pression. Reproductive cycling appears to be related to depression for some women. Social roles and life experiences also influence depression and the duration of dysphoric affect. Women and men may use different cognitive strategies and coping responses to negative events and thus may be differentially dysphoric or depressed. Although both psychosocial and pharmacological treatments for depression lead to the remediation of symptoms, few data are available on the issue of whether men and women respond differently to psychotherapy or antidepressant medication. Systematic basic and applied research on gender and depression must continue and be expanded if we are to understand the affective disorders and answer the age-old question as to why women are more often depressed than men.

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Expertise

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In the past two decades, there has been a significant amount of research on the nature of expertise. Researchers have examined expertise with respect to a variety of tasks, such as problem solving of either puzzles (e.g., Tower of Hanoi puzzle), games (e.g., chess, go), or classroom problems; decision making; troubleshooting mechanical systems; or diagnosing illnesses. The studies have shown that a large, organized body of domain knowledge is a prerequisite to expertise. This knowledge influences the perceptual processes and strategies of problem solving. Thus, it is important to understand how experts' knowledge is organized. We begin with a presentation of the differences in knowledge between experts and novices. The impact of the differences on problem solving and transfer is then discussed. Finally, the limitations of expertise are examined.

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Knowledge can be discussed in terms of its quantity or its structure. There is no question that experts possess a greater quantity of domain-relevant knowledge than do novices, by definition. The amount of knowledge that experts possess can be measured in a variety of ways. However, it is not merely the fact that experts have more knowledge that is important; more crucially, they have their knowledge organized in particular ways, ways that make that knowledge more accessible, functional, and efficient.

The Amount of Knowledge

A classic study of expert-novice differences in the amount of knowledge was carried out by Chase and Simon.[1] Using a recall method, they found that chess experts can recall a greater number of pieces from a chess position than novices. This recall superiority can be explained by the greater number of chess patterns (such as a castle-king position) that experts recognize, and each pattern tends to contain more pieces than a novice's patterns. For example, it is estimated that a chess master has roughly 50,000 patterns in memory, a good player has 1,000, and a poor player has very few. These results have been replicated for schematic drawings of electronic circuit boards, computer programs, internal accounting controls, and medical problem solving, just to name a few.

The Structure of Knowledge

A large amount of domain knowledge is not the only factor responsible for the demonstration of expert-level performance; the organization of this knowledge is also important, although the amount and the organization tend to be correlated.

One way to capture the organization is to see what information experts and novices use to make categorization decisions. A classic demonstration used a card-sorting technique for assessing how experts and novices classify problems.[2] Each card contained the text and diagram for a physics problem. The novices tended to sort problems on the basis of literal, surface features, such as the type of objects involved (e.g., an inclined plane). The experts tended to sort the problems on the basis of the principles used to solve the problems (e.g., conservation of energy). Similar results have been found for categorizing problems in mathematics, computer programming, and genetics and for categorizing real-world objects such as cameras, rice bowls, electronic circuit diagrams, or pictures of dinosaurs.

In addition, experts' knowledge is extensively cross-referenced, with a rich network of connections among concepts. Novices have fewer and weaker links among concepts. In a study of diagnostic reasoning of experts and novices, Feltovich, Johnson, Moller, and Swanson[3] found that novices' knowledge of diseases is anchored in the most prototypical features of the diseases and lacks information on connections to other diseases or on shared features of classes of diseases. Experts' knowledge of diseases is extensively cross-referenced, with rich networks of connections among diseases with similar symptoms.[4]

In sum, experts have a greater tendency to base the organization of their knowledge on meaning, whereas novices base their organization on the surface features of the information presented. Also, experts have more and stronger links among concepts, suggesting that there is a greater degree of connectedness and cross-referencing, and the pattern of connections and cross-referencing can result in a better structure.

PROBLEM SOLVING

The greater amount and better organization of experts' knowledge, as compared to that of novices, results in the two groups demonstrating different problem-solving behaviors. Differences have been captured in problem representations, problem-solving strategies, and the quality of the decisions.

Problem Representation

A representation of a problem consists of the person's interpretation or understanding of the problem. Such an interpretation must be based on the person's domain-related knowledge and organization of this knowledge. One way to begin representing a problem is to classify it as a particular type, because people presumably have solution procedures attached to each "type" of problem. To classify a problem, one needs to pick out the relevant features or must infer additional aspects about the problem given the explicitly stated features. Both of these feature-identification processes are more efficient and superior among experts, because of their richer knowledge base.

