinary processes underlying creativity one must show that creative products cannot be brought about through ordinary thinking. If it turns out that creative advances can be brought about through ordinary thought processes, it then becomes

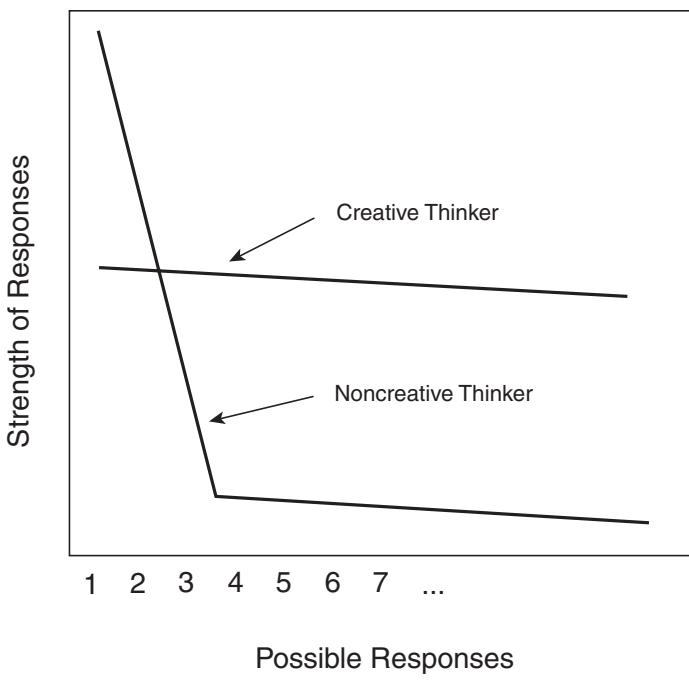


Figure 12.1 Mednick's theory

Source: Mednick (1962).

unnecessary to propose the various possibilities concerning extraordinary thinking that we have considered in the second half of this book. The reason that theorists have developed theories of extraordinary processes that underlie creativity is that many people find it transparently obvious that creative products cannot be understood as the outcome of ordinary thinking (see, e.g., Hausman, 1975; Simonton, 1988). There is then no need to consider further the possibility that creative products of the sorts we have considered in the case studies in Chapters 1 and 5 could be brought about through ordinary thinking.

There may also be a second set of beliefs behind the postulation of extraordinary thinking as the basis for creative production. If creative products could be brought about through ordinary thinking, then, so the argument might go, we all should be creative geniuses. Since we all are not creative geniuses, those products must be brought about by thought processes that are different from those that we ordinary people use. In either case, many researchers have turned directly to the postulation of extraordinary processes of various sorts as the basis for creativity without first examining the creative process in any detail.

One purpose of the case studies in Chapters 1 and 5, as we know, was to challenge the basic assumption that ordinary thinking cannot bring about great creative advances: I hoped to show that those case studies provide evidence that creative advances, some of which were radical leaps beyond what was known at the time, can be understood without postulating anything beyond the components of ordinary thinking processes. If the presentation of the case studies has completely convinced all readers that all creative products can be brought about through ordinary thinking, it becomes unnecessary to go further and critically examine the proposed variants on the view that extraordinary processes underlie creativity. However, for at least two reasons, it is not likely that all readers are convinced that all creative products are brought about through ordinary processes. It is true, first of all, that we have not examined a sweeping range of creative advances, so a critic of the ordinary-thinking view could say (with some justification) that perhaps there is a creative advance not considered in this book that was brought about through extraordinary processes. Furthermore, even if one could analyze *all* creative products, there would never be complete agreement that all of them were indeed the results of ordinary thinking.

Therefore, it is not enough to present case studies that demonstrate the plausibility of the ordinary-thinking view; it is also necessary to demonstrate that the support for each of the alternative extraordinary-thinking views is weak, which would also provide indirect support for the ordinary-thinking view. Thus, this book's second task has been to provide detailed reviews and critiques of theoretical views that provide alternatives to the ordinary-thinking view, to demonstrate that those alternatives are not very strong competitors. The basic task in this chapter is therefore twofold: I will first review the case studies, which I believe provide strong evidence for the ordinary-thinking view; then I will review the results of the discussions in Chapters 6–11, which I believe have called into question each of the variations on the extraordinary-thinking view that we have examined. In addition, the discussion in this chapter will examine several additional points concerning the structure of ordinary thinking in creativity, the use of case studies in the study of creativity, and the status of the ordinary-thinking view of creativity as a scientific hypothesis.

Ordinary Thinking in Creativity

The analysis of problem solving from the cognitive perspective has provided the general stage for the analysis of the thought processes that underlie creativity. Since we all solve problems as part of our ordinary day-to-day activities, problem solving is one manifestation of ordinary thinking.

Problem Solving as Ordinary Thinking

In Chapter 3, I examined a subset of the family of cognitive components that comprise ordinary thinking. Examples of those components were the following:

- Remembering
- Imagining
- Planning
- Deciding

I also outlined the general characteristics of ordinary thinking, which included the following:

- Our thoughts follow one from another, or are related to one another: Our thinking has *structure*.
- Ordinary thinking depends on the past: Our thought exhibits *continuity* with the past.
- Knowledge and concepts direct ordinary thinking: Our thought is directed by *top-down processing* and exhibits *planning*.
- Ordinary thinking can be influenced by environmental events: Our thought is *sensitive to environmental events*.

When an individual is trying to solve a problem, he or she “orchestrates” or organizes a subset of the cognitive components of thinking in order to bring about the solution. So problem solving is the result of the coordination of those cognitive components of ordinary thinking, and the general characteristics of ordinary thinking just listed come about as the result of that organized activity. The reason our ordinary thought has structure, for example, is that problem solving depends on, among other things, memory and planning. Similarly, ordinary thinking depends on the past because memory and top-down processing, which are the residue of the past, play critical roles in problem solving.

Newell, Simon, and their colleagues (e.g., Newell & Simon, 1972; Newell, Shaw, & Simon, 1962; Simon, 1986) were the first modern researchers to propose a direct connection between problem solving and creative thinking: Creative thinking, they suggested, was simply problem solving. They proposed that this was true even in areas that might not have been considered problem solving, such as the creation of paintings and poems. In Newell and Simon’s view, the latter situations could be looked upon as ill-defined problems (see Chapter 3), which required that the problem

solver play a role in specifying the structure in the situation. The cognitive perspective views problem solving as a search through a “space,” which is defined by states and a set of operators that change one state into another. The methods used to search through problem spaces range in specificity, from the very general weak methods, through analogical transfer of varying degrees of remoteness, to the strong methods based on expertise. That general perspective on problem solving has proven widely applicable to problem-solving situations of various sorts (e.g., Lovett, 2003; Newell & Simon, 1972; Robertson, 2001). The analysis in this book is one of several that demonstrate that the cognitive analysis of problem solving is applicable to the discussion of creative advances (see also Weber & Perkins, 1992; Gorman, Tweney, Gooding, & Kincannon, 2005).

