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RESEARCH REPORT

A scientific creativity test for secondary school students

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This study describes the development of a test of scientific creativity for use with secondary school students. A Scientific Creativity Structure Model (SCSM) was constructed on the basis of an analysis of meanings and aspects of scientific creativity found in the literature. 50 science teachers in China took part in an initial evaluation of this model. On the basis of their analyses and comments, and drawing on the experience of the Torrance Tests of Creative Thinking, a 7-item scale for measuring scientific creativity of secondary school students was developed and validated through analyses of item response data of 160 secondary school students in England. Item analyses were conducted to check on item discrimination, internal consistency, agreement between scorers, construct-related validity, and face validity. Analysis showed adequate reliabilities and validities. As an example of how the test might be used, data from the pilot use of the test were used to investigate the relative scientific creativity of students of different age and ability level. The results indicated that for this trial sample, the scientific creativity of secondary school students increases with increase in age, and science ability is a necessary but not sufficient condition for scientific creativity. Further work is also suggested.

Introduction why scientific creativity?

This paper will describe the development of a test of scientific creativity. It may immediately be asked why another test of such creativity is required, since over 100 creativity tests have already been reported in the literature. The answer lies in the specific needs of scientific creativity. Firstly, 'doing science' is far more than either mastering an existing body of knowledge or of following set procedures. Almost by definition scientific research requires creativity in the sense of going beyond existing knowledge and techniques, of creating new understandings. But even at a more mundane level, solving problems in science requires a student to explore his or her repertoire, to imagine a variety of routes to a solution, and frequently to create novel combinations of knowledge or novel techniques for a solution. This is the justification for considering scientific creativity as worthy of attention in the education of students who will either become scientists or who need an understanding of the way that scientists work as part of their general understanding of society. Although there is some research about scientific creativity of scientists, few reports about scientific creativity of secondary students have been found. If scientific creativity is to be an important element in secondary education, then it becomes useful to have an instrument for assessing levels of scientific creativity which could be used for formative or summative purposes. Progress in scientific research depends on the availability of the necessary

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measuring instruments. In general creativity research, the proliferation of research is to a large extent due to the availability of instruments purportedly measuring creativity.

However, general creativity tests will not do for assessing scientific creativity. There is a general consensus that domain-specific knowledge and skills are a major component of creativity. Alexander (1992) and Amabile (1987) emphasized the need for specific domain or discipline-based knowledge and skills for creative thinking. This issue was also addressed by Findlay and Lumsden (1988) and Mumford *et al.* (1991) who defined being knowledgeable as having a knowledge base that is conceptually well-organized and for which retrieval is fluent and efficient in relation to demand in a given problem-solving or creative thinking situation. Other researchers (Albert 1983, Gardner 1983, Feldman 1986) also concluded that creativity is domain specific. As Barron and Harrington (1981) suggested, more domain-specific aspects of divergent thought may underlie creative productivity. According to his research, Sternberg (1996) concluded that the correlation coefficient of creativity between different areas is only 0.37. We conclude that the scientific creativity of secondary school students, a kind of domain-specific creativity, cannot be measured by tests designed for other content areas or age groups.

The nature of scientific creativity

Before considering how such an instrument might be developed, we need to analyse commonly held understandings of the meanings and nature of scientific creativity. The concept of creativity has proven over the years to be an elusive one to define. As early as 1960, Rapucci (quoted by Welsch 1981) counted between 50 and 60 definitions in the literature on creativity. Twenty years later, an extensive review forced Welsch (1981) to conclude that the literature contains such a variance of definitional statements that the task of arriving at an integrated and agreed definition is virtually impossible. Different perceptions of the meaning of creativity have led to a correspondingly wide variety of techniques to assess creativity. Nevertheless it is possible to detect some common themes and we will attempt to combine these into a model of scientific creativity. For example, many researchers combine two or more aspects of the creative process, creative product, creative person and creative environment in defining creativity. In considering the scientific creativity of individual secondary school students within a given school system, the creative environment is out of control of the students so we will aim for a three-dimensional model.

Torrance (1990) considered fluency, flexibility, and original thinking as central features of creativity. Fluency means the number of original ideas produced, flexibility is the ability to 'change tack', not to be bound by an established approach after that approach is found no longer to work efficiently. Originality is interpreted statistically: an answer which is rare, which occurs only occasionally in a given population, is considered original. Hudson (1966) took a similar approach. In asking students how many uses they could think of for a brick, he collected all the answers and gave higher scores to the answers which were rare (which occurred only infrequently) than to common answers. Fluency, flexibility, and originality thus form one dimension of the model, one which can be described as being a personality trait, the characteristics of the creative person. Although divergent thinking is no longer considered to be synonymous with creative ability, it is nevertheless an important component of creative potential (Runco 1991).

When we consider scientific products, we can distinguish between technical products, advances in science knowledge, understanding of scientific phenomena, and scientific problem solving. Cattell (1971) argued that problem solving does not mean solving routine problems using a recipe but finding the answers to new problems. Lubart (1994) pointed out that problem solving can lead to creativity because if a problem exists then there is the possibility of creative solution. Sensitivity to science problems is also considered a component dimension of scientific creativity. Ochse (1990) argued that sensitivity to problems is an important feature of the creative process. Einstein and Infield (1938) suggested that the formulation of a problem is often more important than its solution, which may be a matter of mathematical or experimental skill. Products provide us with the second dimension of our model.

Einstein argued that language, as it is written or spoken, did not seem to play a significant role in his mechanism of thought. He referred rather to psychical signs and more or less clear images which seemed to be voluntarily reproduced and combined (Einstein 1952: 43). This role of imagination is also supported by psychologists (Gardner 1983, Johnson-Laird 1987). This suggests a distinction between creative imagination and creative thinking and this is built into the third, process, dimension of our model.

The three-dimensional Scientific Structure Creativity Model (SSCM) which arises from this analysis is shown in figure 1. The proposed structure is designed as a theoretical foundation on which the measurement of scientific creativity,

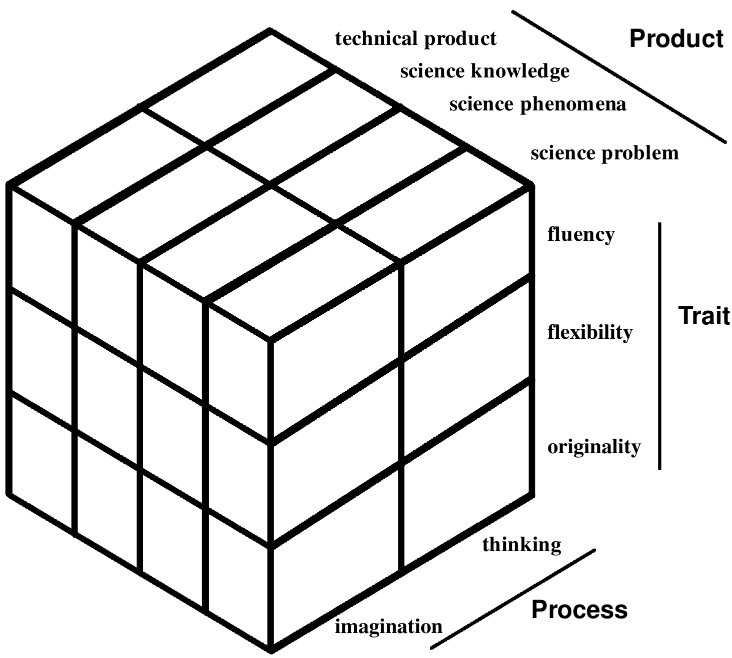

Figure 1. The Scientific Structure Creativity Model (SSCM).

research into scientific creativity, and the cultivation of scientific creativity may be based.

In summary, and in the light of exploration of creativity in the literature, we define scientific creativity as a kind of intellectual trait or ability producing or potentially producing a certain product that is original and has social or personal value, designed with a certain purpose in mind, using given information. This definition may be elaborated with a set of hypotheses about the structure of scientific creativity:

(1) Scientific creativity is different from other creativity since it is concerned with creative science experiments, creative scientific problem finding and solving, and creative science activity.
(2) Scientific creativity is a kind of ability. The structure of scientific creativity itself does not include non-intellectual factors, although non-intellectual factors may influence scientific creativity.
(3) Scientific creativity must depend on scientific knowledge and skills.
(4) Scientific creativity should be a combination of static structure and developmental structure. The adolescent and the mature scientist have the same basic mental structure of scientific creativity but that of the latter is more developed.
(5) Creativity and analytical intelligence are two different factors of a singular function originating from mental ability.

Existing tests

A review of methods used to assess creative thinking is provided by Hocever and Bachelor (1989) who proposed a taxonomy that has eight categories of creativity assessment. They are: tests of divergent thinking; attitude and interest inventories; personality inventories; biographical inventories; rating by teachers, peers, and supervisors; judgements of products; eminence; and self-reported creative activities and achievements. For the purpose of a test to be administered in secondary schools, we chose to focus on the first of these categories.

Perhaps the best known test of general creativity is the Torrance Test of Creative Thinking (Torrance 1990). This is a paper-and-pencil test which taps divergent thinking abilities. Items are scored for fluency, flexibility, and original thinking. Recently, activity- based approaches in measuring creativity have also been used (Kitto *et al.* 1994). As to scientific creativity of secondary school students, several tests have been developed. Friedlander (1983) developed a test in which 143 high school students responded to a plant or animal stimulus through a series of divergent thinking questions dealing with data collection, problem solving, hypothesis construction, and planning experiments. The test showed adequate test-retest reliability and significant correlations with criterion measures of science ability. In India Majumdar (1975) developed the Scientific Creativity Test, which contains material from physics, biology, and mathematics. His main concern was to identify creative scientific talent perceived as necessary to solve mankind's present and future problems. Also searching for such talent, Sinha and Singh (1987) examined the concept of scientific creativity and developed an 84-item English-Hindi instrument for measuring components of scientific creativity in secondary school students. These components are flexibility, novelty, observation abilities, imagination, analysis capabilities, and transformation abilities.

Although these tests are useful in measuring scientific creativity of secondary school students, they are somewhat dependent on science knowledge, so they can not be used for assessing scientific creativity of junior high school students whose scientific knowledge is limited. We also question their cross-cultural applicability since they were developed within specific cultural groups. We believe there remains a need to develop a test which can be used for assessing the scientific creativity of all secondary school students at different ages and in different cultures.

The development of the test

The three dimensional model of scientific creativity described above offers 24 cells for each of which items may in principle be designed. In order to explore the face validity of these cells, a questionnaire was developed with two items for each of the 24 cells – that is 48 items in total. 50 science education researchers and secondary school science teachers in China were asked to review these 48 items and select those which he or she thought would demonstrate scientific creativity in secondary school students. The result suggested that some aspects were considered more important and viable than others and on this basis an initial test of nine items was drafted. Each item encompassed more than one cell of the model.

In drafting these nine items, we referred also to existing general creativity tests, especially the Torrance test, and also considered the ages of the pupils, the context of the test, relevance to the pupils and the process of administration of the test. The first draft of the test was administrated to 60 secondary school students in London. All of the students were girls, and their median age was 13 years. All subjects had English as their first language. In the first trial, we found that the children enjoyed doing the task and the teachers got quite a lot of fun from some of the answers also, but two items proved to be very difficult for the students so we deleted them.

Brief descriptions and illustrations of the test

The test was designed for group administration. The time limit is 60 minutes. Requirements are the same as for other examinations: the examiner seeks to make the students feel at ease but also to work hard to complete the tasks. There is a general instruction printed at the top of the question paper:

> Today we would like you to demonstrate a very important ability – scientific creativity. You have 7 different tasks. Each task investigates different scientific skills , giving you the opportunity to excel at what you are best at! These tasks will enable you to use your creativity, explore new ideas and solve problems. Please try to complete all the tasks in one lesson (50 or 60 minutes). If you have questions about the tasks, please raise your hand and ask the examiner. Please write your school, year, class, name, sex and today's date on the answer sheet before you begin.

It is suggested that at the outset the teacher or examiner give the entire class a general orientation and ask them to keep their answers secret until all have handed in their answer sheets.

Here we will present each of the seven items in the final test, together with an analysis of its aims related to the Scientific Structure Creativity Model (SSCM).

Item 1

> Please write down as many as possible scientific uses as you can for a piece of glass.
> *For example, make a test tube.*

Note that for each of items 1 to 4, one example of an answer is given to help the students understand what is required. The first task is about unusual uses. Based on the model of Torrance's Unusual Test (1962), this task is designed to measure the fluency, flexibility, and originality in using an object for a scientific purpose. Within SSCM this covers science knowledge (in the product dimension), fluency, flexibility and originality (in the trait dimension) and thinking (in the process dimension), so three out of the 24 cells.

Item 2

> If you can take a spaceship to travel in the outer space and go to a planet, what scientific questions do you want to research? Please list as many as you can.
> *For example, are there any living things on the planet?*

To raise new questions, new possibilities from a new angle, requires imagination and is necessary to make real advances in science. The purpose of the second task is to measure the degree of sensitivity to science problems. It is scored for fluency, flexibility, and originality. In SSCM, this covers problems × fluency, flexibility and originality × thinking and imagination, six cells in all.

Item 3

> Please think up as many possible improvements as you can to a regular bicycle, making it more interesting, more useful and more beautiful.
> *For example, make the tyres reflective, so they can be seen in the dark.*

According to SCSM, technical production is a key component of creativity in science. The third task is designed to measure students' ability to improve a technical product. In Torrance's Product Improvement Tasks (Torrance 1962), the products are a toy dog and a toy monkey. In the present study, considering the age and character of the students and the purpose of measurement, we used the bicycle as an object which is familiar to most secondary school students and which contains many scientific principles. This item is also scored for fluency, flexibility, and originality. SSCM cells: technical product × fluency, flexibility and originality × thinking and imagination, six cells.

Item 4

> Suppose there was no gravity, describe what the world would be like?
> *For example, human beings would be floating.*

The purpose of this task is to measure students' scientific imagination. Again it can be used to assess fluency, flexibility, and originality. SSCM cells: phenomena × fluency, flexibility and originality × imagination, three cells.

Item 5

> Please use as many possible methods as you can to divide a square into four equal pieces (same shape).
> *Draw it on the answer sheet.*

This item is a science problem-solving task. It is designed to measure creative science problem solving ability. SSCM cells: problem × flexibility and originality × thinking and imagination, four cells.

Item 6

> There are two kinds of napkins. How can you test which is better? Please write down as many possible methods as you can and the instruments, principles and simple procedure.

This task is used for assessing creative experimental ability. This and item 7 connect with real-world scientific creative activity, which can make the students produce true scientific products. We use these kinds of tasks because when real-world types of problems are used there is a stronger correlation with other domains in creative performance (Okuda *et al.* 1991). SSCM: phenomena × flexibility and originality × thinking, two cells.

Item 7

> Please design an apple picking machine. Draw a picture, point out the name and function of each part.

The seventh task is designed to measure creative science product design ability. SSCM: technical product × flexibility and originality × thinking and imagination, four cells.

It will be seen that not every cell in the SSCM is represented. Within the limits of a paper and pencil test for junior secondary students it proved impossible to write items including the science knowledge × imagination cells.