For instance, consider the familiar physics problem: A block is suspended from a spring, which is attached to the ceiling. Given the initial displacement of the block (how far the spring is stretched), calculate the amplitude and period of the resulting oscillation. In solving this problem, experts translate the literal cues from the problem statement, such as "block," "spring," and "suspended," into derived features, such as "mass (*m*)," "spring-constant (k)," and "gravity (g)." This translation may then activate a category of problems, such as "mass-spring oscillation problems."[2] Thus, experts represent problems on the basis of the derived features. For novices, the process of constructing a representation also involves the activation of a category, except that novices' problem categories are based largely on literal features, such as "the spring."[2]

Differences between experts' and novices' representations are even more apparent in ill-defined problems. An ill-defined problem is a problem whose structure lacks definition in some respect (initial state, set of permissible operators, or goal state[5]). In solving an ill-defined problem, such as one in political science, experts spend a considerable amount of time developing a problem representation by adding many domain-specific and general constraints to the problem—as if they are modifying the problem from an ill-defined to a well-defined one. Novices, however, attempt to solve the problem directly without defining it.[6] Thus, experts and novices essentially construct different representations for the same problem. The constructed representation determines the success of the problem solving.

Problem-Solving Strategies

In searching for a solution, a problem solver may use strategies such as means-ends analysis, subgoaling (generating and solving a subgoal as a step toward solving the goal), generate-and-test, or analogical reasoning. Experts and novices tend to use the same general problem-solving strategies. In a medical diagnosis task, for example, novices and experts both used a generate-and-test strategy in which hypotheses are generated in response to items of patient data and then are tested for confirmation or disconfirmation. Experts, however, tended to generate the *correct* hypothesis more often than novices.

One prominent strategy in which differences between experts and novices have been found is means-ends analysis. Means-ends analysis is simply the strategy of problem solving in which the goal is to reduce the difference between the end state and the current state. One can work either backward or forward using this strategy. With a backward-driven strategy, the problem solver works backward from the goal to the problem givens. With a forward-driven strategy, the problem solver works from the problem givens and uses applicable operators, without regard to the goal. There have been numerous studies examining expert and novice problem solving in domains such as physics, medicine, political science, and accounting. The results of these studies indicate that experts use a forward-driven strategy and novices use a backward-driven strategy.

In mechanics problems, for example, Simon and Simon[7] found that an expert works from the variables given in a problem, successively generating equations that can be solved from the given information. A novice starts with the goal—finding the value for the unknown of the problem—and then generates an equation containing the unknown of the problem. If the equation contains a variable that is not among the givens, the novice selects another equation to solve for that variable, and so on.

Working forward is riskier than working backward in problem solving because operations are executed without first checking to see if they lead toward the goal. It seems more intelligent to organize the problem solving around the goal. Why, then, do experts work forward? It seems that working forward is more efficient if the problem solver knows enough about the domain to recognize the problem type. Once the type is selected, the expert builds a problem representation and executes the solution procedure associated with that problem type. This explanation implies that the choice of a problem-solving strategy is knowledge driven. When problem solvers possess sufficient knowledge about the domain, they use a forward-driven strategy. Otherwise, they use a backward-driven strategy. Thus, experts do work backward when confronted with an unfamiliar problem that cannot be categorized as an instance of a known problem type. Experts in thermodynamics, for example, work backward when confronted with unfamiliar problems.

In summary, experts use recognition processes that are based on a large repertoire of structured knowledge to build a problem representation. The nature of that representation determines to a large extent the strategy used during problem solving. When the problem matches an existing prestored problem type, problem-solving procedures are triggered, and these procedures make the problem-solving process appear forward working. When recognition does not suffice, experts resort to general problem-solving strategies and, as is the case for novices, use a backward-solving approach. Thus, although it may be correct to characterize differences in the way experts and novices use forward versus backward reasoning, these differences are driven by the availability of the problem type, and not the availability of the strategies per se. Therefore, the point is not that experts are better able to use more sophisticated strategies, or use their strategies more competently, but rather that a strategy applied to a well-organized knowledge base produces a more competent performance. This interpretation can be seen more clearly using the generate-and-test strategy, as exemplified in medical diagnoses. In this case, the more accurate hypothesis generated by the expert physician, given a set of symptoms, does not arise because the expert is better at using the generate-and-test strategy.