Is All Creative Thinking Equivalent to Problem Solving?

An important question that remains in applying the cognitive perspective to creative thinking is whether all examples of creative thinking can be conceived of as exemplifying problem solving. The case studies presented in Chapters 1 and 5 can help to answer that question. In Chapter 3, I raised the possibility that creative thinking might be based on ordinary thinking but not structured as problem solving, since not all ordinary thinking involves problem solving. The second column in Table 12.1 analyzes each case study discussed in this book, in order of presentation, to determine whether it can be considered an example of problem solving.

As can be seen, the answer to that question appears to be yes: All of the case studies can be considered to be examples of problem solving. Watson and Crick were explicitly trying to analyze the problem of the structure of DNA (Watson, 1968). Picasso’s creation of *Guernica* also seems to be an example of problem solving, as it is reasonable to describe Picasso’s situation as grappling with the ill-defined problem of expressing in his art the feelings that were aroused by the bombing of the city (Chipp, 1988). Calder too was trying to solve a problem: that of creating moving sculpture in the abstract nonrepresentational style of Mondrian (Calder, 1966; Marter, 1991, p. 102).

Turning to *Les Demoiselles d’Avignon*, the answer is less clear, since in this case there was not an obvious external problem to be solved, as when a patron commissions a portrait from an artist, or a direct stimulus to the work that initiated a problem, as there was with the creation of *Guernica*. Based on the discussion in Chapter 5 of the creation of *Les Demoiselles*, one could say that in creating the painting Picasso was trying to solve the problem of conveying his feelings about the dangers of sexuality. In addition, although this is a point not discussed in Chapter 5, there is some

Table 12.1 Classification of case studies: Is problem solving involved?

Creative advance	Is it an example of problem solving?	Where did the problem originate?	Type of problem
Watson and Crick's double helix	Yes. Watson and Crick were trying to solve the problem of specifying the structure of DNA.	The problem was part of the domain.	Presented
Picasso's <i>Guernica</i>	Yes. Picasso was trying to solve the problem of expressing his feelings about the bombing.	The bombing of Guernica.	Discovered
Calder's mobiles	Yes. Calder was solving the problem of how to incorporate Mondrian's abstract style into moving sculpture.	Calder's visit to Mondrian's studio.	Discovered
Picasso's <i>Les Demoiselles d'Avignon</i>	Yes(?). Picasso was trying to solve the problem of expressing his feelings about the dangers of sexuality; he was also competing with Matisse.	Picasso's feelings. Competition with Matisse.	Discovered Presented(?)
Picasso and Braque's Cubism	Yes. Braque and Picasso were trying to develop a new style.	Braque and Picasso's analysis of Cézanne's late work.	Discovered
Pollock's "poured" style	Yes. Pollock was trying to develop a new style of painting, based on pouring paint.	Siqueiros's influences on Pollock.	Discovered
Darwin's theory of evolution	Yes. Darwin was trying to develop a theory that would explain the evolution of species.	The problem was part of the domain.	Presented
Wright brothers' airplane	Yes. They were trying to solve the problem of building a flying machine.	The problem had been explicitly set hundreds of years earlier.	Presented
Edison's phonograph	Yes. Edison was solving the problem of obtaining permanent records of telephone conversations.	The problem was set earlier by needs of industry.	Presented

Edison's kinetoscope (motion pictures)	Yes. Edison was trying to solve the problem of presenting moving images.	Problem presented during Edison's meetings with Muybridge (?) and/or Marey.	Presented
Edison's light bulb	Yes. Edison was trying to solve the problem of producing electric lighting that would be usable domestically.	The problem had been set many years earlier.	Presented
Edison's electrical system	Yes. Edison's project had been to design a light bulb that would work within an electrical system.	Edison's entrepreneurial orientation.	Presented
Watt's steam engine	Yes. Watt was trying to solve the problem of getting a miniature Newcomen engine to work efficiently.	Overall problem: Watt's employment. Specific problem: inefficiency of Newcomen engine.	Presented Discovered
Whitney's cotton gin	Yes. Whitney was solving the problem of designing a machine that could clean short-stapled cotton.	The problem existed in the South.	Presented
Franklin on DNA	See double helix.	See double helix.	
Wilkins on DNA	See double helix.	See double helix.	
Pauling on DNA	See double helix.	See double helix.	
Lamarck on evolution	See Darwin.	See Darwin.	
E. Darwin on evolution	See Darwin.	See Darwin.	
Earlier attempts to invent flying machine	See Wright brothers.	See Wright brothers.	
Earlier attempts to invent electric light	See Edison's electric light.	See Edison's electric light.	

evidence that Picasso painted *Les Demoiselles d'Avignon* in response to a painting by Henri Matisse (1869–1954), who was Picasso's main rival as the outstanding young artist in Paris at the time (Rubin, 1994). The brazen sexuality as well as the radical stylistic features in Picasso's painting may have been implemented at least in part in an effort to outdo Matisse. If either of those possibilities is true, then *Les Demoiselles* can be classified as an example of problem solving in art.

The development of Cubism by Picasso and Braque can be seen as their attempt to develop a new style of representation in painting, which would be an example of solving a problem. Especially in the early stages of their collaboration, the two artists actively analyzed each other's works, which is further evidence of the problem-solving nature of the activity (Rubin, 1989). Pollock too was working on developing a new style, so his breakthrough can also be classified as the solution to a problem (Varnadoe, 1998). Darwin was explicitly trying to solve the problem of developing a theory that could explain how species evolved (Eiseley, 1961; Gruber, 1981). The Wright brothers were trying to solve the problem of building an airplane (Heppenheimer, 2003). Edison's inventions are all examples of problem solving (Israel, 1998). The phonograph was designed to solve the problem of how to record sound to preserve telephone messages. The kinetoscope was designed to solve the problem of how to make moving images visible. The electric light and the electrical lighting system were designed to provide a practical and safe alternative to the extant gas lighting system. Watt was explicitly assigned the problem of preparing a miniature steam engine for a lecture demonstration (Basalla, 1988), and Whitney was trying to solve the problem of cleaning short-stapled cotton (Basalla, 1988).