Scoring procedures

The scores of task 1 to 4 are the sums of fluency score, flexibility score, and originality score. The fluency score is obtained simply by counting all of the separate responses given by the subjects, regardless of the quality. The flexibility score for each task is obtained by counting the number of approaches or areas used in the answer. The originality score is developed from a tabulation of the frequency of all of the responses obtained. Frequencies and percentages of each response are computed. If the probability of a response is smaller than 5%, we give it 2 points; If the probability is from 5 to 10%, we give it 1 point; If the probability of a response is greater than 10%, we give it 0 points.

The score of task 5 is computed again by tabulating all answers of all subjects, and then rating a particular answer for its rarity value. If the probability is less than 5%, it gets 3 points; for probabilities from 5 to 10, it gets 2 points; If the probability is greater than 10, it gets 1 point. We only have one score for each method of division in task 5. (Most students can get 3 or 4 points, some can get 20 to 30 points. Generally, it is impossible to get 0 points because there are 3 or 4 very simple divisions.)

The score of task six is the sum of the flexibility score and the originality score. The flexibility score has a maximum of 9 points for one correct method (instrument: 3 points; principle, 3 points; procedure, 3 points). The originality score is computed as before: if the occurrence of the method generally is less than 5%, it gets 4 points; if the probability is between 5–10%, it gets 2 points; if the probability is larger than 10%, it gets 0 point. We used a different scoring system in this task because it is more difficult for students to design an original method in testing the napkins than to get a original answer in task 1 to 4.

The score of task seven is decided by the functions of the machine. A particular function of the picking machine could include reaching the apples, finding the apples, picking the apples, transporting the apples to the ground, sorting out the apples, putting the apples in containers, moving on to the next tree. Each function got 3 points. According to the originality, we give a score of 1 to 5 points based on an overall impression having marked all the other scripts.

Trial

In the present study to trial the new instrument, the test was administered to a sample of 160 students selected from year 7, year 8 and year 10 in a secondary school in England. The school was a suburban mixed comprehensive school with a broad ability range intake. There was one top band, one middle band, and one bottom band in terms of science ability in each year. This ‘science ability’ was assessed in the school by the science teachers, using traditional course marks and end-of-year test marks. We make no claims about the validity of this process but the rating probably represents approximately some combination of general intellectual ability, specific science ability, and motivation/diligence. Ninety of the students (56%) were female and 70 (44%) were male. The age of the participants ranged from 12 to 15 years.

Item analyses

Item analysis included the calculation of item discrimination and test internal consistency.

Discrimination

The item discrimination was calculated in terms of a t ratio, taking the upper and lower 27 percent cases of the sample. Items were only considered for the final form of the test if the t value is significant at the 0.01 level or less.

Internal consistency

This was investigated by two methods. Firstly Pearson product-moment correlation coefficients between items were calculated as well as between each item and the total score. These data are shown in table 1. The correlations between items vary from a moderate 0.345 (between item five and item six) to a high 0.729 (between item one and item two) with a median of 0.570. The correlations between

Table 1. Correlation coefficients of item scores as well as item and total score (n = 160).

	One	*Two*	*Three*	*Four*	*Five*	*Six*	*Seven*	*Total*
One	1.000							
Two	0.729	1.000						
Three	0.615	0.587	1.000					
Four	0.661	0.638	0.638	1.000				
Five	0.540	0.421	0.578	0.526	1.000			
Six	0.479	0.502	0.510	0.558	0.345	1.000		
Seven	0.570	0.564	0.632	0.596	0.440	0.641	1.000	
Total	0.829	0.825	0.815	0.835	0.654	0.751	0.800	1.000

All the correlations are significant at the 0.01 level (2-tailed).

Table 2. Effect of removing items one at a time (n = 160).

	Corrected Item-Total Correlation	*Alpha if Item Deleted (whole test alpha = 0.893)*
One	0.761	0.869
Two	0.727	0.875
Three	0.741	0.871
Four	0.766	0.868
Five	0.576	0.892
Six	0.630	0.888
Seven	0.731	0.873

items and total score vary from 0.654 to 0.829, which is respectably high. All of the correlation coefficients are significant at the 0.01 level.

Secondly the degree to which the scores consistently measured the abilities defined by the test was determined by computing the Cronbach Alpha coefficient of internal consistency. The alpha value based upon scores of 160 secondary school students is 0.893. For a test with only seven items this is a very satisfactory indication of internal consistency.

We also calculated the corrected item-total correlation and Cronbach Alpha coefficients as each item is removed one by one. Details are shown in table 2. All the corrected item-total correlation and Alpha values are lower than that if the item is not removed. This indicates that all of the 7 items contribute to the central test construct of scientific creativity. Overall these results indicate that the test enjoyed considerable internal consistency and that each item individually and the items altogether are measuring the same thing.

Inter-scorer reliability

Since there is an element of subjectivity in interpreting the scoring rules, it was necessary to check that the scoring system could be interpreted reliably by someone who had not be involved in the test development. Scores for 50 students were

Table 3. Agreement between two scorers.

	Scorer Agreement (n = 50 answer sheets)
One	0.88
Two	0.897
Three	0.913
Four	0.875
Five	0.867
Six	0.823
Seven	0.793

Table 4. Factor loadings of each item (one factor).

	Component (n = 160)
One	0.836
Two	0.809
Three	0.827
Four	0.840
Five	0.685
Six	0.724
Seven	0.805

obtained independently by two scorers. One was not associated with the research project, and the other was the main researcher. Pearson product-moment correlation coefficients between the two sets of scores are presented in table 3. The correlations between scores vary from 0.793 to 0.913 with a median of 0.875. The results suggest that the scoring procedure is adequately objective.

Validity

Two aspects of the validity were investigated. One is construct-related validity. Guilford (1950) explicitly stated that the first step in validating creativity tests should be factorial validity, a form of construct validity, determined by factor analysis of test scores. When factor analysis with principal components was run on the data from this test, only one factor was obtained. The solution cannot be rotated. As shown in table 4, all items loaded sizeably (from 0.685 to 0.840) on to one factor which explains 63% of the total variance. Kline (1993) suggested items selected for a unifactorial test should load significantly on only one factor, and in most cases the load should be larger than 0.3. According to Horn and Cattell (1966) creativity is a second order ability factor titled a 'retrieval capacity' or 'general fluency', which loads on ideational fluency, association fluency and irrelevant associations tests. It is the general retrieval power which accounts for a variety of skills. In his three dimensional structure of intellect, Guilford (1956) connected divergent production with creative thinking, where many alternative ideas need to be brought to light with ease. According to these researchers, scien-

Table 5. Face validity: teachers and science educators.

	Teachers' Response (n = 35)	
Item	*Can*	*Cannot*
One	21	14
Two	25	10
Three	26	9
Four	28	7
Five	22	13
Six	29	6
Seven	31	4

tific creativity of secondary school students, as a domain creativity, should be unifactor so it is reasonable for us only get one factor in the analysis. The result suggested that the test has good construct-related validity, measuring one factor, scientific creativity.

Another type of validity determined in this study is face validity: do the items look like they test scientific creativity? To obtain a measure of face validity of the creativity test, 35 science education researchers and science teachers from England and China were asked the question, 'which items in the test can measure scientific creativity of secondary school students?' The results are shown in table 5, suggesting a high degree of face validity amongst science education researchers and science teachers.

Acceptability to students

Finally, for a test to be used successfully in assessing scientific creativity of secondary school students, it should have at least some level of acceptance by the students. To test this, 60 students tested were asked the question, 'Which items did you find interesting and which uninteresting in the test?' Results are shown in table 6, indicating a satisfactory level of acceptability by the students.

Table 6. Students' attitude to the tests.

	Students' Response (n = 60)	
Item	*Interesting*	*Not interesting*
One	46	24
Two	54	6
Three	50	10
Four	52	8
Five	45	15
Six	53	7
Seven	56	4

Table 7. Comparisons by age.

Age	*n*	*Mean*	*Std. Deviation*	*Mean Difference*	*Significance* $p <$
12	58	45.36	20.18		
13	49	56.92	21.25	−11.56	0.01
15	53	62.52	23.45	−5.6	0.05

Comparisons by age

The main purpose of this paper is to report on the development and characteristics of a test of scientific creativity. However, as an illustration of the way it may be used to research the development of scientific creativity, we will report something of the profile of the sample of students who have used the test for this report.

Comparisons were made in terms of the subjects' age. As shown in table 7, 12-year-old children scored significantly lower than did 13-year-old children (significant at the 0.01 level). But the mean difference between 13-year-old children and 15-year-old children is significant only at the 0.05 level. When one-way ANOVA was run, $F = 6.53$, $p = 0.002$. That indicates an overall difference for the three age groups, so we can conclude that the scientific creativity of these secondary school students increases with the increase of age but that it is not linear relationship.

There is no general agreement about the development of creativity. Findley and Lumsden (1988) remarked that from the age of 7 to early adolescence there seems to be a continual decline in creativity caused by greater attention to peer pressure and social conventions. But Chein (1982) concluded that the creative thinking abilities of gifted students increases with age. Lubart (1994) has suggested that creativity is related to both knowledge and experience. Amabile (1987), Sternberg and Lubart (1991) and Feldhusen (1995) all report that domain-specific knowledge and skills are a necessary component of creativity. Creative thinking is also moderately related to academic achievement (Zheng and Xiao 1983) although there seems to be no linear relationship between knowledge and creativity (Simonton 1983). With the increase of age, scientific knowledge, experience, and skills increase so according to the above researchers, scientific creativity should increase but it should not have linear relationship with age. This is supported by the results reported here.

Comparisons by ability level

Comparisons by science ability level were also investigated. The results are shown in table 8. The middle ability band scored significantly higher than did the bottom band, but there was no significant difference between the top band and middle band although the score of the top band is higher than that of middle band. This indicates an overall difference for the three ability levels so we can conclude that science ability is a necessary but not sufficient condition for scientific creativity.

A key component of science ability is cognition in the science domain, that is it is related to intelligence. Much theory and research has concluded that creativity is influenced by cognition, thinking, or intelligence. Guilford (1967) proposes divergent thinking abilities as the crux of creativity while Sternberg and Lubart (1991)

Table 8. Comparisons by ability level.

Ability Level	*n*	*Mean*	*Std. Deviation*	*Mean Difference*
Top	61	59.17	22.13	
Middle	67	58.03	17.34	1.14
Bottom	32	27.74	12.28	30.29**

** Mean difference significant at the 0.01 level (2-tailed).

presented an investment theory of creativity. The theory comprises six resources for creativity of which intelligence is one. Although creativity is related to intelligence, it is also influenced by other factors, such as motivation, personality, knowledge, and environment. The development of creativity is the effect of all these factors. So intelligence appears to be a necessary but not sufficient condition for creativity (Rossiman and Horn 1971); that is, although intelligence appears to allow the development of creativity, it does not ensure that creative expression always will be forthcoming (Schubert 1973). It is clear that all these theories and researches are consistent with the conclusion of the present pilot study.

Summary and further work

The study reported here is a preliminary attempt to develop and validate a scientific creativity test for secondary school students, with the hope that more empirical work of this nature will be taken up by interested creativity and science education researchers. A 7-item test was developed based on a Scientific Creativity Structure Model derived from theoretical accounts of the nature of scientific creativity. Internal consistency, agreement between scorers, construct-related validity and face validity were found to be satisfactory. For the sample tested, comparisons were made in terms of the students' age and science ability level. The result of these investigations suggest that this test should be useful in assessing scientific creativity of secondary school students.

However, more work needs been done to further validate the test. Test-retest reliability should be evaluated. Relationships between this test and other scientific creativity tests as well as other general creativity tests might be studied. More importantly, predictive validity should be determined. In developing this test, we started with a questionnaire given to Chinese as well as English science education researchers and science teachers, but only English students took part in this study. So larger samples from different cultures should be investigated in future research.

Although this study concluded that with the increase of age, the scientific creativity of secondary school students increases, and science ability is a necessary but not sufficient condition for scientific creativity, we cannot generalize these conclusions beyond the present limited sample. Nevertheless we believe that the instrument described here could be of use for researchers interested in, for example, the factors which influence the development of students' scientific creativity and whether students' scientific creativity can be developed by a specific intervention programme.

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In Praise of Convergent Thinking

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ABSTRACT: Free production of variability through unfettered divergent thinking holds out the seductive promise of effortless creativity but runs the risk of generating only quasicreativity or pseudocreativity if it is not adapted to reality. Therefore, creative thinking seems to involve 2 components: generation of novelty (via divergent thinking) and evaluation of the novelty (via convergent thinking). In the area of convergent thinking, knowledge is of particular importance: It is a source of ideas, suggests pathways to solutions, and provides criteria of effectiveness and novelty. The way in which the 2 kinds of thinking work together can be understood in terms of thinking styles or of phases in the generation of creative products. In practical situations, divergent thinking without convergent thinking can cause a variety of problems including reckless change. Nonetheless, care must be exercised by those who sing the praises of convergent thinking: Both too little and too much is bad for creativity.

Discussions of creativity in the early post-Sputnik era were largely shaped by Guilford's 1949 presidential address to the American Psychological Association (Guilford, 1950). Although Guilford (1950) also drew attention to the importance in creativity of factors such as personality, the ideas of convergent and divergent *thinking* dominated discussions following his article. Guilford (1950) also acknowledged the importance for creativity of knowledge of facts and, thus, of convergent thinking but, despite this, creativity quickly came to be equated with divergent thinking; and the two kinds of thinking were not infrequently presented as conflicting or competing processes (e.g., Getzels & Jackson, 1962). Convergent thinking was sometimes even seen as bad or, at best, a necessary evil that is greatly exaggerated in education and business (e.g., Cropley, 1967). In more recent years, however, there has been increasing recognition of the fact that actual creative production does not derive from divergent thinking alone but also requires convergent thinking (e.g., Brophy, 1998; Rickards, 1993). The contribution of convergent thinking to the generation of creative products is the subject of this article.

Convergent Versus Divergent Thinking

Convergent thinking is oriented toward deriving the single best (or correct) answer to a clearly defined question. It emphasizes speed, accuracy, logic, and the like and focuses on recognizing the familiar, reapplying set techniques, and accumulating information. Therefore, it is most effective in situations where a ready-made answer exists and needs simply to be recalled from stored information or worked out from what is already known by applying conventional and logical search, recognition, and decision-making strategies. One of the most important aspects of convergent thinking is that it leads to a single best answer and, thus, leaves no room for ambiguity: Answers are either right or wrong. Convergent thinking is also intimately linked to knowledge: On the one hand, it involves manipulation of existing knowledge by means of standard procedures; and on the other hand, its main result is production of increased knowledge.

Divergent thinking, by contrast, involves producing multiple or alternative answers from available information. It requires making unexpected combinations, recognizing links among remote associates, transforming information into unexpected forms, and the like.

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Answers to the same question arrived at via divergent thinking may vary substantially from person to person but are of equal value. They may never have existed before and are often novel, unusual, or surprising. Sometimes this is true merely in the experience of the person producing the variability in question or for the particular setting, but it may also be true in an absolute sense. Some examples of the characteristics of the two kinds of thinking are given in Table 1.