Decision Quality

In game and classroom problems, experts' superior knowledge structure and strategies allow them to perform the tasks more quickly and to produce more accurate solutions than novices. Researchers have examined the relationship between knowledge and decision quality in real-world problems, too, and these results seem to parallel those for classroom problems. In marketing, for example, effective salespeople have been found to have category structures containing more descriptors of both customers' traits and sales strategies and to exhibit more sophisticated sales scripts than ineffective salespeople.[8]

In some real-world problems, however, results of the studies carried out indicate that expert judgment is seldom better than that of novices and is easily improved on when replaced with simple mathematical models. In public accounting, for example, there were no significant relationships between expertise and decision quality.[9] Why do experts in some real-world problems perform so poorly? Why is there a discrepancy between real-world problems and other types of problems? Researchers have just recently started studying these questions. The following four factors may explain these differences: the degree of structure of the problem, the approach (cognitive science or behavioral decision theory) used to study the problem solving, the lack of a "right answer" or of a correct solution procedure, and mismatch between the expertise of the subjects and the task. For example, expert physicians were found to be slightly better than novices and worse than a simple regression model in selecting candidates for internships and residencies.[10] This poor performance by physicians may be explained by the fact that selecting interns is not a task at which physicians are experts. Personnel selection requires a great deal of knowledge about how past experience, intelligence, knowledge, skills, abilities, and motivation lead to outcomes such as high performance.

TRANSFER OF EXPERTISE

One of the characteristics of expertise is that it is task specific. There appears to be little transfer from high-level proficiency in one domain to proficiency in other domains. This result has been found across a large range of problems. For instance, although go and gomoku are played on the same board and with the same pieces, go experts' recall of gomoku displays is poor and vice versa. Voss, Greene, Post, and Penner[6] compared the problem-solving behavior of expert political scientists, expert chemists, and novice political scientists in solving real-world problems related to Soviet agriculture. They found that the chemists' protocols, on the whole, were much like those of novices, sparse and dealing with low-level, specific problems that were subproblems for the experts. Patel, Evans, and Groen[11] compared the performance of subjects from three medical subspecialties, cardiology, surgery, and psychiatry, in solving a problem in the domain of cardiology. Cardiologists' diagnoses were more accurate than those of surgeons and psychiatrists. The lack of transfer between problems confirms the role of an appropriate knowledge base, both declarative and procedural, in accounting for expertise.

The reviewed literature indicates that, in general, there is no transfer of proficiency between domains. Within a specific domain, however, there is transfer from one task to another. If learning is the construction of conditional rules, then within a domain, transfer of learning from one task to another is determined by the number of rules the two tasks share. The extent to which a person, having learned a text editor, transfers positively to a second text editor depends on the number of rules the two editors share.[12] Thus, the lack of transfer in the studies of political science and medicine may be due to very few rules being shared by the experts' domains.

PITFALLS OF EXPERTISE

In some situations, novices not only can perform as well as experts, but actually surpass experts. One can handicap experts in at least three ways: by putting them in a situation in which they cannot make use of their greater knowledge base, by selecting a task in which interpreting the problem at a deeper level may interfere with problem solving, and by selecting a task for which a standard response may be inappropriate. An example of the first case is to present expert chess players with randomized chess positions (i.e., the pieces on the board have been placed randomly). In such conditions, the experts' recall of the chess positions is slightly worse than novice players'.[1] The second case can be illustrated by a recognition task. Baseball experts, more often than novices, falsely recognize synonym sentences about baseball as being the original sentence that was presented.[13] One interpretation is that experts store the semantics of the sentences, thus confusing their surface distinctions, whereas novices remember verbatim sentences. Similarly, novice computer programmers surpass experts in answering concrete questions about how a program functions because the experts' representations no longer include the details of how the program functions.[14] The third case can be illustrated by a transfer of knowledge from one situation to another. Marchant, Robinson, Anderson, and Schadewald[15] presented a court decision about the deductibility of a business expense to expert and novice accountants and required them to make a decision about the deductibility of a business expense in a similar case. Significantly more novices than experts transferred the knowledge from the court decision to the new case. Apparently, tax experts had a highly proceduralized general strategy of deducting all business expenses, which led to inflexibility.

SUMMARY

A fundamental goal of science is to find invariants. The studies described here support five invariants of expertise. First, experts, by definition, know more about their domain than do novices. Second, experts not only know more, but their knowledge is better organized. Third, on the basis of their greater knowledge and better organization, experts perform better than novices in domain-related tasks. Fourth, experts' skill is domain specific: There is very little transfer to unrelated domains. Finally, there are also many situations in which experts do not excel.

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