Other cases have been added at the bottom of the table that were discussed during the presentation of the focal case studies listed there. Examples are Pauling's, Wilkins's, and Franklin's work on DNA; Lamarck's and Erasmus Darwin's theorizing about evolution; other inventors' attempts to invent a flying machine; and so forth. All those cases would also be examples of problem solving, since the unsuccessful individuals were trying to solve the same problems that the successful individuals solved. Indeed, as we know, in some cases (e.g., DNA) the successful and unsuccessful individuals were working in close physical as well as intellectual proximity. There have also been case studies of creative advances in science and technology carried out by other investigators that were not discussed in Chapter 5 due to lack of space. (For examples, see Weber and Perkins, 1992, and Gorman and colleagues, 2005.) Those cases would also fit the definition of problem solving as discussed here. Klahr and Simon (1999) provide summaries of several of those cases.

In addition, the computer programs developed by Langley and colleagues (1987; see Chapter 3 for a review) are examples of the application of weak problem-solving methods to simulations of situations that involved creative thinking (e.g., Kepler's discovery of his laws of planetary motion). If one accepts those computer programs as simulations of creative thinking (although, as noted in Chapter 3, some researchers do not accept that assumption [Csikszentmihalyi, 1988]), they offer further support for the role of problem solving in creative advances.

One might also apply notions of problem solving to the three examples of career development discussed in Chapter 5, which demonstrated the relevance of the 10-Year Rule in the development of creative individuals, specifically Picasso, Mozart, and the Beatles. One can look upon Picasso's career development, for example, as an attempt to learn how to draw and paint. As noted earlier, Pariser (1987) has described the "task" of the young artist as learning how to solve certain problems of representation, and he has proposed that all artists go through essentially the same sequence of learning. We can also take this orientation toward Mozart's career development and that of the Beatles; in both situations we have individuals learning how to solve problems within their chosen genre of expression. In general terms, when an individual has made a decision to pursue a career in some creative domain, the subsequent work to acquire the skills to excel within that domain is a problem-solving task. Accepting this conclusion would mean that the career development of all the individuals listed in Table 12.1 also qualifies as examples of problem solving, since none of them achieved what they did without acquiring expertise in their domains (see also Chapter 5).

In Chapter 3, in introducing the cognitive perspective on problem solving, I advocated some caution concerning whether we could consider all creative thinking to be the result of problem solving. As a result of the summary just presented, which is based on a relatively broad range of cases (and, as noted, other cases not reviewed here), that caution may have been unnecessary. In light of these findings, it seems reasonable to adopt as a working assumption the premise that creative thinking is an example of problem solving.

Different Kinds of Problems?

Although all the examples of creative advances that we have discussed here can be classified as problem solving, there are interesting differences in how those problems originated. That question is considered in the third column of Table 12.1. In some of the examples, the individuals were explicitly trying to solve problems that had been established by those who

came before them in that domain. This was true of the double helix, Darwin's development of the theory of evolution through natural selection, the Wright brothers' invention of the airplane, Edison's inventions, and Whitney's cotton gin: All are clearly examples of problem solving in which the problem existed before the individual began to work in that domain. Following Csikszentmihalyi and Sawyer (1995), we can call them *presented* problems.

In the remaining examples in Table 12.1, on the other hand, the problem-solving activities came about in response to problems that had not been formulated before the individual came on the scene, and the individual who solved the problem played a central role in formulating it. For example, although Watt had been given the problem of preparing a model Newcomen engine for a lecture demonstration (a presented problem), the specific design of Watt's new steam engine—and, indeed, the fact that Watt invented a new steam engine at all—was the result of a problem that he formulated, or *found*, or *discovered* as he was attempting to repair the demonstration Newcomen engine. That problem only came into existence as a result of Watt's activities. There was no need in society for a new steam engine, at least not in the coal mines where Newcomen engines were in maximum use (Weisberg, 1993), so the problem of improving the Newcomen engine did not exist except in Watt's mind. However, the problem was obvious to Watt: He could not get the Newcomen engine to run well enough to serve in the demonstration, which was his assignment.

Based on this example, it would be useful to make a distinction here between the problem the person is trying to solve and the basis for initiation of his or her problem-solving activity. As a result of his interaction with the Newcomen engine, Watt discovered a problem, which he then set out to solve. That solution was a new type of engine. We discussed in Chapter 3 the notion of problem finding, as formulated by Getzels and Csikszentmihalyi (1976), to describe the behavior of the student artists in their study as they decided on the grouping of objects for the still life painting that they were preparing to execute. The individuals who produced the most effective paintings, as judged by artist judges, were those who spent the most time arranging the objects before they began to paint. In the discussion of that research in the context of the cognitive analysis of problem solving in Chapter 3, I concluded that it was more straightforward to say that the art students actually had two problems to solve: (1) formulating the subject for the still life and (2) rendering it in paint. Those are both presented problems, and it seemed at that point unnecessary to introduce *problem finding* as a new theoretical term.

In the context of discussing Watt's invention, however, problem finding

becomes a useful description of what happened. Watt found a problem that he did not have when he began, which he then went to work on. So Watt's dual-cylinder steam engine can be described as being the result of problem solving, but it is the solution of a problem that Watt found or discovered rather than an already extant one. In the third column of Table 12.1, the initiating conditions for Watt's problem-solving activities are described. His overall problem was one that was formulated as part of his employment, so it was a presented problem. His second problem, increasing the efficiency of the Newcomen engine, was a discovered problem. Henceforth, when discussing Watt's invention of the dual-cylinder steam engine for which he is famous, I will label it the solution of a discovered problem.

As discussed in Chapter 3, other researchers have found it useful to incorporate problem finding or similar terms in discussions of creativity in other contexts (e.g., Reiter-Palmon and colleagues, 1997; see also Runco, 1994; for reviews see Runco and Sakamoto, 1999, and Nickerson, 1999). It is not clear at present whether the distinction between found or discovered problems and extant or presented problems is important vis-à-vis the understanding of the creative process as problem solving. That is, solution processes may be the same in both types of problems; this point will be addressed shortly.

The notion of problem finding or discovery is also relevant to Calder's development of mobiles. Calder's switch to the abstract style that marks his mobiles came about as his response to a visit to Mondrian's studio. That is, at that point he set himself the problem of trying to produce moving sculpture in Mondrian's abstract or nonrepresentational style. So the visit to Mondrian's studio was the stimulus for Calder's finding or discovering a problem that did not exist until then. From that point on, perhaps throughout the rest of his career, he attempted to solve that problem.