Contrary to what is sometimes assumed, both convergent and divergent thinking lead to production of ideas. Nonetheless, there is a major qualitative difference: Convergent thinking usually generates *orthodoxy,* whereas divergent thinking always generates *variability* (Cropley, 1999); otherwise, it would not be divergent. This seems at first glance to confirm that divergent thinking is synonymous with creativity. Indeed, in discussing creativity, Guilford (1959) focused on sensitivity to problems, word fluency, ideational fluency, semantic flexibility, associational fluency, and originality; all aspects of divergent thinking. However, production of variability by means of fluency, flexibility, and originality does not, on its own, guarantee creativity. Variability may cause surprise in the beholder, it is true, but this is not necessarily enough because surprise can be produced through mere unregulated self-expression (e.g., daubing paint on paper, writing text in any way that pleases the writer, or picking out notes at random on the piano) or by doing things differently from the usual regardless of accuracy, meaning, sense, significance, or interest.

Therefore, it is necessary to distinguish between mere novelty and novelty that earns the label "creativity." The former involves what Cattell and Butcher (1968, p. 271) called "pseudocreativity": The novelty derives only from nonconformity, lack of discipline, blind rejection of what already exists, and simply letting oneself go. Based on the German of Heinelt (1974), I have added to this "quasicreativity" (e.g., Cropley, 1997, p. 89), which has many of the elements of genuine creativity—such as a high level of fantasy—but only a tenuous connection with reality. An example would be the novelty generated in daydreams. What is needed for creativity, however, is not just something that surprises by deviating from the usual, but something that invokes what Bruner (1962, p. 3) called "effective surprise." The questions that arise now are whether divergent thinking alone generates *effective* novelty, whether convergent thinking plays any role in generating such novelty and, if it does, what this role is.

Effortless Creativity: Effective Novelty Without Convergent Thinking?

The idea of *effortless* creativity is seductive: It would involve effective novelty produced without any of the tiring and time-consuming activities typical of

Table 1. *Example of Convergent and Divergent Thinking*

Kind of Thinking	Convergent	Divergent
Typical Processes	Being logical	Being unconventional
	Recognizing the familiar	Seeing the known in a new light
	Combining what "belongs" together	Combining the disparate
	Homing in on the single best answer	Producing multiple answers
	Reapplying set techniques	Shifting perspective
	Preserving the already known	Transforming the known
	Achieving accuracy and correctness	Seeing new possibilities
	Playing it safe	Taking risks
	Sticking to a narrow range of obviously relevant information	Retrieving a broad range of existing knowledge
	Making associations from adjacent fields only	Associating ideas from remote fields
Typical Results for the Individual	Greater familiarity with what already exists	Alternative or multiple solutions
	Better grasp of the facts	Deviation from the usual
	A quick, "correct" answer	A surprising answer
	Development of a high level of skill	New lines of attack or ways of doing things
	Closure on an issue	Exciting or risky possibilities
	A feeling of security and safety	A feeling of uncertainty or excitement

convergent thinking (such as acquiring information, puzzling out, testing and checking, etc.). Of course, it is possible to imagine lucky hits or flukes, wild speculations, or dreams that turn out to be novel and effective. However, the key question is whether creativity can, in the normal course of events, result from divergent thinking alone. Two well-known mechanisms that seem to involve production of effective novelty without convergent thinking are luck or chance and intuition.

Luck and Chance

There are many examples of apparently lucky combinations of events that led to acknowledged creative solutions (see Rosenman, 1988): For instance, Pasteur, Fleming, Roentgen, Becquerel, Edison, Galvani, and Nobel all described chance events that led them to breakthroughs. Some famous thinkers such as Ernst Mach, Etienne Souriau, or Alexander Bain have even concluded that luck is the main factor in creativity. Austin (1978) identified four kinds of happy chance: *blind chance* (the individual creator plays no role except that of being there at the relevant moment); *serendipity* (a person stumbles on something novel and effective when not looking for it); the *luck of the diligent* (a hardworking person finds in an unexpected setting something that is being sought—Diaz de Chumaceiro, 1999, p. 228, called this "*pseudo*serendipity" because in genuine serendipity the person would not be looking for what was found); and *self-induced luck* (special qualifications of a person—such as knowledge, close attention to detail, or willingness to work long hours—create the circumstances for a lucky breakthrough). Case studies suggest that genuinely creative people enjoy a combination of all four kinds of luck, which raises the question of whether it is a matter of luck at all because at least the luck of the diligent and also self-induced luck clearly contain elements of convergent thinking (hard work, knowledge, etc).

Among the more theoretical discussions of the role of chance in creativity is the evolutionary view of, among others, Campbell (1960) and Simonton (1988). In this approach, ideas are thought to evolve through what Sternberg and Davidson (1999, p. 68) called "haphazard recombinations" of ideas in a process of "blind variation" (Campbell, 1960, p. 380). Occasionally, a happy combination occurs: When this is recognized as involving a creative "configuration" (Simonton, 1988, p. 2), "selective retention" (Campbell, 1960, p. 380) occurs. However, even if this is an accurate description of the process of production of effective novelty, the "mental elements" (Simonton, 1988, p. 6) involved in the haphazard recombinations are themselves pieces of information (facts, principles, relations, rules, laws, formulae, etc.)—in other words, they are the result of convergent thinking. The case study of Becquerel (discussed in the following) gives an example of what looks at first like a lucky accident, but in reality is based on convergent thinking.

Intuition

In his now classical stage model, Wallas (1926) identified a stage of *incubation* during which ideas seem to churn and work in a person's head without the person being aware of them, until—apparently out of the blue—an answer pops up. This is the classical definition of intuition: A process of fermentation until an idea is suddenly there, even seeming to come from nowhere. Mozart, for instance (see Hadamard, 1945), described how complete musical compositions just came into his head—for instance, during sleepless periods at night—and only the details had to be tidied up later. There is, however, considerable doubt about the accuracy of Mozart's description of how he composed. For instance, corrected trial versions of Mozart compositions have been found that, according to his account, never existed.

In fact, far from being an example of production of effective novelty without convergent thinking, intuition may well derive from convergent thinking at least as much as from divergent thinking. Even people who have not consciously acquired knowledge and experience in an area sometimes already have in their head a rough outline of the solution they are seeking, despite not necessarily being aware of this. The task involved in solving a problem is that of defining and refining this rough idea, not producing something from nowhere. The preliminary outline is acquired via the convergent process of *implicit learning*—of which the learner is unaware—for instance, in the course of everyday life (for a fuller account of what is meant by implicit learning, see Seger, 1994). To take a simple example, during the course of riding to school every day in a bus and sitting just behind the driver, a child might learn a great deal about how buses work without realizing it and without ever having thought of the ride as a learning experience.

Implicit learning leads to *tacit knowledge* that people do not know they possess. Such knowledge can prestructure thinking about an issue. For instance, the person in the earlier example might possess a great deal of tacit knowledge about the design of buses. As a result, on being hired in adult life to design a new bus, this person would already possess a preliminary framework that could suggest where the required answer might be found or approximately what the eventual solution might look like. The apparent bolt from the blue would really involve logical extension of what the person in question already knew. In other words, the basis of intuition—which appears at first glance to be the epitome of creativity coming from nowhere—is knowledge, and knowledge is acquired via convergent thinking. In fact, both luck and intuition seem to derive from psychological characteristics that are, to a considerable degree, convergent in nature. The importance of such characteristics was summed up by the celebrated father of vaccination, Louis Pasteur, in a frequently cited aphorism he uttered in a lecture in 1854: "Chance favors only the prepared mind" (p. 473). The essentially convergent nature of the prepared mind is sketched out in the following.

Effortful Creativity: The Prepared Mind

In 1896, the French physicist, Antoine Becquerel, left a piece of photographic paper and a container with uranium salts in it in a drawer of his desk (Nobel Foundation, 1967). On opening the drawer some time later, he noticed that the photographic plate had fogged. This unexpected event piqued his curiosity. He eventually concluded that the uranium had emitted some kind of radiation, which was responsible for the fogging. He then showed that this differed from X-rays in being deflected by electromagnetic fields (i.e., it was a previously unknown phenomenon). After initially being called *Becquerel rays,* the radiation subsequently became known as radioactivity. Was the discovery of radioactivity an example of creativity? It would be hard to answer, "No." (Becquerel shared the 1903 Nobel Prize for physics with Marie and Pierre Curie.) Did the creativity, then, come from nowhere; either through blind good fortune, intuitive inspiration based on nothing, or in a burst of pure divergent thinking (which if it did not produce a winner would be regarded as wild speculation)? Does creativity perhaps involve nothing more than being open for ideas and being able to recognize that a particular idea is a solution to something or other, thus seizing the opportunity when it occurs? Ghiselin (1955) seemed to support this view by arguing that recognizing a solution when one occurs is the key to creativity.

What is easy to overlook is what it was that made it possible for Becquerel to capitalize on the opportunity chance presented. He could not have done this had he not possessed, among other things, the following:

- The general knowledge that permitted him to realize that the fogging was unusual and important.
- The specific knowledge that told him that some kind of radiation had caused the phenomenon.
- The research skills that enabled him to clarify the whole situation.

Indeed, had Becquerel not already been engaged in relevant research, the uranium and the photographic plate would not have found themselves in the drawer together in the first place: Therefore, he could be said not only to have been able to profit from chance because of, among other things, his knowledge and skills but, in fact, by his own effort to have created the lucky chance in the first place. This was not an example of effortless creativity but required the prepared mind referred to earlier. Furthermore, the properties of Becquerel's prepared mind were largely convergent in nature involving, especially, knowledge and specialized technical skills.

However, it must be admitted that knowledge does not always facilitate creativity. A striking example of the unprepared mind is the failure of the German–Latvian pathologist, Eugen Semmer, to recognize a solution of spectacular proportions in the course of his work in the Institute of Veterinary Medicine in Riga. In 1870, Semmer published an article in the widely-read, German-language scientific journal, *Virchows Archiv* (which still exists), reporting on the strange return to health of two horses that were suffering from what we would now call *infections.* He examined the now-recovered horses and discovered that while at the institute they had accidentally been exposed to spores of the fungus *penicillium notatum,* which had apparently been responsible for them inconveniently getting better. Semmer saw the horses' return to good health as a problem that made it impossible for him to investigate the cause of their death, and reported in the journal on how he had succeeded in eliminating the fungus from his laboratory.

Apparently, both Semmer himself, as well as the distinguished readers of the journal, failed to recognize that he had discovered a novel (and as we now know, extremely effective) curative agent (i.e., antibiotics), and medicine had to wait another 70 years for Fleming to discover penicillin. In a sense, Semmer's mind was unprepared not because he possessed insufficient knowledge, because he could hardly be expected to have known about bacteria (whose existence had not yet been discovered), but the *wrong kind* of knowledge. He was thorough and skilful enough to discover the presence of the fungus spores and to see that they had saved the horses, and was thus well on the way to discovering penicillin, but failed to appreciate their significance because he focused his attention on life-taking rather than life-saving factors: Had he been a clinician, he might immediately have seen the possibilities of his accidental discovery. This raises the question of what role knowledge plays in creativity and, because knowledge is the principal product of successful convergent thinking, once again of the role of convergent thinking.

Knowledge and Creativity

Although some writers (e.g., Hausman, 1984) argued that true creativity is always so novel that it is *unprecedented* and thus has no connection to anything that went before, others such as Bailin (1988) unequivocally stated that creative products are always conceived by both the creative person and external observers in terms of existing knowledge. To take an obvious example, many of the inventions of America's most distinguished inventor, Thomas Alva Edison, were improvements on existing technology or ideas. Edison also worked with a large staff of engineers and technicians who constantly improved their own existing ideas: For instance, over the course of time they took out more than 100 patents for the electric light bulb alone. Indeed, in an aphorism that became widely known after being printed in *Harper's Monthly* in September 1932, Edison concluded that, "genius is 1% inspiration, 99% perspiration" (Josephson, 1959, p. 97), thus coming down squarely on the side of convergent thinking.

Lubart (2000–2001) expressed the link between knowledge and creativity in a homely but convincing way: He suggested that there may well be no difference between the *processes* of divergent and convergent thinking, but that differences in outcome may depend instead on " … the quality of the material (e.g., knowledge)" (p. 301). Lubart extended this thought with the concrete metaphor: "The engine is the same, but some people use better grade fuel" (p. 301). Those who have only limited or narrow knowledge (the poorer grade of fuel) would not be able to combine ideas, make unexpected associations between pieces of knowledge, or synthesize apparently unrelated facts because they would not possess the ideas, knowledge, or facts on which to operate.

Scott (1999) listed a number of creativity researchers who all give a prominent place to knowledge in creativity (e.g., Campbell, Wallas, Mednick, Chi, Weisberg, Amabile, Simonton, Albert, & Gruber). Ericsson and Lehmann (1999) summarized the link between knowledge and creativity by concluding that:

> The empirical evidence on creative achievement shows that individuals have not been able to make generally recognized creative contributions to a domain unless they had mastered the relevant knowledge and skills in the course of a long preparatory period. (p. 706)

Ericsson and Lehmann (1999, p. 700) repeated the idea that there is a "10 year rule": An apprenticeship of at least 10 years is necessary for acquiring the fund of knowledge and skills necessary for creativity.

It is not my intention to discuss in detail here the substantial literature on knowledge and creativity (for such a discussion, see Scott, 1999) or to review the highly formalized discussions found in cognitive psychology. In this article, my interest lies in the fact that a role for knowledge in creativity would strengthen the link between creativity and convergent thinking. What, then, broadly speaking, is the role of knowledge in creativity? In what way is knowledge (and thus the processes of convergent thinking through which it is acquired, stored, and retrieved when needed) linked to generation of effective novelty?

Knowledge Provides a Well From Which Ideas Are Drawn

Already, before the beginning of the modern era, the idea that creativity draws from the wellspring of conventional knowledge was well-established:

Rossman's (1931) study of inventors, for instance, concluded that they "manipulate the symbols of … *past experience* [italics added]" (p. 82). He also showed that they combined "*known* [italics added] movements" (p. 77). Feldhusen (1995, p. 255) and other writers have made an important point by emphasizing the "knowledge base" of creativity. An example of the value of a knowledge base is to be seen in Charles Babbage's (circa 1840) transfer of the punched card system for controlling the work of the Jacquard loom from the French fabric-making industry to a mechanical calculating machine, thus laying the foundation for what we now call a "computer"—a momentous piece of creativity that derived, nonetheless, from knowledge of *existing* systems for controlling machines. As Bailin (1988) put it, novelty "always arises out of what already exists " (p. 5). Weisberg (2003) showed that even an extraordinarily radical product such as Picasso's *Les demoiselles d'Avignon* derived from what Picasso had experienced up until the time he painted it.

The position of knowledge as the basis of creativity has been put in more formal terms by Boden (1994a), using the language of artifical intelligence. What I call "knowledge," Boden (1994a) called "cognitive maps" of a "conceptual space" (p. 8). The more structural features of a conceptual space such as, let us say, music are represented in a person's mind (i.e., the more the person knows about music, the more creative the person can be). Boden (1994a) gave the example of Mozart and concluded that Mozart's creativity arose from his vast musical knowledge.