Braque and Picasso's development of Cubism out of Cézanne's late work (see Chapter 5) was also the solution to a discovered problem. There was no problem to be solved before Braque and Picasso began to consider the implications of those Cézanne works and before they began to collaborate on the task of extending and elaborating what they found in Cézanne into a new style of representation. This example may be like Watt's steam engine: As Braque and Picasso were working, the problem evolved. Pollock's development of his mature poured paintings of the late 1940s (see Chapter 5) came about in a way similar to Calder's. Pollock seems to have discovered the germ of the style as a result of his exposure to Siqueiros's painting style and his interactions with Siqueiros and the other young artists in Siqueiros's workshop and elsewhere around that time. If that is correct, then Pollock too discovered a problem, like Calder, which he then, also like Calder,

solved over the next several years. The problem was to use the techniques demonstrated by Siqueiros and experimented with by the young artists as the basis for developing a style of painting that could serve his needs as an artist.

Guernica was also the solution to a found problem, since Picasso's desire to paint was a response to news of the bombing. Before that external stimulus occurred, Picasso presumably had no desire to create an antiwar painting, or at least there is no evidence that he was making preparations to paint one. The problem that resulted in Picasso's painting *Guernica* was comparable to the one that developed when Calder visited Mondrian's studio. Like Calder's problem, Picasso's problem was discovered by him in his response as an artist to an external event, rather than being suggested to him by someone else.

If we consider *Les Demoiselles d'Avignon* in this context, the development of that painting may require us to make some finer distinctions. Assuming that Picasso's desire to create that painting originated at least in part from his feelings at that time toward women and sexuality, then the problem was discovered on a basis different from the others discussed so far: It came out of an artist's feelings. That would be an example of a discovered problem that originated internally. If feelings of rivalry with Matisse also played a role (Rubin, 1994), then the problem may have also had a presented component, since other people may have stimulated that rivalry. A further question is whether any scientific or technological advances came about in the same way, that is, as the result of an individual's internal response to an external event. On the basis of the sample of cases discussed here, one might say that the Wright brothers' decision that their flying machine had to have a control system that the pilot could use was based on their discovery of a problem that was based at least in part on the subjective response to an external event: the death of Lilienthal.

The third column of Table 12.1 summarizes the origins of the problems dealt with in the case studies. As can be seen, there was a range of paths to the problems that resulted in the production of the innovations considered in the case studies.

Are Different Types of Problems Solved Differently?

We have now analyzed the types of problems associated with the innovations in the case studies discussed in Chapters 1 and 5. The presented-discovered distinction raises the question of whether the two types of problems are solved through different means. Table 12.2 summarizes for each case study the type of problem that was involved and the specific aspects of problem solving from the cognitive perspective that can be found in

Table 12.2 Problem solving in the case studies.

Creative advance	Type of problem	Components of problem solving seen
Watson and Crick's double helix	Presented	Analogical transfer from Pauling; working backward; strong methods of analysis based on expertise; logical inferences based on data.
Picasso's <i>Guernica</i>	Discovered	Transfer from <i>Minotauromacy</i> ; planning of overall structure and of specific characters.
Calder's mobiles	Discovered	Transfer of Mondrian's style; use of expertise; analysis of problems with motors as sources of movement.
Picasso's <i>Les Demoiselles d'Avignon</i>	Discovered	Planning of overall structure and characters; adoption of "Iberian" style based on Iberian sculpture; radical change in three faces based on "primitive" sculpture.
Picasso and Braque's Cubism	Discovered	Transfer of Cézanne's style; analysis in the development and elaboration of the new style; use of expertise.
Pollock's "poured" style	Discovered	Transfer of Siqueiros's methods; development through practice of system capable of behavioral adjustments.
Wright brothers' airplane	Presented	Analogical transfer from bicycle and birds; use of reasoning in designing wing-warping system; use of expertise to construct airplane.
Edison's phonograph	Presented	Transfer from telegraph recorder-repeater.
Edison's kinetoscope	Presented	Transfer from phonograph.
Edison's light bulb	Presented	Transfer (unsuccessful) from earlier researchers' attempts; analysis of problems with platinum; use of expertise.
Edison's electrical system	Presented	Transfer from gas-lighting system.
Watt's steam engine	Presented/discovered—external	Transfer from Newcomen engine; analysis of problems with Newcomen engine.
Whitney's cotton gin	Presented	Analogical transfer from gin for long-stapled cotton; use of logic in analysis of new design; use of expertise as machinist to construct machine.

each. Examining those components will allow us to scrutinize whether found or discovered problems are solved in a different way from presented or already-extant problems. Based on the information in Table 12.2, there do not seem to be clear differences between the methods used to solve discovered versus presented problems. In both types of problems, we see the individuals relying extensively on the past, either their own past works or related work by others. That reliance on the past is as strong in art as it is in science and technology.

Extraordinary Processes in Creativity?

We have now considered the case studies of creative thinking as examples of problem solving. We now turn to the second task for this concluding chapter, a reconsideration of the evidence in support of the various examples of the view that creativity is the result of extraordinary thinking.

Leaps of Insight in Problem Solving

The idea that creative ideas come about in leaps of insight, which allow the thinker to go far beyond what might have been possible through ordinary analytic thinking, was reviewed in Chapter 6. The Gestalt view of insight and its neo-Gestalt offspring hypothesize that insight results from a restructuring of a problem—the individual's suddenly discovering a new way to represent a problem and striking out along a new solution path—and assume that such restructurings are the result of processes different from those underlying analytic problem solving. Although the specific perceptually based mechanisms postulated by the Gestalt psychologists are no longer held in favor by most modern psychologists who study creative thinking, there is still a significant stream of research based on the assumption that the processes underlying insight are different from those underlying problem solving based on analytic methods (see Table 6.3, p. 309; for critique see Table 6.7, p. 331).

Two sorts of evidence were reviewed in examining the support for that view, and that review pointed to the conclusion that insight in problem solving is the result of ordinary analytic thought processes. First, examination of evidence presented in support of the Gestalt view, both from classic research and from more modern studies, indicated that there is no unequivocal support for that position. Many of the experimental findings that are presented in support of the Gestalt view of insight do not stand up to close inspection. Second, laboratory studies of problem solving have provided evidence that indicates that leaps of insight during the solution of problems can be brought about as the result of analytic processes; that is,

Aha! experiences come about as the result of people's reasoning their way through to the solution of a problem (Perkins, 1981; Fleck & Weisberg, 2004, 2006). Such results indicate that the critical element in producing Aha! experiences may not be a unique set of processes as much as an element of surprise when an unexpected solution suddenly becomes clear, and unexpected solutions can be brought about through ordinary analytic problem-solving processes. Thus, evidence that problems are in some cases solved suddenly does not rule out ordinary processes in the solution.