Knowledge Defines What Is Creative

As Sternberg and Lubart (1999, p. 3) put it, a creative product must be adapted to "task constraints." Boden (1994b) made this point very strongly by arguing that it is dealing with the task constraints that makes a product or idea creative instead of merely original (occurring for the first time). Without task constraints, ideas could not cause surprise because there would be no expectations from which they would deviate. Therefore, paradoxically, novelty is determined by existing knowledge and not just by the product itself. Csikszentmihalyi (1999) extended the idea of existing knowledge as defining creativity when he described creativity as a novel variation in a domain of practice that experts in the domain recognize as novel and effective, and regard as worth incorporating into it. The experts judge according to their knowledge of their domain, which they have acquired through convergent thinking.

Although it goes beyond the limits of this article, it is interesting to note that because knowledge in a domain changes with the passage of time (usually by increasing), whether novelty is judged to be effective—and thus creative—may change with time. Indeed, once incorporated into existing knowledge, novelty of necessity ceases to be novel, thus creating a further paradox: Novelty (a) derives from what is already known; (b) is judged effective (or not) in terms of the already known; (c) passes into the body of knowledge if it is judged to be effective; (d) thereon ceases to be novel, and (e) having lost its own status as novel now influences the assessment of later novelty.

It is also interesting to note that additions to knowledge can have the opposite effect from the one just described, which involves novelty more or less inevitability destroying itself. With the passage of time, novelty initially regarded as not effective (or possibly not even novel) can come to be adjudged novel and effective and, thus, creative. Although this phenomenon can result from factors such as changes in conventions, social values, or taste (such as in aesthetic creativity), what is important here is that it can also result from convergent thinking. In 1832, the French mathematician, Evariste Galois, now regarded as one of history's most original mathematicians, was killed at the age of 20 in a duel so hopelessly uneven that he knew that he was doomed (see Rothman, 1982). He left a body of mathematical writings that were so important to him that he worked on his notes even on the night before his death. After the fatal duel, his writings were examined, but their contents were found to lead nowhere, despite the importance that he had attached to them and the fact that he was already known as an original mathematical thinker. The mathematical propositions were novel, to be sure, but they were judged to have no foundation in mathematical knowledge (i.e., to be lacking in effectiveness). It was only after the passage of several years—during which mathematical knowledge advanced enough to catch up with what Galois already knew—that his creativity was recognized. He is now famous as the founder of group theory known today as "Galois Theory." In other words, his divergent thinking could not gain recognition until convergent thinking had advanced sufficiently to make the effective novelty of his ideas apparent.

Knowledge Guides and Shapes Creativity

Despite the position of writers such as Simonton (1988), I take the view that production of effective novelty does not occur through a process of what Simon (1989, p. 377) called "brute force": making blind associations among already-known elements and occasionally recognizing, perhaps by good fortune, that a new combination offers the required solution. To generate effective novelty, divergent thinking must be guided by knowledge about how to acquire, organize, or apply knowledge: heuristics, strategies, hunches, "rules of thumb" (Rickards, 1999, p. 219), or what is sometimes called "metacognition" (e.g., Flavell, 1976, p. 232). Such knowledge indicates which kinds of attack on a problem are likely to be fruitful (or are already known to be fruitless), defines the pathways, methods, and tools through which progress can be made, and specifies the nature of acceptable solutions. To take an absurdly simple example, a person lacking knowledge of electricity would not spend much time developing the radio or the telephone as communication devices. Looked at the other way around, engineers working in the product development department of a large automobile manufacturer would be unlikely to stake their careers on an electronic matter transmitter as a means of mass transport.

Even aesthetic creativity in fields such as poetry or music rests on a foundation of skills, expectations, conventions, and the like: Poets or musicians have to know and stick to the rules for the novelty they produce to be judged effective. To take a simple example, sonnets always have 14 lines (otherwise, they are not sonnets), while there are rules about the rhyme schemes that are permissable as well as about the organization of contents: For instance, sonnets are often divided into an 8-line section in which a general theme is introduced, followed by a more specific 6-line section offering some conclusions, consolations, or the like. In "On his Blindness," John Milton (1673) lamented in the first 8 lines that his blindness was hindering him in serving God; but then, in the closing 6 lines, consoled himself with the thought that God can get along perfectly well without the humble work of a mere mortal. Sawyer (1999) showed that even jazz improvisation, which may look to the unitiated like pure divergence, is governed by rules and involves organized reuse of the already known. He gave the example of Charlie Parker, who developed for himself a repertory of about 100 "motifs" or "licks" (Sawyer, 1999, p. 36), each between 4 and 10 notes in length, which he then combined and recombined to generate effectively novel performances out of the already existing elements.

Converting Existing Knowledge Into New Ideas

Sternberg (1999) turned to the question of the processes through which existing knowledge is used to produce creativity. He introduced the useful idea of creativity as "propelling a field," (p. 83) and suggested a number of ways in which this can occur:

1. *Conceptual replication* (the known is transferred to a new setting).
2. *Redefinition* (the known is seen in a new way).
3. *Forward incrementation* (the known is extended in an existing direction).
4. *Advance forward incrementation* (the known is extended in an existing direction but goes beyond what is currently tolerable).
5. *Redirection* (the known is extended in a new direction).
6. *Reconstruction and redirection* (new life is breathed into an approach previously abandoned).
7. *Reinitiation* (thinking begins at a radically different point from the current one and takes off in a new direction).

Of these, only the last involves something quite new. All the others are based on modifying what already exists.

Savransky (2000) also discussed the processes through which existing knowledge is used to develop effective novelty: He argued that inventive solutions to problems always involve a change in what already exists. He discerned six ways in which this can occur. Slightly modified for present purposes, generating effective novelty involves, according to Savransky, one or more of the following:

1. *Improvement* (improvement or perfection of both quality and quantity of what already exists).

2. *Diagnostics* (search for and elimination of shortcomings in what already exists).
3. *Trimming* (reduction of costs associated with existing solutions).
4. *Analogy* (new use of known processes and systems).
5. *Synthesis* (generation of new mixtures of existing elements).
6. *Genesis* (generation of fundamentally new solutions).

As was the case with Sternberg's (1999) list, only the last of these involves something fundamentally new.

The Russian researcher, Altshuller (1988), also emphasized the role of the already known in his procedure for finding creative solutions to problems—known as TRIZ (a transliteration of the Russian acronym for "theory of inventive problem solving"). This procedure is based on an analysis of thousands of successful patent applications (i.e., on effective novelty that is already known). It argues that all engineering systems display the same systematic patterns of change. Creativity is the result of development of what exists according to these trends. TRIZ identifies these systematic processes of novelty generation so that people working with a new problem can apply them to derive their own novel solutions.

The Joint Role of Divergent and Convergent Thinking

What, then, is the role of convergent and divergent thinking in generating effective novelty? How do the two combine to produce it?

Generating and Exploring Variability

Finke, Ward, and Smith (1992) distinguished between two broad processes in the production of effective novelty: on the one hand, *generating* novelty; and, on the other hand, *exploring* this novelty once it has been generated. The first kind of process produces novelty, to be sure, but on its own it can easily lead not to creativity but to quasi- or pseudocreativity (unless there is a blind hit). Suppose that a civil engineer noticed that both steel reinforcing rods and spaghetti are long; tubular; and, under certain circumstances, flexible; thus, the engineer saw that spaghetti has some similarities to steel rods. This would involve a changed perception of spaghetti (generation of novelty). There really are similarities between reinforcing rods and spaghetti, and settings may well exist where this variation from the usual perception of steel and spaghetti really could lead to effective novelty (even if it is difficult to imagine what this setting might be). However, most civil engineers would probably reject, out of hand, the actual use of spaghetti instead of reinforcing rods and predict a catastrophe if spaghetti were used to replace steel (i.e., they would *explore* the novelty and would decide against it). This rejection of the novelty would be based on the engineers' knowledge of basic principles of civil engineering, such as strength of materials. Therefore, converting mere novelty into effective novelty (i.e., creativity) requires both generation (via divergent thinking) and also exploration (via convergent thinking).

Lonergan, Scott, and Mumford (2004) summarized recent thinking in this area, and concluded that the idea of a two-step process is now widely accepted. In my terms, this would involve novelty generation followed by (or accompanied by) exploration of the novelty from the point of view of workability, acceptability, or similar criteria to determine if it is effective. Only then would we speak of creativity. It is tempting to think of exploration as essentially a process of evaluation, and Runco (2003) supported this view. He argued that creativity requires a combination of divergent and convergent thinking; he further argued that convergent thinking involves "critical processes" (p. 432)—*critical* meaning not merely that the processes are necessary for creativity, but also that they involve criticism of the results of the divergent thinking (i.e., what I have just called "evaluation").

Continuing with the (admittedly whimsical) example of making a link between spaghetti and reinforcing rods via divergent thinking, Table 2 gives examples of processes of divergent and convergent thinking in both generating and evaluating phases of idea production, and suggests what the results might be if divergent thinking were not tempered by convergent thinking.

I do not intend to deny the importance of divergent thinking in production of effective novelty. However, although necessary, it is not sufficient on its own except perhaps for occasional flukes when blind luck leads to effective novelty. Convergent thinking is necessary, too, because it makes it possible to explore, evaluate, or criticize variability and identify its effec-

Table 2. *Processes of Divergent and Convergent Thinking in Generating Novelty*

	Generation of Variability		Generation of Orthodoxy	
Phase	**Examples of Processes of Divergent Thinking**	**Result**	**Examples of Processes of Convergent Thinking**	**Result**
Generating	Linking Transforming Reinterpreting Branching out	Engineer sees similarity between steel rods and spaghetti	Recognizing the familiar Reapplying the known Sticking to the rules	Engineer does not see a similarity between steel and spaghetti
Exploring	Shifting contexts Exceeding limits Crossing boundaries Creating surprise	Engineer concludes that steel rods can be replaced with spaghetti: Novelty to be sure—but in this case, a disaster!	Avoiding risk Being certain Staying within limits Seeking simplicity Assessing technical and financial feasibility	Engineer sticks to steel rods to reinforce concrete: No innovation, but building does not fall down!

tive aspects. In the enthusiasm for divergent thinking, it is thus important not to forget the contribution of convergent thinking, although it is also important not to overemphasize it as I believe is usually done in schools and universities. Table 3 gives examples of vital convergent thinking processes in both the generating and exploring phases of generation of variability.

Risks in the Introduction of Novelty

What are the risks if novelty is introduced without appropriate exploration (i.e., if divergent thinking is not accompanied by convergent thinking)? Figure 1 considers a number of possibilities. If no variability is generated (no divergent thinking), nothing changes and orthodoxy rules, bringing, however, the risk of stagnation and similar problems. This is the situation depicted in the first row of the figure. It is, of course, the safest pathway in settings where errors are punished but doing nothing is tolerated without sanctions; but, absence of creativity is of no interest to us here.

Table 3. *Examples of the Contribution of Convergent Thinking to Creativity*

Phase of Production of Effective Novelty	Convergent Thinking[a]
Generating Variability	Accumulating factual knowledge Observing closely Remembering accurately Drawing "correct" conclusions Thinking logically Processing information rapidly
Exploring variability	Recognizing promising lines of attack Zeroing in on potential solutions Seeing limits Being aware of weaknesses Weighing up feasibility Recognizing a solution

[a]Necessary but not sufficient prerequisites for generation of effective variability.

A new set of possibilities opens up when variability actually is generated. It is possible for this to be accepted without exploration (i.e., divergent thinking without convergent thinking). If such novelty proves to be ineffective, we can speak of "recklessness," which raises the danger of disastrous change. If, despite the lack of exploration, the novelty proves to be effective, this is more a matter of luck than judgment; then we can speak of "blind creativity," with the danger of overconfidence in the future. Therefore, not only does lack of knowledge reduce the possibility of generation of variability in the first place, but even where variability is generated, lack of exploration (convergent thinking) raises the possibility of reckless variability and exposes the system in question to the risk of disastrous change or overconfidence.

Figure 1 also depicts the various possibilities if exploration does take place (i.e., divergent thinking accompanied by convergent thinking). Where convergent thinking following on divergent thinking leads to a correct decision—in the case of convergent thinking we can speak of "correct" and "incorrect"—to implement change (i.e., to the introduction of effective novelty), creativity occurs. This is the ideal result. Where convergent thinking correctly leads to rejection of the variability generated through divergent thinking, the possibility of disastrous change is avoided but at the risk of

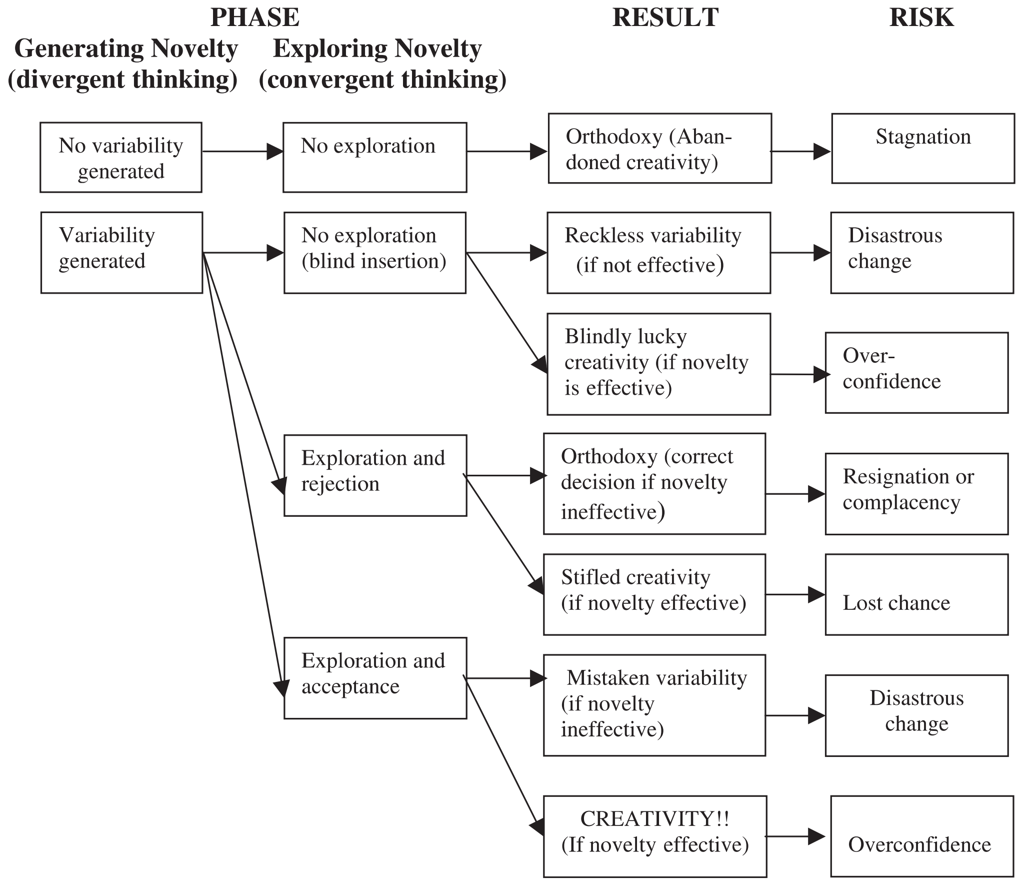

Figure 1. *Consequences of differing combinations of divergent and convergent thinking.*

resignation or complacency. Of course, the convergent thinking is not always correct: In the Computer Users' Committee at the University of Hamburg in the early 1980s, I fought against the introduction of remote computer terminals on the grounds that desk-top computing would never catch on. Errors of exploration (mistakes in convergent thinking) can lead to "stifled" creativity (false negatives) or "mistaken" variability (false positives) and raise the danger of a lost chance or, again, disastrous change.