In a related vein, studies of insight in problem solving have demonstrated that restructuring in problem solving can be brought about by new information acquired as people work through a problem. Unsuccessful solution attempts, initiated by the problem instructions' interacting with the individual's knowledge, can result in new information's becoming available. That new information can result in the development of a different path toward solution of the problem—a restructuring of the problem—from that initiated by the information available when the person began working on the problem (Fleck & Weisberg, 2004; Weisberg & Suls, 1973). So the occurrence of restructuring is not, *per se*, evidence that nonanalytic thought processes were involved in problem solving.

Genius and Madness

The idea that psychopathology or an inherited tendency toward psychopathology facilitates creative thinking has emerged in several variants over the years as the specific state assumed to be critical to facilitating creativity has varied from schizophrenia to bipolar disorder. Research indicates that the relation between psychopathology and creativity is more complex than the simple notion that psychopathology fosters a looseness or bizarreness in thinking that facilitates creativity.

It seems to be true that psychopathology is more prevalent among creative individuals and their relatives (but see Becker, 2000–2001). However, there is little direct evidence that the creative thought processes are positively affected by psychopathology. In addition, there is evidence that causality may sometimes operate in the direction opposite to that assumed by advocates of the genius and madness view. That is, there is evidence that creative achievement, rather than being the result of psychopathology, may stimulate the development of psychopathology (Johnson et al., 2000). In addition, the link between psychopathological tendencies and creativity may be very indirect, as a person may be attracted to a domain because the attitudes espoused by the members of that domain fit the individual's preferred attitude toward the world (Sass, 2000–2001). In such a case, the creative process is basically independent of the personality factors.

The Unconscious

The idea that the unconscious is critical in creativity has two components. First, based on the influence of Freud and the notion of primary-process thinking, some researchers assume that the unconscious can make connections among ideas that would be beyond the reach of conscious secondary-process thought. That is, unconscious associations are organized into flat hierarchies. Second, it is assumed, based on the theorizing of Poincaré (1913), that humans can carry out parallel processing, which means that one can be incubating a problem, or working on it unconsciously, while consciously carrying out other activities. Parallel processing of that sort can result in a sudden solution to a problem that one was not consciously thinking about—an illumination. Also, the large-scale parallel processing postulated by Poincaré can result in a thinker's making connections that could not be made through limited-capacity conscious thinking.

Research support for the two components of the unconscious view, however, is not very strong. Concerning primary-process thinking, there have been studies that have attempted to measure the contribution of that process to creativity, but the results have been weak. The hypothesized process of parallel processing that results in unconscious incubation has not been supported by experimental studies. The only support for unconscious processes in creativity comes from self-reports from creative thinkers, which are of questionable value as evidence for a scientific theory of creativity. However, it should be emphasized that it is not clear at present how one might explain the occurrence of incubation and illumination through the action of ordinary thought processes. A number of researchers have proposed explanations for illumination that do not depend on the unconscious (e.g., Seifert et al., 1995; Smith, 1995), but none of those explanations seems capable at this point of explaining how a person who is not thinking about a problem can suddenly recall the problem and be presented with the solution.

Olton (1979) has proposed that effects usually attributed to unconscious processing are in reality the result of conscious thinking about a problem during the time one has supposedly stopped thinking about it. However, Olton's creative-worrying explanation cannot explain how a person can report the sudden solution to a problem that he or she had not been thinking about, assuming that people are aware when they carry out creative worrying. In order to extend Olton's explanation to account for such illuminations, I speculated that they might be brought about as the result of very brief and therefore nonremembered incidents of thinking about the problem, although I emphasized that there is no support whatever for that speculation. The reports of illuminations provided by many individuals, if true, are phenomena still in need of an explanation.

Divergent Thinking

Divergent thinking—thought processes that allow a person to produce numerous and varied ideas, which facilitate the person’s breaking away from the ordinary—was postulated as a critical component of creativity over 50 years ago by Guilford (1950). Guilford’s proposal resulted in the development of tests to measure that postulated capacity as well as numerous studies that examined the relationship between divergent thinking and various aspects of the creative capacity. Over the years, divergent thinking has come to be considered creative thinking, and scores on divergent-thinking tests have sometimes been equated with ratings of creativity, although Guilford postulated divergent thinking as only one component of the creative process, and (as discussed in Chapter 9) Guilford’s conception of creative thinking went beyond divergent and convergent thinking, although that other work is not central to current research and theory (Mumford, 2001).

Numerous studies have attempted to determine the relationship between scores on divergent-thinking tests and creative performance as assessed in various ways. Results indicate that divergent-thinking scores are not always related to measures of creativity and that they may not be very strong predictors of later creative performance. One can also question the basic set of assumptions underlying Guilford’s postulation of divergent thinking as a critical component of the creative process. First, one can question whether there is a general set of thinking skills that underlies creativity in all domains, as the development of general tests of divergent thinking seems to assume. Second, one can challenge Guilford’s assumption that the creative process involves two stages: production of numerous ideas followed by selection of promising ones for further consideration. This bottom-up conception seems to conflict with the evidence of top-down process in the case studies of creativity.

Creative Personality

In addition to postulating divergent thinking as the core cognitive component of creativity, Guilford (1950) also proposed that an individual’s personality was an important factor in making a person creative. This hypothesis has led to numerous studies that have attempted to measure the “creative personality,” those characteristics that differentiate individuals of creative accomplishment from their less-creative or noncreative peers. In this area one can draw mixed conclusions. On one hand, studies of the creative personality are limited in what they can tell us about personality factors that play a role in a person’s becoming creative. Almost all of those studies are correlational in design, which limits the types of conclusions that can be drawn about cause-effect relationships. The few studies that have

used prospective or longitudinal designs have not found strong relationships between personality characteristics and creative accomplishment.

However, a set of findings concerning the relationship between creative personality, cognitive processing, and creativity has recently been advanced, centered around the notion of openness to experience. Researchers have proposed that creative individuals are able to process a wider range of information than are less-creative people, and that the more-creative persons are less prone to actively inhibit the processing of peripheral information. This breadth of processing of internal as well as external information makes it more likely that an individual will make a connection between remotely associated stimuli. This breadth of processing is assumed by some to be the result of inherited personality characteristics (e.g., Eysenck, 1995). This broader-processing view of creativity seems to conflict with the results from the case studies of creative advances presented in this book. In Chapter 10 I noted that one way out of that impasse was to consider the possibility that the conclusions from the case studies are open to doubt. Perhaps the case studies do not provide the window into the creative process that I have assumed they do. This point will be discussed in more detail in a later section.

Confluence Theories of Creativity

Confluence theories of creativity attempt to bring together findings from several areas—studies of cognition, personality, and social-environmental factors—in developing integrated theories of creativity. Amabile's research (1983, 1996) broke new ground in emphasizing the role of social-environmental factors, including the individual's motivation toward the task, as determinants of creativity. The importance of intrinsic motivation was emphasized in her work. Sternberg and Lubart (1995) used stock market investment as a metaphor for the creative process, investigating the resources required for creativity and discussing how those resources should be best managed for maximum return. Simonton's (1999, 2003) theory is built on Campbell's (1960) Darwinian notion of blind variation as the first step in the creative process. The creative individual is assumed to be capable of producing improbable combinations of ideas due to the structure of his or her ideas.

Each of these theories has furthered our understanding of creativity in some areas, but general questions can be raised about their adequacy. First, all three theories postulate that the creative process is based on breaking away from the past. One may recall Simonton's (1995b, p. 484; 2005) conclusion, discussed in Chapter 11, that the creative individual must be able

to make wild or bizarre connections between ideas. That assumption seems to be contradicted by the case studies in this book. Second, the confluence theories assume that there are general creativity-relevant cognitive skills that would be relevant to innovations across domains. However, there is evidence that creativity depends on the development of domain-specific expertise rather than domain-general skills. Finally, all the theories assume that personality factors play a role in determining whether an individual is creative. As we have just seen, that assumption is problematic.

Extraordinary Processes in Creativity: Conclusions

We have now reviewed the variations on the extraordinary-process view of creativity that were examined in this book. Overall, the support is not very strong for any of them. In conjunction with the positive results from the case studies reviewed earlier, this finding suggests to me that there is no compelling reason to introduce anything beyond ordinary processes into explanations of creativity. We can rephrase this conclusion in an informative way by reexamining Mednick's (1962) associative hierarchies. Figure 12.2 presents Mednick's hierarchies again, through the prism of the conclusions in this chapter. The creative and noncreative thinker are assumed to have identical response hierarchies. That is, all people have a store of knowledge organized in the same way: We all have stronger versus weaker responses

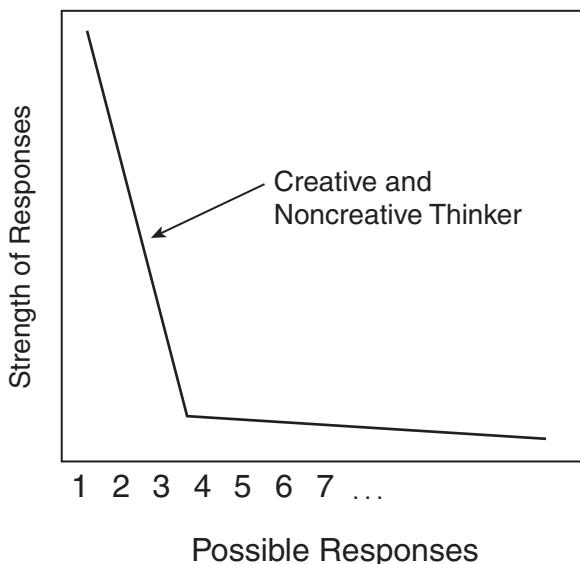


Figure 12.2 An alternative view: Identical hierarchies for creative and noncreative thinkers

to every situation, and the creative individual's responses are no stronger or weaker than anyone else's. The reason that Mednick and those who accepted his analysis felt it was reasonable to postulate a flat hierarchy for the creative person is because we laypeople often cannot understand how a creative person came up with an idea. Since our ideas do not enable us to follow the train of thought that led to a creative advance, it seems reasonable to assume that a thought process or a set of associations structured differently from ours was involved.

However, on the basis of case studies, it seems more reasonable to conclude that we cannot follow the thought process of the creative individual because we do not possess the same content of thought as the creative person. For example, we might not be able to understand how Picasso could have thought of Goya when he was working on *Guernica*, so we assume that Picasso's knowledge must be organized differently from ours. However, if one thinks about the subject matter of Goya's work, and if one knows how Picasso felt about Goya's work, then it is understandable that the bombing of Guernica could bring to mind Goya's *Disasters of War*. The reason we do not understand Picasso's thinking is that we are ignorant of his database, not that his thinking works differently from ours. This analysis of the difficulty of understanding the creative thought process leads to two questions, one concerning the logic behind the use of case studies to analyze creativity, and the second concerning the scientific status of the proposal that creativity is the outcome of ordinary thinking processes.

On Using Case Studies to Study Creativity

The present analysis of the creative process has placed much emphasis on information gleaned from case studies of seminal creative advances in several domains. Those case studies are—at least to me—intrinsically interesting, and they can draw people to the scientific study of creativity. However, in this book I have attempted to use the case studies as more than interesting anecdotes to pique the curiosity of the reader: I have assumed, here and elsewhere (e.g., Weisberg, 1993, 1999, 2003), that case studies can provide useful data on the creative process. Others have made similar assumptions (e.g., Gruber, 1981; Holmes, 1980, 1996; Gorman and colleagues, 2005; Tweney, 1989). It may be helpful in bringing this book to a close to consider again some of the characteristics of the case-study method, so that one goes away from this work with as clear a picture as possible of the strengths and weaknesses of the conclusions that have been drawn here.

First of all, as noted in Chapter 2, case studies provide access to individuals who otherwise would be outside of the range of study. Through the use of

the case study, individuals who are no longer alive, or who, through their celebrity, are otherwise inaccessible, become possible sources of information about the creative process. Researchers who study creativity hope to ultimately make generalizations about the creative process that will apply to all individuals, ranging from the person who simply produces some small-scale novelty in his or her day-to-day activities to those who change the world with their works. In order to make wide-ranging generalizations, one must study creativity at the highest level as well as the more prosaic (e.g., undergraduates solving problems in the laboratory). One cannot assume that conclusions drawn about day-to-day creativity will hold for creative production at the highest level. This difficulty leads in my view to the necessity of trying to use case studies as a means of acquiring data about the creative process from people who are beyond the reach of the typical psychological investigation. One cannot simply assume that the creative process works the same way at all levels; one must study creativity at all levels to demonstrate that the processes are the same.