How Do Divergent and Convergent Thinking Work Together?

I have argued that both divergent and convergent thinking are necessary for the production of effective novelty, and that achievement of such novelty without appropriate convergent thinking brings risks such as overconfidence. How do the two work together?

Prerequisite Models

The simplest explanation of the joint roles of divergent and convergent thinking in production of effective novelty is based on the idea that convergent thinking is a *prerequisite* for effective divergent thinking. An example is to be seen in Vincent van Gogh. His early work was driven by humane impulses (personal disappointment in love and a desire to bring other people beauty and consolation), which he initially tried to express by becoming a missionary before turning to painting. However, his paintings lacked formal, technical skill (convergent knowledge), and he had to return at the age of 32 to the Academy of Art in Antwerp where training in painting techniques allowed his flair for color and light to come to fruition. No one had to teach van Gogh how to produce novelty, but it was only after he had mastered techniques through hours of repetitious, convergent work that his paintings satisfied the prevailing norms for effective novelty.

The simplest prerequisite approach is the *summation model*: Divergent thinking and convergent thinking seem to add something to each other or even to compensate for defects in each other. More dynamic is the *threshold model*: Below some threshold level of convergent thinking, effective divergent thinking is thought to be impossible; but, as the level of convergent thinking approaches the threshold from below, the possibility of divergent thinking rises (i.e., divergent and convergent thinking are positively correlated to this point). Once the threshold has been passed, convergent thinking has no further effect on divergent thinking—van Gogh, for instance, did not continuously become more and more creative as his technical skills increased. Once these had become adequate as a vehicle for expressing his divergent thinking, creativity was inhibited or facilitated by factors other than convergent thinking.

A further elaboration of this approach is the *channel model,* according to which convergent thinking provides the channel or pathway through which information reaches the systems responsible for divergent thinking, thus determining how much and what kind of information is processed. A variant of this is the *capacity model,* which argues that convergent thinking determines the amount of information that reaches cognitive systems; divergent thinking then being applied to whatever information becomes available. As in the sense of Lubart (2000–2001), convergent thinking would thus influence the *level* of performance by providing high or low octane fuel (channel model) or sufficient or insufficient fuel (capacity model), but divergent thinking (or absence thereof) would influence the *kind* of performance.

Style Models

A second way of conceptualizing the interaction between production of variability and production of singularity is the *style* approach. According to this, convergent and divergent thinking do not directly influence each other. Both involve application of a superordinate ability to acquire, process, and store information; form abstract, general networks; develop knowledge matrices; and form systems and the like. Whether convergent or divergent products result depends on the way in which this thinking power is applied: to produce more of the same, or to generate novelty. This conceptualization of the interaction regards differences between convergent and divergent thinking as qualitative rather than quantitative: Regardless of level, mental ability can tend to be convergent or divergent. An example of this approach is seen in the work of Hudson (1968).

The Alternation Approach

I prefer a conceptualization based on the "classical" phase model, which was first introduced into creativity research about 80 years ago (Wallas, 1926). In the phase of *preparation,* a person becomes thoroughly familiar with a content area. In the *incubation* phase, the person "churns through" or "stews over" the information obtained in the previous phase. The phase of *illumination* is marked by the emergence of a solution, not infrequently seeming to the person involved to come like "a bolt from the blue." Finally comes the phase of *verification* in which the person tests the solution thrown up in the phases of incubation and illumination. The solution may emerge into consciousness all at once, thus seeming to have appeared from nowhere and creating the subjective feeling of effortless creativity. This would explain why some creative people overlook preparation and incubation in describing their own creativity.

Empirical studies of the process of creation in people actually engaged in producing something new, as well as retrospective studies in which acknowledged creators described how they obtained new ideas, have cast doubt on the validity of the phase model (see Glover, Ronning, & Reynolds, 1989) as an exact literal description of the production of an effectively novel product in real-life settings. Nonetheless, it offers a helpful way of looking at the production of effective novelty as a process and of describing the contributions of divergent and convergent thinking to this process.

Various considerations that I have spelled out elsewhere (e.g., Cropley, 1997) suggested that Wallas's (1926) four stages need to be extended by adding after *verification* two further stages: *communication* and *validation.* Furthermore, an initial stage of *information* needs to be taken into account: In this stage, the necessary problem awareness and intention develop. These

Table 4. *Creative Processes, Traits, and Motives in the Phases of Production of Novelty*

Phase	Action	Result	Necessary Process
Information	Perceiving	Initial activity	
	Learning	General knowledge	Convergent thinking
	Remembering	Special knowledge	
Preparation	Identifying problem	Focused special knowledge	Convergent Thinking
	Setting goals	Rich supply of cognitive elements	
Incubation	Making associations	Combinations of cognitive elements	Divergent thinking
	Bisociating		
	Building networks		
Illumination	Making a promising new configuration	Novel configuration	Divergent thinking
Verification	Checking relevance and effectiveness of the novel configuration	Appropriate solution displaying relevance and effectiveness	Convergent thinking plus divergent thinking
Communication	Acting on feedback	Effective presentation to others	Convergent thinking plus divergent thinking
	Achieving closure		
Validation	Judging relevance and effectiveness	Product acclaimed by relevant judges	Convergent thinking

considerations yield an extended model involving seven phases (see Table 4).

The phases of information and preparation may be vital in the whole process. Without problem awareness there will be no pressure for divergent thinking. Furthermore, the way the problem is defined, the pathways to a solution that are considered appropriate, and the kinds of solution regarded as feasible may all be determined in these phases via convergent thinking. Therefore, information may be both decisive and yet potentially problematic, as I discuss in the following; for instance, because it involves placing limits on divergent thinking, quite possibly without any intention of doing so. Normally, those who know the most are the best prepared; therefore, problems of information may apply particularly to experts (see the following).

Striking about the phase model, for present purposes, is that in some phases divergent thinking is needed; in others, however, convergent thinking; yet, in others, both are necessary. The crucial idea here is that although both are needed for production of effective novelty, this is not necessarily at the same moment in the process; the creative person may alternate from one kind of thinking to the other, according to the demands of the particular phase of the process of production of effective novelty. Facaoaru (1985) showed that creative engineers were good at both divergent and convergent thinking, whereas Hassenstein (1988) went so far as to argue that a new term is needed to refer to the rounded intellectual ability that combines both divergent and convergent thinking—*Klugheit* (cleverness).

A Precautionary Note

I do not want to imply that convergent thinking is always beneficial for creativity. In addition to possibly leading to errors (see Figure 1)—for instance, as a result of lack of knowledge, incorrect information, misunderstanding, and the like—convergent thinking can channel information processing into a narrow range of approaches—possibly without the person concerned being aware of this—thus narrowing the range of variability produced (via divergent thinking) or even blocking it altogether. Therefore, from the point of view of creativity, convergent thinking can be a good or a bad thing. For instance, working successfully in an area over a long period of time (i.e., enjoying an extremely thorough preparation and even becoming an expert) can provide a substantial knowledge base that can be manipulated to yield effective novelty (i.e., it can benefit divergent thinking). However, the preexisting knowledge of an expert can also act as a corset that blocks novel ideas so that thinking leads only to production of tried and trusted "correct" answers.

The well-prepared expert can even develop a vested interest in maintaining the *status quo.* Radical new solutions to old and intractable problems may threaten the self-image and the social status of experts who have labored long on a particular problem by rendering their lifetime's work irrelevant. The result may be that they resist introduction of novelty. Other processes that can lead to a negative correlation between creativity and expertise are cognitive in nature (e.g., sets, functional fixity, and confirmation bias). Mumford and Gustafson (1988) and Martinson (1995), among others, suggested that the relation between level of preexisting knowledge and creativity is *U-shaped*: Both very high (great expertise) and very low (ignorance) levels of preexisting knowledge inhibit production of effective novelty. What is needed is enough convergent thinking, but not too much.

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Gender Differences in Creativity

ABSTRACT

Research on gender differences in creativity, including creativity test scores, creative achievements, and self-reported creativity is reviewed, as are theories that have been offered to explain such differences and available evidence that supports or refutes such theories. This is a difficult arena in which to conduct research, but there is a consistent lack of gender differences both in creativity test scores and in the creative accomplishments of boys and girls (which if anything tend to favor girls). As a result, it is difficult to show how innate gender differences in creativity could possibly explain later differences in creative accomplishment. At the same time, the large difference in the creative achievement of men and women in many fields make blanket environmental explanations inadequate, and the explanations that have been proposed thus far are at best incomplete. A new theoretical framework (the APT model of creativity) is proposed to allow better understanding of what is known about gender differences in creativity.

INTRODUCTION

More than thirty years ago, Kogan (1974) conducted an extensive and then-definitive review of gender differences in creativity. He opened his paper with a point that is as salient today as it was when it was written: Any behavioral scientist who would argue that one gender is more creative than another would face tremendous scrutiny and a row of critics. With some relief, he continued, he found "relative equality" in creativity among males and females.

In this paper, we update and review gender differences in creativity up to the present day and try to understand these differences using a hierarchical model of creativity that looks at both general factors that influence creativity across many domains and more domain- and task-specific factors that have more limited applicability. There are many new studies of gender differences, some using very different methodologies, techniques, and populations than those reported in

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Kogan's 1974 review. Yet we find that we share Kogan's relief that although there is considerable evidence of differences in patterns and areas of strengths between the genders, there is *still* relative equality in creative ability.

There has clearly been a greater openness to investigating gender differences in recent years, and some authors, such as Piirto (1991a, 1991b, 2004), have made powerful arguments to explain the observed differences. Yet despite the many studies that have been done, gender differences in creativity has not become an important focus in either the creativity or psychology of women literatures. A few examples of this neglect:

- A handbook on the psychology of women (Denmark & Paludi, 1993) hailed as the most "comprehensive" and "systematic" review of literature available on the psychology of women (Babledelis, 1995, p. 639) made no reference to either creativity or divergent thinking. Neither did Unger's (2001) *Handbook of the Psychology of Women and Gender* or Worrell's (2001) two-volume *Encyclopedia of Women and Gender*.

- Neither creativity nor divergent thinking is mentioned in the third and latest edition of Halpern's (2000) *Sex Differences in Cognitive Abilities*.

- Gender differences were not mentioned as a topic by the 20 authors who contributed to Sternberg's (1988) edited volume *The Nature of Creativity*. In Sternberg's (1999) *Handbook of Creativity,* gender differences are cited once (and tangentially) in the otherwise comprehensive 490-page book.

Why the neglect? Perhaps because the findings have been inconsistent; were there either clear evidence of consistent gender differences or theories that made testable predictions of such differences, there would certainly be more interest among creativity researchers and women's studies faculties.

The largest inconsistency is between scores of tests designed to predict creativity and actual creative accomplishment. Most studies relating to gender differences in creativity have focused on divergent thinking, and these have not produced clear or consistent gender differences (although there is a relative wealth of data here, in which clever readers might discover more of a pattern than we have been able to find). The differences in real-world creative accomplishment are large and significant (Simonton, 1994); it is here that explanations are most needed. Several have been provided, but none with enough power to push the issue into the mainstream of creativity research or to separate it from other issues in the psychology of women. It is to be hoped that the present review will stimulate theorists and researchers to extend the ideas and findings reported below in ways that will enrich our understanding of why men have been so much more prominent than women among those of the highest creative accomplishment (an understanding that might help us restructure our schools, reconsider the ways accomplishment is typically recognized, or otherwise change the world in ways that lead to less waste of human creative talent).

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We have elsewhere presented the APT model of creativity (Baer & Kaufman, 2005a, 2005b; Kaufman & Baer, 2004, 2005a), a hierarchical model with several levels:

1. *Initial Requirements* include things that are necessary (but not sufficient) for *any* type of creative production — notably intelligence, motivation, and suitable environments.
2. In *General Thematic Areas* there are skills, traits, and knowledge that promote creativity across many related fields but not all fields.
3. In *Domains* there are more limited factors that promote creativity only in a specific domain.
4. Finally, even within a domain such as biology there are *Microdomains,* each with its own very specialized knowledge that one must master to make creative contributions.

The APT model's general hierarchical framework will help explain different aspects of the problem women have had in achieving levels of creative productivity comparable to their male counterparts. Familiarity with more detailed aspects of the model is not necessary for the purposes of this paper, but interested readers can find the most complete exposition of this model in Kaufman and Baer, 2005a.

There is at least one over-arching reason at the level of Initial Requirements why women's creative productivity has lagged in almost all fields: the Initial Requirement of a conducive environment in which to develop expertise and in which one's creative performance is judged have been different for men and women. The relative lack of supporting environments — including the failure to nurture early talent, the demands and expectations of society (and especially of motherhood), and the control of entry into many fields and their resources by men — has hindered women's accomplishments in virtually all domains. There are also limitations that vary from field to field and domain to domain which explain differences in creative achievement by women in different domains (Helson, 1991a, 1992b, 2004; Simonton, 1992, 1994). These issues will be discussed below in the section on Theories of Gender Differences in Creativity.

A note on this paper's organization: The categories provided in the outline of this paper are not mutually exclusive. Some overlap is probably inherent in the topic, and a bit more overlap was caused by an attempt to make it easy for readers to locate in one section of this review the kinds of specific information they are looking for on a particular topic. Because some research reports and theoretical articles are related to different aspects of the general topic of gender differences in creativity, some articles are of necessity cited in more than one section of this review. Because of the large number of studies (especially in the area of divergent thinking test score comparisons), many of the studies listed in the tables are not discussed elsewhere in the paper (see Baer, in press, for more in-depth discussion of the divergent thinking tests).

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EVIDENCE OF GENDER DIFFERENCES IN CREATIVITY

OVERVIEW

This section reviews research that touches on or directly addresses the question of gender differences in creativity. We have divided this section based on age (preschool/elementary, middle school, high school, and adults). When participants fell into more than one age category, we used the age of the most participants.

In the first subsection (Gender Differences in Scores on Creativity Tests), differences in scores on creativity tests — mostly divergent thinking tests — are considered. Here is a one-sentence summary of that subsection: While there are research results pointing in various and often contradictory directions, the evidence does not clearly support gender differences in creativity based on test results; however, to the extent that a case for such gender differences can be made, the available evidence suggests that women and girls tend to score higher on creativity tests than men and boys.