If case studies are attractive because of their intrinsic interest, one faces the possibility that one's choice of subject matter will be in some way biased, because the case studies that are interesting might be so because of some common peculiarity of structure, and therefore any conclusions from those case studies will be incomplete and/or invalid. For example, one might choose case studies (inadvertently) because they provide information concerning the genesis of an innovation. Perhaps case studies that would not provide such information (and that would, *ipso facto*, contradict the ordinary-thinking view) are ignored as not interesting. One way to address this possible difficulty is to have as many people as possible analyze as wide a range of case studies as possible. The present set of case studies is one small step in that direction, as are those by other investigators just mentioned. There have been few attempts to synthesize results across a wide range of studies, perhaps in part because it is difficult to specify dimensions along which cases can be compared. The discussion earlier in this chapter of the features of the case studies presented in this book is one attempt to provide specification of underlying similarities and differences across studies, but that is just a beginning.

A further question of importance in this context is whether the data from case studies are useful. Picasso's sketches, for example, are objective data, but what do they tell us about his creative process? I have assumed that the sketches tell us something about the play of thoughts that comprised the process whereby *Guernica* was created. That is, the string of sketches corresponds to a string of states in a *state + operator* sequence, comparable to that which can be obtained in the study of ordinary problem solving through

the collection of verbal protocols. (See the discussion in Chapter 3 on the solution to the Towers of Hanoi as obtained through a verbal protocol.) In other words, I am interpreting Picasso's sequence of sketches as a visual protocol obtained during Picasso's creative process.

However, it is possible that the sketches are more downstream than I have assumed. Might a sketch itself be the *result* of a complicated creative process, rather than a window into a relatively early stage of the creative process for another work? That possibility might be correct, but at this point we cannot say. One way to obtain more information about the status of sketches as products of the creative process might be to have artists create works in the laboratory and to obtain verbal protocols and preliminary sketches at the same time (assuming that collecting verbal protocols does not interfere with producing preliminary sketches; Ericsson & Simon 1996; Schooler and colleagues, 1993; Fleck & Weisberg, 2004, 2006). Such a study would provide evidence of the amount of complex processing that accompanies sketches and would enable us to decide what they tell us. It should be noted that this problem also arises for any case study material, such as laboratory notebooks (e.g., Gruber, 1981; Holmes, 1980).

Thus, it must be acknowledged that at present all conclusions based on case studies are tentative. However, given the limited number of cases studied, and the difficulties in comparing them across dimensions, any conclusions would be tentative anyway.

Is It Possible to Test the Hypothesis That Ordinary Thinking Is the Basis for Creativity?

The final point to be discussed concerns the scientific status of the notion that ordinary thinking is the basis for creativity. Any set of statements purporting to be a scientific explanation of any psychological phenomenon must be subject to empirical test and, perhaps most important, must be subject to possible falsification (Rosenthal & Rosnow, 1991). If a proposed theory is formulated in such a way that it is able to explain everything—that is, if it is able to account for every set of facts that arises and that might arise—then the theory is empty: It is stated in such vague terms that it is useless. Although the proposed theory may be seen as making testable claims, it is necessary that we have available, before we begin to test anything, some idea of what sorts of specific results would prove the theory *wrong*. It is not necessary that such results arise; rather, it is necessary that such results be specifiable and that experiments testing the proposed theory be designed so that it is possible that such results could occur.

It is important to examine those foundations for scientific reasoning

because we must be aware of potential problems with the ordinary-thinking view as a scientific theory. The hypothesis “ordinary thinking is the basis for creativity” may appear to be a testable hypothesis about the structure of creative thinking. However, it might in actuality be so vague that any results from any case study, for example, could be seen as being an example of ordinary thinking. Are there any kinds of thinking that might be seen in a case study that would not be examples of ordinary thinking? In other words, what kinds of thinking would be examples of extraordinary thinking? This question is just another way of asking what sort of results would disconfirm the hypothesis that ordinary thinking is the basis for creativity. I have tried to address those potential problems in several ways. First, in Chapter 3 (and briefly at the beginning of the present chapter), I presented a set of cognitive components that can be taken as comprising, at least in part, the components of what we call ordinary thinking. I also described several general features of ordinary thinking. I hoped in so doing to provide enough specificity to enable one to determine if a creative product was or was not brought about as the result of ordinary thinking. For example, from the premise that ordinary thinking is based on the past, one could make the strong prediction that every creative advance should be based on the past. That is, we should be able to point to antecedents for every creative product. As one example, consider *Guernica* and *Minotauromacy*. Based on the overlap in structure and characters, and the relatively close proximity of the two works in time, it is plausible that there is a link between them. Similarly, we know on the basis of much information that the double helix and the alpha-helix are linked, one being the antecedent to the other.

A related prediction is that if we cannot find an antecedent for a creative advance it should be possible to construct the pathway whereby the innovation came about independently of any direct antecedent. Let us consider two cases in which there are no direct antecedents for the innovation, the Wright brothers’ flyer and Edison’s light bulb. The Wrights rejected previous attempts to build airplanes, but there were other sources of information that they used: the bicycle and birds’ control systems. That information was from situations analogous to the Wrights’. Taking that information, and combining it with what we know about the Wrights’ expertise, one can construct a plausible scenario for the development of the airplane that fits with known facts and does not insult our understanding of how humans think. That is, we do not have to postulate any sort of thought processes that go beyond what we know about how ordinary people think. Similarly, Edison began working toward a light bulb by trying to use the methods that had been tried by earlier researchers, and he produced the same failures that they did. Again, however, based on the information we have about

Edison's activities (e.g., Israel, 1998; Weisberg et al., 2006) we can build a plausible path that leads from work with platinum burners to a realization of the need for a better vacuum pump to a return to carbon and success. Again, the plausible path does not require that we make of Edison more than any person could be.

From those examples, we can draw a general conclusion: We can explain creative advances without involving bizarre associations or incomprehensible connections between thoughts. If there is no antecedent, however, for some creative advance, and there is no plausible path that can be constructed, based on information available to the creator, then it must be acknowledged that that advance is not explainable through ordinary thinking. The adequacy of ordinary thinking as an explanation of creative advances would thereby come into question. Furthermore, in order to maintain an empirically based scientific orientation to the enterprise, when one is faced with a creative advance for which there is no antecedent and no plausible path, one cannot fall back on the excuse that the historical record is incomplete. That is, if we only had this document, or that one or the other, then we would find an antecedent, and so on. Such a move would be a retreat into a nonempirical and untestable mode, and would therefore be unacceptable.