The second subsection (Gender Differences in Subjective Assessments) goes into more detail about self-assessments, assessments by others, and personality-style assessments. The third subsection (Gender Differences in Creative Achievement) considers differences in creative accomplishment. This subsection does *not* document differences in achievement across a wide variety of domains. The existence of such differences is widely recognized, but far more research effort has gone into trying to understand the causes of such differences (as described below in the Theories of Gender Differences in Creativity section of this paper) than has gone into trying to document them. The evidence of differences in creative achievement reviewed in this subsection includes just one study of what might be thought of as long-term real-world achievement. (That study is, in fact, an investigation of publication success in the field of creativity research.) The rest of the subsection reviews gender differences in studies of the creativity of actual products (e.g., poems, stories, collages) created by subjects in psychological experiments.

GENDER DIFFERENCES IN SCORES ON CREATIVITY TESTS

Divergent thinking tests have dominated creativity testing, and the various Torrance Tests (Torrance, 1966a, 1966b, 1966c, 1970, 1981, 1988, 1990a, 1990b; Torrance, Khatena, & Cunnington, 1973) have dominated the field of divergent thinking testing. Perhaps most popular are the *Torrance Tests for Creative Thinking* (TTCT; Torrance, 1966c, 1970, 1974, 1990a, 1990b). According to one view of creativity research (Torrance & Presbury, 1984), three-quarters of all published studies used one of the Torrance Tests, and one meta-analytic evaluation of the effects of various creativity training programs (Rose & Lin, 1984) judged the Torrance Tests to be so pervasive that it included only studies which had employed these tests. Add to these studies those that have used one of the Wallach and Kogan (1965) divergent thinking tests and it is easy to see that divergent thinking tests have been ubiquitous as measures of creativity.

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For at least 25 years a debate has raged over the validity of these tests as measures of creativity (e.g., Baer, 1993; Barron & Harrington, 1981; Crockenberg, 1972; Kogan, 1983; Oon-Chye & Bridgham, 1971; Runco, 1991a). It is interesting to note in this regard that longitudinal validation studies of the Torrance Tests of Creative Thinking (Torrance, 1966c, 1974) have suggested that these divergent thinking tests are more predictive of creative behavior in males than females (Arnold & Subotnik, 1994; Cramond, 1994; Howieson, 1981), although these validity studies have themselves been criticized for lacking validity (Anastasi, 1982; Baer, 1993; Crockenberg, 1972; Kogan, 1983). This review of gender differences in creativity will not attempt either to review or to take sides in those controversies; it will likewise remain agnostic regarding the validity of all other measures of creativity. However, to review gender differences in the results of creativity testing means, for better or worse, reviewing mostly studies of gender differences in divergent thinking test scores.

No simple conclusions can be drawn from the empirical evidence on gender differences in creativity test scores; there are studies that report that girls and women score higher than boys and men, and there are studies that report the opposite. The former (that is, studies in which girls and women score higher) are more numerous, so it would be hard to make a case for an overall male advantage. The case for a female advantage is also less than conclusive, however, both because there are many studies pointing in opposite directions and there are many that report no significant gender difference.

Table 1 lists all comparisons in which no gender differences in creativity were found. This list includes 21 studies that used various divergent thinking tests, one that used the Remote Associates Test (RAT; Mednick, 1962; Mednick & Mednick, 1967), and two that assessed evaluative thinking. Table 2 lists all studies in which males scored higher than females. There were just three such studies, all using divergent thinking tests. Table 3 lists all comparisons in which females outscored males, six of which compared divergent thinking test scores. Table 4 lists all studies in which the results were in some way mixed, including 17 studies using divergent thinking tests and two using the RAT. Although a great many studies have looked for gender differences in scores on tests designed to measure and predict creativity, few have found such differences and no consistent pattern has emerged from this research.

GENDER DIFFERENCES ON SUBJECTIVE ASSESSMENTS

Self-Report Assessments of Creativity

Goldsmith and Matherly (1988) gave 118 college students three self-report measures of creativity and found no gender differences. The subjects also completed three self-report measures of self-esteem. There was a positive correlation between the self-report measures of creativity and the self-report measures of self-esteem, but the relationship was both stronger and more consistent for women than for men. This gender difference in the relationship between self-esteem and creativity confirmed a prediction based on a study by Forisha (1978), which found

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TABLE 1. Creativity Measures Where No Gender Differences Found.

Author and date	Creativity measure	Participants
Parish and Eads (1977)	Divergent thinking test	76 college students
Jacquish and Ripple (1980)	Adaptation of Cunnington and Torrance's sounds and images (1965)	Caucasian middle-class preadolescent males and females (mean age 10.8)
Ziv (1980)	TTCT (Torrance, 1974)	98 10th grade students
Amabile (1983)	Verbal creativity using poetry-writing task	Adult males and females
Amabile (1983)	Verbal creativity using story-telling task	Male and female children
Amabile (1983)	Verbal creativity using caption-writing task	Adult males and females
Runco (1986a)	Wallach and Kogan battery (1965)	150 5th-8th grade students
Runco (1986b)	Wallach and Kogan battery (1965)	228 5th-8th grade students
Runco and Albert (1986)	Wallach and Kogan battery (1965)	228 gifted (43%) and nongifted (57%) 5th-8th grade students
Runco and Bahleda (1986)	Wallach and Kogan battery (1965)	234 5th-8th grade students with IQs ranging from 97-165
Sajjadi-Bafghi (1986)	Thinking creatively with sounds and words test (Torrance, Khatena, & Cunnington, 1973)	Middle school students in India, grades 7th-9th
Shukla and Sharma (1986)	Divergent thinking test to predict scientific creativity	230 middle school students in India
Runco, Okuda, and Thurston (1987)	Wallach and Kogan battery (1965)	120 students (IQ range 98-165) between 11-13 years old
Runco and Okuda (1988)	Three divergent thinking tests	Scientifically and mathematically talented students (19 males and 10 females)

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TABLE 1 (cont.). Creativity Measures Where No Gender Differences Found.

Author and date	Creativity measure	Participants
Kelgeri, Khadi, and Phadnis (1989)	Medhi's (1973a) verbal test	200 randomly selected urban and rural 8th-10th grade students in India
Chrisler (1991)	TTCT (Torrance, 1962)	11 men (mean age 31.6 years) and 20 women (mean age 36.2 years)
Runco (1991b)	Evaluative thinking	4th-6th grade students
Gaynor and Runco (1992)	Divergent thinking test	114 4th-6th grade students
Runco and Smith (1992)	Evaluative thinking	27 male and 31 female university students
Sansanwal and Sharma (1993)	Scientific creativity test (Madjumar, 1975)	228 randomly selected students aged 13-16 years in India
Barrantes, Caparros, and Obiols (1999)	Divergent thinking test	59 college students
Hakstian and Farrell (2001)	Openness to experience	2,375 college students and non-management job applicants
Saeki, Fan, and Van Duesen (2001)	TTCT	51 American and 54 Japanese college students
Tan (2001)	Methods of fostering classroom creativity	117 elementary school teachers from Singapore
Lee (2002)	Divergent thinking test	82 college students
DeSousa Filho and Alencar (2003)	TTCT (Torrance, 1974) and test of creative divergent production (Urban & Jellen, 1996)	55 Spanish children
Rawashdeh and Al-Qudah (2003)	TTCT (Torrance, 1974)	139 8th grade students from Ajloun Governorate schools in Jordan

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TABLE 1 (cont.). Creativity Measures Where No Gender Differences Found.

Author and date	Creativity measure	Participants
Cheung, Lau, Chan, and Wu (2004)	Wallach-Kogan creativity test (1965)	1,418 Hong Kong students ranging from 1st-9th grade
Harris (2004)	RAT	404 college students
Harris (2004)	Openness to experience	404 undergraduate students
Kaufman, Baer, and Gentile (2004)	Assessment of creative products	8th graders from 32 states, taken from the 1998 NAEP classroom writing study
Chan (2005)	Self-assessments of creativity	212 gifted Chinese students
Charyton (2005)	tests of general, scientific, and artistic creativity	100 music and 105 engineering college students
Donnell (2005)	TTCT, Verbal Form B	gifted middle school students
Zachopoulou & Makri (2005)	Divergent Movement Ability Test (Cleland & Gallahue, 1993).	preschool and elementary school children

TABLE 2. Creativity Measures Where Males Scored Higher.

Author and date	Creativity measure	Participants
Zheng and Xiao (1983)	Divergent thinking and creativity ratings made by the students' teachers	812 Chinese high school students
Tegano and Moran (1989)	Multidimensional stimulus fluency measure (Moran, Milgram, Sawyers, & Fu, 1983)	Preschool, 1st, and 3rd graders
Rajendran and Krishnan (1992)	Mehdi's (1973a) verbal test and Mehdi's (1973b) nonverbal test	250 secondary students in Madras, India
Cox, B. F. (2003).	Khatena Torrance Creative Perception Inventory (1977)	adult community college students

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TABLE 3. Creativity Measures Where Females Scored Higher.

Author and date	Creativity measure	Participants
Singh (1979)	Divergent thinking abilities and personality traits	Adolescent males and females in India
Jaquish and Ripple (1980)	Adaptation of Cunnington and Torrance's sounds and images (1965)	European-American middle class adolescent males and females
Kershner and Ledger (1985)	TTCT (Torrance, 1962, 1974)	30 gifted and 30 average IQ children ages 9 to 11
Hines (1990)	Associational fluency	52 male and 89 female undergraduates
Rejskind, Rapagna, and Gold (1992)	Divergent thinking test	244 gifted students (152 males and 92 females)
Kim and Michael (1995)	TTCT (Torrance, 1990a, 1990b)	Korean 11th grade students
McCrae et al. (2002)	Openness to experience	230 students twice — during 6th grade and four years later
McCrae et al. (2002)	Openness to experience	1,947 high school students
Misra (2003)	Openness to experience	156 Indian students

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TABLE 4. Creativity Measures Where Mixed Scores Found.

Author and date	Creativity measure	Participants	Mixed results
Bowers (1971)	Eight different divergent thinking tests	36 women and 36 men	Females outscored males in 6 of 8 tests, but not significantly; females' scores correlated with personality variables, but not males'
Kirkland (1974) and Kirkland & Barker (1976)	Torrance repeated figures circle test	undergraduate and graduate students	Females' scores were influenced by pre-testing activities, but not males'
Hargreaves (1977)	Circle test (Torrance, 1962)	10 and 11 year old studentss	No gender differences in scores, but gender differences in patterns of responses
Raina (1980)	Verbal and nonverbal divergent thinking	110 9th grade science students in India	No significant gender differences (but females scored higher on both)
Amabile (1983)	Creativity in art using a collage-making task assessed for creativity by artists, art critics, and art teachers	Children and adult males and females	Females rated higher in creativity in one sample of adults but in several other studies using the same task with both children and adults there were no significant gender differences
Bharadwaj (1985).	Fluency	19 and 21 year old college students in India	Females had higher fluency scores at both ages and higher flexibility scores at age 19, but among 21 year olds males had higher flexibility scores.
Richardson (1985)	Divergent thinking test and RAT	320 Jamaican 16 year old males and females	Females scored higher on RAT but no significant differences on divergent thinking tests (although females scored higher on all four)

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TABLE 4. (cont.) Creativity Measures Where Mixed Scores Found.

Author and date	Creativity measure	Participants	Mixed results
Ruth and Birren (1985)	Verbal and nonverbal divergent thinking tests	150 young (25-35 years), middle aged (45-55 years), and old (65-75 years) males and females	Both genders scored higher on one of the two verbal and one of the two nonverbal tests
Chusmir and Koberg (1986)s	RAT (Mednick, 1962; Mednick & Mednick, 1967) and manifest needs questionnaire (Steers & Braunstein, 1976) 96 male and 69 female managers	96 male and 69 female managerss	No mean gender differences, RAT scores correlated with need achievement for males and need affiliation for females
Lewis and Houtz (1986)	Square test (adapted from Circle test; Torrance, 1962)	Kindergarten and 1st grade students	No gender differences in scores, but gender differences in patterns of responses
Runco (1986a)	Self-report of creative activities involving scores of quality and quantity	150 5th-8th grade students with mean IQ of 133	Of 14 comparisons, the only gender difference was in quantity of creative performance in music
Schmidt and Sinor (1986)	Measure of creativity thinking in music (Webster, 1987, 1989)	34 second grade students	Males scored higher on three levels, no gender difference on fourth level
Dhillon and Mehra (1987)	Medhi's verbal and figural divergent thinking tests (1973a, 1973b)	160 middle and high SES Indian children ages 9 to 11s	High SES females scored higher on both tests, but middle SES children showed no gender differences
Goldsmith and Matherly (1988)	Self-report measures of creativity and self-esteem	118 college studentss	No gender differences in creativity; stronger correlation between creativity and self-esteem for females than males

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21626057, 2008, 2, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/j.2162-6057.2008.tb01289.x by New Aarhus University, Wiley Online Library on [07/12/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 4. (cont.) Creativity Measures Where Mixed Scores Found.

Author and date	Creativity measure	Participants	Mixed results
Dudek and Verreault (1989)	TTCT (Torrance, 1974)	100 high and 100 low scoring males and females from 1,450 5th and 6th grade students	No gender differences in scores, but females had more libidinal primary process and males had more aggressive primary process content
Paguio and Hollett (1991)	Torrance's thinking creatively in action and movement and Martin's temperament assessment battery	38 preschoolers ages three to four years	No gender differences in scores, but temperament had modest relationship to creativity in females, but not in males
Gough (1992)	Assessment of creativity of graduate students by their professors	1,028 graduate students from University of California at Berkley (623 male, 405 female) between 1950-1981	Patterns of correlations of creativity ratings with various personality measures were different for females and males
Baer (1993)	Assessment of various creative products	50 academically gifted 8th grade studentss	No gender differences in poems, stories, and mathematical word problems; males scored higher in equations
DeMoss, Milich, and DeMers (1993)	TTCT (Torrance, 1990a, 1990b)	128 high achieving 8th and 9th grade students	Females score higher on verbal, males score higher on figural
Dudek, Strobel, and Runco (1993)	Verbal and figural forms of the TTCT (Torrance, 1966c)	1,445 5th and 6th grade students in 11 English-speaking Montreal schools	Females scored higher in three of four comparisons
Feist & Runco (1993)	Publications in creativity journals	All contributors to the *Journal of Creative Behavior* 1967-1989e	Males contributors out-numbered females 3 to 1, but the ratio decreased over time
Sansanwal and Sharma (1993)	Divergent thinking test	Students in India	Females scored higher on verbal and nonverbal creativity, males scored higher on originality

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TABLE 4. (cont.) Creativity Measures Where Mixed Scores Found.