In a similar fashion, the idea that ordinary thinking is structured according to logic and similarity among thoughts leads to the expectation that without too much difficulty (again, not having to bring in wild or bizarre connections among ideas) we should be able to construct the path leading to an innovation. To the degree that gaps are left in that path, the explanation is unacceptable and the ordinary-thinking theory is not supported. When these factors are weighed, it seems that it is possible to subject the ordinary-thinking view to empirical test, and doing so requires only that case studies be carried out with care.

On Creative Ideas and Creative People

Two final questions remain to be considered—briefly, although they have potentially broad implications. The first is whether, if all new ideas are based on the past, there are really any new ideas at all; that is, based on the ordinary-thinking view, does it make sense to talk about creativity? The second question is what the characteristics are of the people who produce innovation; that is, what is it that makes someone creative?

Are There New Ideas?

The ordinary-thinking view assumes that all innovation is built firmly on the past, and evidence to support that assumption has been presented

throughout the book. Examining the third column of Table 12.2, we can see the influence of the past in all the case studies. Acknowledging the role of the past in creative advances sometimes leads to strongly negative conclusions concerning the creative process and creative people. That is, after discussing such examples of creative achievement as *Guernica* and the discovery of the double helix, I have had colleagues and students say to me that those case studies show that there is no such thing as creativity. The commentators draw the conclusion that all new ideas are simply ripped off from old ideas, so there is really nothing that can be called new. It follows from the conclusion that there are no creative products that there are no creative people, since everyone is just taking ideas from everyone else.

This question was considered in Chapter 1, but it is important enough to warrant further discussion here. If one rejects the notion of creativity because of examples such as those in Table 12.2, it is because one has assumed either explicitly or implicitly that real creativity must be able to produce something that has no connection to what came before. Since the examples in Table 12.2 are definitely connected to what came before, based on that assumption, they must not be creative. However, that basic assumption—that there can be innovations that are independent of the past—may be an unrealistic one. How could a person produce something that had no connection to his or her past? First of all, we are organisms whose functioning is inextricably tied in with our memories, so it would be highly unlikely that we could turn off the influence of memory on what we do. Also, even if we decided to try to produce something “completely different,” the only way we could do that is through reference to what is already available. That is, in producing the new we must explicitly reject the old, which means that the influence of the old will be detectable in the new (Bailin, 1988).

Furthermore, if our new product is to make any sense to those who examine it (and to us who produced it), then it can only do so with reference to the past. To make sense of any object or event, we analyze that object or event on the basis of what we know. The conclusion to be drawn from this is that the basic assumption that it is possible for a truly creative person to produce something that completely breaks with the past is fiction. It should also be noted that, although the innovations presented in Table 12.2 are dependent on the past, they do make breaks with the past. Each of those innovations goes beyond the past in a significant way or ways, which means that there is real innovation in each of them. For example, the double helix was based on the alpha-helix, but in many ways it was not the alpha-helix. Similarly, *Guernica* may have built on *Minotauromacy*, but it was not a copy of *Minotauromacy*. The Wright brothers may have used the bicycle as the

basis for the control system in their flyer, but the flyer is not a bicycle. We can conclude that human beings (and some animals) produce true innovations, and therefore the creative process is real.

On the Creative Person

We saw in the review of studies of the creative personality from Chapter 10 that the support for the existence of a unique creative personality—or two creative personalities, one for the arts and the other for the sciences—is not very strong. Let us assume for the sake of discussion that there is not a unique set of personality characteristics that play a role in causing people to develop into creative individuals. We have also concluded that creativity is based on ordinary thinking, which means that the cognitive characteristics of individuals who produce world-class innovations are not basically different from those of the rest of us. Those conclusions leave us with the question of whether there are any consistent differences between individuals whose lives are marked by outstanding creative achievement and those who do not produce significant innovations. Is there nothing that might distinguish individuals of creative achievement from individuals of no creative achievement?

One possibility is that the motivation of those two kinds of people might differ. Perhaps individuals who achieve much in some creative domain do so because, in Joy's (2004) terms, they are motivated to be different, and the way they have chosen to be different is in a domain marked by creative achievement. Perhaps the difference between the greats, the near-greats, and the unknowns is that the greats, more than other people, want to be great. They would then work harder at acquiring the expertise that supports innovation, and they would work harder at putting their expertise to use in producing novel outcomes, the more novel the better. The need to be different might manifest itself in different ways in different professions—accountants, say, versus car salespeople—but one might find that people high in the need to be different, no matter what their profession, tend to do things in novel ways. If the person involved is a painter or an architect or a poet or a novelist or a scientist, then he or she might produce something that will affect the lives of many of us. Thus, once one has acquired expertise within some domain, if one has a strong need to be different in that domain, then one might be likely to behave in ways that will produce outcomes that will be creative. That desire to be different might be related to the intrinsic motivation that Amabile (1996) has found to be important in creative achievement, as well as to the need to take risks that Sternberg and Lubart (1995) find important. In addition, as Winner (1996) suggests, the desire to acquire expertise in the first place—that is, the desire to acquire the skills

to enable one to achieve a high level of innovation in the domain—might also be the result of the need to be different.

The conclusions just drawn about what factors determine whether an individual will achieve creative success may strike one as very unsatisfactory. Surely there must be more than motivation and expertise to achieving greatness in some domain that demands creativity. On the other hand, when one begins to try to specify just what those other things might be, there is not much to postulate. Perhaps the creative individual puts a unique spin on the way he or she thinks, which paves the way for novel ideas. However, if creative thinking is based on ordinary thinking, then that unique spin does not occur. Maybe the creative individual is more intuitive than the noncreative. If that intuition involves insight, however, the premise does not hold, because we have seen that there does not seem to be a unique set of processes that bring about insight. Maybe the creative individual is more flexible and less rigid than the noncreative person. That premise is still another manifestation of the familiar tension view, but by now we have seen much evidence that creative achievement is not based on breaking away from the past. And so forth, and so on.

It seems, then, that research in creativity does not support the existence of unique characteristics that explain why it is that some of us are creative while others are not. So perhaps it is nothing more than that some people want very much to be creative, and they have acquired the means to do so. To many people, that may be a laughable oversimplification of the circumstances that result in people's producing innovation. However, based on the discussion in this book, it may be the strongest and most reasonable possibility available to us at present. Therefore, a promising direction for future research would be to examine in detail how ordinary thinking can produce innovation, and how a person's needs can influence how he or she decides whether to use ordinary thinking in that way.

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