Author and date	Creativity measure	Participants	Mixed results
Lau and Li (1996)s	Creativity assessment by teachers and peers	633 Hong Kong 5th grade students and their teachers	Males were regarded as more creative by peers, but no gender differences found in teacher's ratings
Ai (1999).	Relationship of creativity to academic achievement	2,264 high school students aged 13-18 years old in Basque County, Spain	Flexibility and elaboration more important for males, fluency and elaboration more important for females.
Averill (1999)	ECI	Males and females	Females scored higher in preparedness and effectiveness/authenticity, no gender differences in novelty
Campos, Lopez, Gonzales, and Perez-Fabello (2000)	Figural TTCT	728 Spanish high school students	Females scored higher on abstractness of title subtest, no gender differences on rest of figural form A
Chan, Cheung, Lau, Wu, Kwong, and Li (2001)	Wallach-Kogan ideational fluency test (1965)	462 Hong Kong elementary studentsl	Males scored higher in verbal, no gender differences in figural
Costa, Terraciano, and McCrae (2001)	Different components of openness to experience factor	Secondary analysis of 23,031 people from 26 cultures	Females scored higher in aesthetics, feelings, and actions, males scored higher in ideas, no gender differences in fantasy or value
Fichnova (2002)	Wallach-Kogan ideational fluency test (1965)	Preschool students ages 3 to 6 years old	Females scored higher in verbal, males scored higher in figural
Kaufman (in press)	Self-reports in different domains of creativity	2,459 high school and college students	Males higher on two of five factors and 28 of 56 domains; females higher on two of five factors and 15 domains

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that creative production in women was associated with sex-role masculinity (a construct that includes the personality traits of competence and self-reliance).

Runco (1986a) had 150 5th-through-8th grade students with mean IQ of 133 report on their creative activities in seven domains — writing, music, crafts, art, science, performing arts, and public presentation — as part of a study designed to assess the predictive validity of divergent thinking test scores. From these self-reports, scores for both quality and quantity of creative performance in each of the seven areas were computed. Significant gender differences were found only for a self-report of quantity of performance (e.g., "never," "once or twice," "three to five times," "six or more times") in music performance.

Chan (2005) asked 212 gifted Chinese students to self-assess their creativity, family hardiness, and emotional intelligence, and found no significant gender differences for all constructs. Kaufman (in press) asked 3,553 individuals (mostly high school and college students) to rate themselves in 56 different domains of creativity. Of the five factors derived from the 56 domains, males rated themselves higher than females on the science-analytic and sports factors, females rated themselves higher on social-communication and visual-artistic. There were no differences on the verbal-artistic factor. At the domain level, there were significant gender differences in 43 of 56 domains. Males self-reported creativity higher than females in 28 areas and overall; females self-reported higher creativity in 15 areas. In most cases, self-assessments were consistent with gender stereotypes. It is important to clarify, however, that the discrepancies may easily be a result of internalized gender stereotypes, as opposed to actual differences in creativity.

Henderson (2003) found no gender differences in self-reported creative achievement of 247 inventors working in multinational firms who responded to a 90-question on-line survey. Women in this study did report more publications and conference presentations than men, however. Early environments were important; subjects cited many instances of early family, school, community, and higher education experiences that had influenced their ability to invent.

Assessments of the Creativity of Individuals by Others

Gough (1992) looked for correlations between professors' assessments of psychology graduate students' creativity, defined as "The creative quality of the student's thinking and research in psychology" (p. 228), and various personality and cognitive test scores. This continuing assessment procedure began with graduate students in psychology at the University of California at Berkeley in 1950 and included 1,028 graduate students (623 men, 405 women) between then and 1981, the period covered by Gough's report.

Gough (1992) found that the Creative Personality scale (Gough, 1979) was the only one of 37 Adjective Check List (Gough & Heilbrun, 1983) scales that was significantly correlated with creativity for both women (.26) and men (.17). There were several Adjective Check List scales correlated with assessments of only women's or only men's creativity. Gough (1992) also compared correlations of women and men's creativity ratings with their scores on California Personality

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Inventory scales. Overall the patterns showed only minor differences. A new scale, Creative Temperament (CT), was developed using this sample of graduate students and their professors' ratings of their creativity. Not surprisingly, this CT scale was correlated with the creativity ratings of both women (.33) and men (.25) in this sample.

Another method of creativity assessment is to ask teachers or peers to rate a person's creativity. Lau and Li (1996) asked 633 Hong Kong fifth-grade students and their teachers to evaluate the creativity of the students in their class. Boys were regarded as more creative by their classmates, but there was no gender difference in teachers' ratings. It should be noted that although used routinely in screening for gifted/talented programs, Howieson (1980) and Wallach (1970) have warned that teacher ratings of students' creativity may be poor predictors of creative performance.

Creative Personality Tests

In addition to Gough's work on creativity and personality, there are several studies that specifically try to measure creative personality. Many of the major self-report personality tests (e.g., the California Psychological Inventory; Myers-Briggs Type Indicator) include creativity indices. Perhaps the most consistent finding on personality and creativity is that on the five-factor personality test (e.g., Goldberg, 1992), Openness to Experience correlates strongly with creativity (see Feist, 1999; McCrae, 1987).

Several studies have explored gender differences on the Openness to Experience factor. Some studies have found that girls score higher on the Openness to Experience factor. McCrae et al. (2002) measured personality in 230 students twice, during the sixth grade and then four years later. Girls scored higher at both points in time. In a second study, McCrae et al. (2002) tested 1,947 high school students and found females scored significantly higher on Openness. Misra (2003) studied 156 Indian students and also found higher Openness scores in females. Other studies found no differences in Openness to Experience, including Hakstian and Farrell (2001; 2,375 college students and non-management job applicants) and Harris (2004; 404 undergraduates).

Costa, Terracciano, and McCrae (2001) analyzed gender differences in Openness to Experience based on a secondary analysis of 23,031 people from 26 cultures. They analyzed different components of Openness to Experience, and found that women scored higher than men on Openness to Aesthetics, Feelings, and Actions. Men scored higher than women on Openness to Ideas. There were no differences on Openness to Fantasy or Values. As with Kaufman and Baer's (in press) findings, these differences may be related to gender stereotypes as much as individual beliefs.

GENDER DIFFERENCES IN CREATIVE ACHIEVEMENT

The focus of this section is on assessments of creative achievements, not assessments of the creativity of individuals. Because of space limitations we have not listed studies that simply demonstrate that men have been more successful

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in a given domain than women. Readers are referred to Piirto (2004) for more extensive information on gender differences in creative accomplishments.

ASSESSMENTS OF CREATIVE PRODUCTION

Evaluations of Individuals' Creative Products

Almost no differences in creativity among male and female subjects have been reported in a series of studies using Amabile's (1982, 1983) Consensual Assessment Technique. In each of these studies, subjects are asked to create something (a poem, story, collage, etc.). These products are later rated for creativity by experts.

In a series of studies of creativity in art using a collage-making task, Amabile (1983) found no significant gender differences. Using the same task with adults, in one study, "there was a nearly significant sex difference. Females made collages that were rated higher in creativity than those made by males ($p < .052$)" (p. 49), but in other research using the same task there were no significant gender differences.

In three studies of verbal creativity among adults using a poetry-writing task, Amabile (1983) reported that there were no significant gender differences. In three additional studies of verbal creativity involving either story-telling by children or caption-writing by adults, no gender differences were reported.

In an investigation by Baer (1993), fifty academically gifted eighth-grade students wrote poems, stories, mathematical word problems, and original mathematical equations. Only among the equations was there a significant gender difference (in which males scored higher than females). In the six other studies reported, which involved second-, fourth-, and fifth-grade students, as well as one study that focused on adults, no gender differences were observed.

Kaufman, Baer, and Gentile (2004) studied 102 poems, 103 fictional stories, and 103 personal narratives taken from the 1998 NAEP Classroom Writing Study. In the NAEP study, eighth graders from 32 states were asked to choose their two best pieces of writing that they had completed for their regular classroom assignments. Three groups of experts read all 308 pieces of writing. The experts included teachers of 8th grade creative writing, psychologists who studied creativity, and published creative writers who had extensive experience working with middle school students. Across all groups of experts, no gender differences were found for the poems, stories, or narratives.

A Study of Gender Differences in Authorship

In a study of trends in the creativity literature, Feist and Runco (1993) counted the numbers of male and female contributors to the *Journal of Creative Behavior* from 1967 until 1989. Over this 22-year period, there were approximately three times as many male authors as female authors (mean number of male authors/article = .93; mean number of female authors/article = .33). The number of female authors increased, however, from a per-issue mean of little more than 0 in 1967 to a per-issue mean of just under 3 for the years 1980-1989. The mean

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number of male authors per issue dropped during the same period, although only slightly, from about 6 in the late 60s to about 5 in the 80s. The number of women authors reached a plateau in the 1980s. Feist and Runco noted that this follows the trend in other journals, specifically the Australian Journal of Psychology, where the number of women authors increased into the 1970s and then reached a plateau.

Emotional Creativity

Emotional creativity is "the development of emotional syndromes that are novel, effective, and authentic" (Averill & Thomas-Knowles, 1991, p. 270). Averill and Nunley (1992) presented evidence that "women may be more emotionally creative than men" (p. 159), although they caution against emphasizing any conclusions based (as this one was) on paper-and-pencil tests. Averill (1999) later created and tested the Emotional Creativity Inventory (ECI). The ECI has three facets — preparedness (e.g., background knowledge about emotional creativity); novelty; and effectiveness/ authenticity. Averill found that females scored higher than males on the preparedness and effectiveness/authenticity facets, as well as on the overall mean score. There were no differences on the novelty facet.

THEORIES OF GENDER DIFFERENCES IN CREATIVITY

This section reviews theories of gender differences that theorists believe have an impact on creativity or explain gender differences in creative accomplishment. This is an area that the reader will probably not be surprised to hear is fraught with controversy.

Abra and Valentine-French (1991) surveyed available explanations for gender differences in creative achievement and argued that, although empirical studies of creativity have mushroomed, these studies have told us little about the causes of the great difference between women and men in creative achievement at the highest levels; this is due, in large part, to the fact that such studies "typically assess creativity with one of the available tests (e.g., Guilford, 1967; Mednick, 1962) of which the validity is suspect" (p. 237). According to Abra and Valentine-French (1991), this problem is compounded by the fact that most of the subjects of these studies have been either children or college students who have, at best, creative potential, but who have not yet exhibited the kind of creative achievement in which significant gender differences are apparent.

Abra and Valentine-French (1991) considered both nature and nurture arguments for the observed gender differences in creative accomplishments and noted the special problem of disentangling the two when considering gender differences (e.g., "identical twin pairs with one male and one female pair are in short supply" (p. 240)). They argued that possible explanations range from differences in specific cognitive abilities and in educational opportunities to differences in selfishness and competitiveness, and they considered possible genetic and environmental sources of such differences in an often speculative vein. Their conclusion that "creative achievement depends on both biological and environmental

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factors. . . . [and] because men and women differ in both factors, either or both could have produced the achievement difference" (p. 235) will settle few arguments about why we find significant gender differences in many fields of endeavor.

The remainder of this section is divided into three subsections. The first looks at biological theories of gender differences in creativity — theories that are clearly on the nature side of the nature-nurture controversy — and also examines the theory that androgynous males and females may be more creative than their less androgynous counterparts, a theoretical approach which includes arguments from both sides of the nature-nurture issue. The second subsection looks at several developmental theories of gender differences influencing creativity in specific age groups and settings. The final subsection provides a unifying perspective using the framework provided by the APT hierarchical model.

BIOLOGICAL EXPLANATIONS

Vernon (1989) argued that although social-environmental influences are certainly major causes of differences in the numbers of highly creative men and women in various fields, these factors are not sufficient explanation for the patterns of achievement that have been observed. "It is entirely implausible that human society should approve of females becoming highly talented performers of music, dance, and drama, and even allowing them to become creative writers, while, at the same time, disapproving of their becoming musical composers or painters. To me, this is the crux of the argument for attributing sex differences in creativity at least, in part, to genetic factors" (pp. 102-103).

Simonton (1994) at least partially refuted this argument by pointing out that active sex discrimination has often prevented women from acquiring the resources necessary for achievement. "This male domination of resources alone could explain why women have the best prospects in literature. It doesn't require a well-equipped laboratory, a full orchestra, or a large block of marble to write a masterpiece of fiction or poetry" (p. 36). In addition to direct sex discrimination, Simonton argued that at least three other factors have led men and women to compete for acclaim on an uneven playing field: different socialization practices for girls and boys, different costs of marriage and family for men and women, and the effects of a "gender ambience of a particular civilization at a given time. . . . not very sympathetic to female attainments" (p. 36). Simonton (1992) conducted an interesting, though somewhat inconclusive, empirical test of the hypotheses that three cultural factors which change over time — the creative zeitgeist, levels of machismo mentality, and sexist ideologies — influence creative productivity of men and women in different ways by comparing the creative productivity of men and women in Japan over a period of 1,400 years. Prevalence of gender-biased belief systems was negatively associated with female literary and nonliterary eminence; overall, however, literary success of women and men was linked to similar contextual factors.

Although authors like Vernon (1989) may find logical grounds for speculating that genetic differences must account for some of the observed gender differences in creative achievement, specific genetic or other biological theories of

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gender differences in creativity are difficult to find. Hassler, Nieschlag, and de la Motte (1990) reviewed research suggesting that musical talent and spatial ability are highly correlated, pointing out that in one group — women composers — this correlation is not found. This difference may be related to differences in testosterone levels on brain development, which may in turn result in gender differences in patterns of hemispheric dominance. Such testosterone-related differences would be consistent with Geschwind and Galaburda's (1985) hypothesis that there is a relationship between anomalous hemispheric dominance and special talents, Waterhouse's (1988) thesis that special cognitive talents have specific neurological substrates, and Gronemeyer's (1984) speculation that there may be a specifically female way of composing (for example, by using the human voice). Hassler et al. (1990) conducted three experimental studies that provided limited support for all three hypotheses.

One currently popular explanation rooted in biology for gender differences at the most extreme levels of creative performance is based on evidence that, even when mean levels are identical on a given trait, men and women often have different normal curves, with men's curves often being flatter. Steven Pinker summarized the statistical basis for this claim as follows: "[E]ven in cases where the mean for women and the mean for men are the same, the fact that men are more variable implies that the proportion of men would be higher at one tail, and also higher at the other. As it's sometimes summarized: more prodigies, more idiots" (Pinker & Spelke, 2005, para. 24). Pinker reports data from Hedges and Nowell (1995) showing that in 35 or 37 cognitive areas tested, the male variance was greater than the female variance. Such differences could explain why at the very highest level of accomplishment men are over-represented and women under-represented while at the same time acknowledging overall equal levels of creativity between genders.

DEVELOPMENTAL THEORIES

Several theorists have suggested explanations for possible gender differences in creative behavior that are related to specific developmental periods and task constraints.

CHILDREN IN PRESCHOOL AND ELEMENTARY SCHOOL

Exploratory Behavior and Divergent Thinking

Singer and Singer (1990) argued that failure to engage in exploratory behavior as a toddler is related to lack of curiosity in boys, but to problematic personality and social adjustment in girls. Singer and Rummo (1973) found that kindergarten boys who scored high on divergent-thinking tests were rated by teachers as more playful, open, curious, and expressive than their peers, while girls who scored high on divergent-thinking tests were *less* open, expressive, self-confident, and effective in peer relations than their peers. Saracho (1992) found significant gender differences in cognitive style among 3- to 5-year-old subjects and discussed the possible significance of the relationship of cognitive style and play to creativity.

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Hutt and Bhavnani (1976) found gender differences in the ways 3- to 5-year-old children explored novel toys. Forty-eight girls and boys were classified as *non-explorers*, who looked at but did not actively investigate or inspect the toy; *explorers*, who actively investigated the toy but did little else with it; and *inventive explorers*, who, after investigating the toy, used it in many imaginative ways. Most girls were classified as non-explorers, while most boys were classified as inventive explorers. When the children were 7 to 10 years old, they were given the Wallach and Kogan (1965) battery of divergent thinking tests. The relationship between inventive exploration and scores on a divergent-thinking test 4 years later was positive, but much more so for boys than girls. Similarly, failure to explore was negatively correlated with later divergent-thinking test scores for boys, but not for girls.

Hutt and Bhavnani (1976) argued that this difference may be explained by the fact that preschool girls, who are more linguistically and socially competent than preschool boys, may engage in more symbolic and therefore covert role-play than boys, and that this kind of imaginative activity would not be very obvious to an observer. It should be noted that the behavioral differences observed by Hutt and Bhavnani (1976) are consistent with gender stereotypes; it is not clear whether such differences are due to nature or nurture (Berndt, 1992; Maccoby & Jacklin, 1974; Vernon, 1989).

ADULTS

Several theorists have tried to explain why there are so many more creatively accomplished men than women. Helson (1990) argued that cultural values, social roles, and sexist thinking are now recognized as key reasons for the comparative lack of creative accomplishment by women. In comparison to the situation just 30 years ago, we now "realize that social roles have not been structured so that many women would ever become high achievers. It is hard to feel a sense of mystery about why there are more eminent men than women" (p. 46).

According to Helson (1990), "differences between men and women in biology and early socialization experience are 'exaggerated' by culture" (p. 47). Among the differences in early socialization experiences that culture exaggerates are differences in the ways parents perceive and interact with their daughters and sons. "Right from childhood, women are less likely to be picked as special by their parents" (p. 48). These early differences are then intensified by cultural rules, roles, and assumptions.

Readers are encouraged to consult the original papers for a more thorough exegesis, including interesting experimental evidence drawing both on Helson's (1983, 1985, 1987; Helson, Roberts, & Agronick. 1995; Helson & Wink, 1987) own research and related work by such researchers as Albert (1980), Block (1984), and Bloom (1985).

In an article with the provocative title "Why Are There So Few? (Creative Women: Visual Artists, Mathematicians, Musicians)," Piirto (1991b) made the interesting observation that girls do not show less creative achievement until after high school and college. Differences seem to come, according to her own research and to

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studies she reviewed by Helson (1983), Getzels and Csikszentmihalyi (1976), and Barron (1972), "in the choices that creative people make after college, a time when commitment and regular effort in the field of creativity matter" (p. 146). This is related to such things as the conflict between family roles and professional roles, parents' and teachers' values and expectations, and self assessments of the quality of one's work. It may also be rooted in gender differences that predate post-college decisions by as much as a decade, differences in how boys and girls develop distinctive styles of expression and discourse (Piirto, 1991a). Belenky, Clinchy, Goldberger, and Tarule (1986) and Gilligan, Lyons, and Hanmer (1990) argued that girls favored connectedness rather than separateness, and this may prefigure choices later in life that preclude the kind of intense commitment to a field necessary for creative eminence. Piirto (1991b) concluded that teachers should focus more on the motivation and "encouraging commitment and intensity for both boys and girls" (pp. 146-147).

Cole and Zuckerman (1987) tested one hypothesis that has been proposed to explain why women scientists generally publish fewer papers than men when matched for age, doctoral institution, and field. They interviewed 73 female and 47 male scientists and concluded that, although married women scientists "do pay a price to remain scientifically productive" (p. 125), a price which generally involves eliminating everything from their lives but work and family, "women scientists who marry and have families publish as many papers per year, on the average, as single women" (p. 125). They caution that these results should not be interpreted as meaning that marriage and children have no effect on the careers of women scientists; however, the difference between publication rates of female and male scientists is not explained by marriage and motherhood.

Two other theories that attempt to explain gender differences in adult creative achievement deserve brief mention. In their effort to understand why men tend to achieve more than women to an extent not explainable by differences in divergent thinking abilities, Ruth and Birren (1985) recently revisited Maslow's (1971) and Greenacre's (1971) explanations of the relatively low incidence of creative contributions by women to the arts and sciences. "[Women] appear more interested in the creative process itself than in its end-product. Women sometimes have difficulties in externalizing their inner creative processes or have a lower need of achievement in creative endeavors" (Ruth & Birren, 1985, pp. 100-101). These differences, Ruth and Birren argued, are probably "not inherent, but reflect cultural values which are manifest in upbringing, educational possibilities, and freedom of action for the two sexes" (p. 101).

Seeking a very different kind of explanation, Harris (1989) reviewed studies of color and shape preferences which have shown significant gender differences. For example, girls tend to prefer lighter colors than boys (although there are exceptions to this generalization, notably a strong preference by girls for rich reds and red-purples). Harris argued that these differences have resulted in a devaluation of the work of women artists by both men and women, and that society needs to adjust its perceptions to allow women's creative expression to be more highly valued.

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EFFECTS OF EXTRINSIC CONSTRAINTS ON MOTIVATION

Amabile's (1983) intrinsic motivation theory of creativity is well known, as is the fact that extrinsic constraints like rewards tend to undermine intrinsic motivation (Lepper, Greene, & Nisbett, 1973). Some researchers have argued that there may be important gender differences in the ways extrinsic constraints impact intrinsic motivation and influence creative performance.

Baer (1997) asked eighth-grade subjects (66 girls, 62 boys) to write original poems and stories under conditions favoring both intrinsic and extrinsic motivation. In the intrinsic motivation conditions, subjects were told that their poems and stories would not be evaluated; in the extrinsic condition, subjects were led to expect evaluation, and the importance of the evaluation was made highly salient. The poems and stories were judged for creativity by experts. There was a significant gender x motivational condition effect. For boys, there was virtually no difference in creativity ratings under intrinsic and extrinsic conditions, but for the girls these differences were quite large. This was confirmed in a follow-up study (Baer, 1998b) using students of the same age, in which the negative impact of both rewards and anticipated evaluation were shown to be largely confined to female subjects. More recently, Conti, Collins, and Picariello (2001) found that girls were less creative in competitive situations and boys were more creative in competitive situations.

It may be that boys are less sensitive to interpersonal communications than girls (Gilligan, Lyon, & Hammer, 1990; Pool, 1994), which would make their levels of intrinsic and extrinsic motivation less susceptible to messages that would affect levels of motivation in girls. There is some empirical evidence in the creativity literature to support this hypothesis. Kogan (1974) noted that the testing situation — individual versus group — resulted in significant differences in the divergent thinking test scores of girls, but not of boys. Katz and Poag (1979) found that, on Guilford's (1967) Alternate Uses Test, "males alone improve when given instructions to be creative; females, if anything, are slightly poorer under the creativity inducing set [of instructions]" (p. 523).

An alternative explanation is that there may be differences in the ways girls and boys (and possibly women and men) respond to evaluation. Deci, Cascio, and Krusell (1975) presented evidence showing that "positive feedback increases the intrinsic motivation of males, whereas it decreases the intrinsic motivation of females" (p. 84). The difference in response to praise — an important extrinsic motivator — may be even more complex. In a study of fifth- and sixth-grade boys and girls in which two kinds of praise — praise for effort and praise for ability — were manipulated, Koestner, Zuckerman, and Koestner (1987) found that girls showed greater intrinsic motivation when given effort praise, whereas boys showed more intrinsic motivation when given ability praise. However, in a later study (Koestner, Zuckerman, & Koestner, 1989) of the same two kinds of praise using college students as subjects, they concluded, "women tended to display more intrinsic motivation in the no-praise condition than in the two praise conditions, whereas men showed the reverse pattern" (p. 383).

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Differences of this type might be hidden in most intrinsic-extrinsic motivation research, which typically shows a decrease in creativity under conditions favoring extrinsic motivation (Amabile, 1983; for exceptions to this effect, see Amabile, 1990). In Baer's (1997) study, gender differences overall (combining intrinsic and extrinsic conditions) were *not* statistically significant (p = .16), but the difference between the combined (male and female) means of the intrinsic and extrinsic groups *was* statistically significant (p = .02) — despite the fact that virtually *all* the impact of different motivational conditions occurred for the girls, while the boys were not touched by the change in motivational conditions. In Amabile's (1983) research in support of the intrinsic motivation theory of creativity, subjects were either mixed in gender or, in several studies, all women. Further research is needed to determine what gender (or gender x age) limitations there may be on the applicability of the intrinsic motivation theory of creativity.

THE APT MODEL OF CREATIVITY AND GENDER DIFFERENCES

Domain-specificity is one of the most controversial issues in creativity research (Baer, 1998; Kaufman & Baer, 2005b, Plucker, 1998), but we believe both sides in this debate offer ideas that can help us understand the seemingly conflicting evidence on gender differences in creativity. There are domain-general effects — at the level of Initial Requirements in the APT model — that help explain some gender differences, and there are more domain-specific effects (at the levels of General Thematic Areas, Domains, and Micro-Domains) that help us understand other kinds of gender differences in creativity.

Looking first at the test performance data, overall there appear to be few differences in measured abilities, with girls and women out-scoring boys and men to a small degree. These tests are designed to measure general divergent thinking skills, and these skills are hypothesized to contribute to creative performance across domains. In terms of the creativity-relevant skills that have been measured, there is no reason to predict greater male than female real-world accomplishment or creativity.

We know, of course, that there are gender differences in creativity at the highest levels, as judged by the experts in their respective domains, with men dominating most fields. So there seems to be some general factor at work that is limiting female accomplishment. We believe the primary general factor to be the Initial Requirement of environment. This is also in line with research showing that divergent thinking tests are, in general, more predictive of creative achievement in males than females (Arnold & Subotnik, 1994; Cramond, 1994; Howieson, 1981). The environments in which male creators work are generally more conducive to creative accomplishment than those of female creators, allowing men more regularly to express their creative abilities than women. Mcvey (2004) found that adolescent girls in single-sex high schools had significantly higher creativity scores (originality test scores and expert's ratings on a creative writing task) than matched female subjects in a co-ed high school, suggesting environmental effects on the girls' creative performance.

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Boys and girls grow up in different environments and rapidly become different, as some of the developmental theories cited above note. They also face different societal constraints, as Piirto (2004) and others have well documented, and possible bias in the judgments of experts in their fields as well as different access to resources in general (Simonton, 1994, 1996). In addition, gender differences in ways that male and female subjects in laboratory studies respond to extrinsic constraints (Baer, 1997, 1998b) lead to lower creative performance when extrinsic constraints are made salient are an additional environmental check on women's creative performance. Girls and boys, and women and men, simply do not live in environments that are equally conducive to creative accomplishment.

But not all fields show the same imbalance, which is the argument that led Vernon (1989) to reject global environmental explanations for gender differences in creativity and look for biological explanations. This is where lower, more domain-specific levels of the APT hierarchy can help us. There are general factors limiting women's creative accomplishment across the board, but there are also specific factors that limit it more, or less, in given domains. Piirto (2004) and Simonton (1994, 1996) outlined many such domain-specific factors, such as (1) issues regarding the amount of resources necessary to achieve in a given Micro-Domain (e.g., a particle accelerator for a nuclear physicist v. pencil and paper for a poet), (2) issues regarding stereotypic gender-appropriate behavior in different Domains (e.g., biology is less "masculine" than physics), and (3) issues regarding different expectations and access in General Thematic Areas (e.g., women have had easier access in most domains that are part of the General Thematic Area of communication than in the General Thematic Area of math/science).

The evidence does not point toward simple explanations of gender differences in creativity because the factors underlying these differences are diverse and complex. These many kinds of influences also operate at many different levels — some very general, some influencing large areas, and some operational only in very limited domains.

CONCLUSIONS

Lack of differences between girls and boys, and between men and women, is the most common outcome of the many studies reported above. In some cases, especially in the area of divergent-thinking testing, there are significant numbers of studies in which one group or the other scores higher, but these are generally counter-balanced by studies showing just the opposite. It is unlikely that a meta-analysis would show a significant overall gender difference on these tests, but it should be noted that if there were to be an overall "winner" in the numbers of studies in which one gender outperformed the other, it would be women and girls over men and boys.

There continue to be large gender differences in creative productivity, and these differences represent the most significant unanswered questions about gender and creativity. It is clear that a large part of those differences is environmental, including differences in adult expectations of girls and boys, differences in opportunities available to male and female children and adults, and differences in the kinds of experiences women and men are likely to have. There are also differ-

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ences in how different kinds of creative works — including those more typically produced by women and men — are valued by society. These factors are at work, in different ways and to greater and lesser degrees, at all levels of domain generality and specificity.

It is of course possible that there are significant creativity-relevant differences rooted in biology, although the most convincing evidence of this sort thus far does not suggest that either biological maleness or femaleness leads to greater creativity. What kind of research should be done to help untangle gender and creativity issues? It will need to be more complex than giving more creativity tests to boys and girls. Looking for gender differences in the interactions among aptitudes, motivations, and opportunities would be one promising area to investigate. Looking for changes over time in situations where gender bias has been reduced would be another. And while we wait for these and other, more conclusive research results, we would argue that assuming any gender differences in creativity are most likely the product of differing environments would represent the best overall synthesis of what we currently know about gender differences in creativity.

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COMMENTS AND CORRECTIONS

The Standard Definition of Creativity

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This Correction focuses on issues surrounding definitions of creativity. No topic is more central to research on creativity. There is a clear need to "correct" at least one all-too-common oversight found in definitions within the creativity literature.

Not surprisingly, nearly every article in the *CRJ* at least briefly defines creativity. The problem is that many articles cite books or articles from the 1990s or, at best, the 1980s, when defining creativity, when, in fact, the definition they are using—which is broadly accepted and thus can be called the *standard definition*—actually has a long history. It is a shame that the early discussions of the standard definition are ignored. Some of them are rich and remain entirely relevant. They are cited in the following.

The overarching purpose of all Corrections is to remind researchers that the field of creativity studies predates online literature searches. Although the science of creativity is, in some ways, unique and unlike other scientific endeavors (see Runco, in press, for details), the field of creativity studies relies on the scientific method and is implicitly collaborative. Research builds on previous research. Originality is a core value in creativity studies, but this does not justify ignoring relevant research that was done previously. Good research is integrated into the larger field, citing what came before, in addition its originality and utility. Corrections in the *CRJ* ensure that due credit is given to earlier research.

The field of creativity studies has roots in the 1950s, 1940s, and 1930s. *Domain differences* were examined in the 1930s (e.g., Patrick, 1935, 1937, 1938), and social criteria of creativity relying on *consensual agreement* go back at least to 1953 (Stein, 1953), just to name two examples. When was the standard definition of creativity first proposed?

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THE STANDARD DEFINITION

The standard definition is bipartite: Creativity requires both originality and effectiveness. Are two criteria really necessary?

Originality is undoubtedly required. It is often labeled novelty, but whatever the label, if something is not unusual, novel, or unique, it is commonplace, mundane, or conventional. It is not original, and therefore not creative.

Originality is vital for creativity but is not sufficient. Ideas and products that are merely original might very well be useless. They may be unique or uncommon for good reason! Originality can be found in the word salad of a psychotic and can be produced by monkeys on word processors. A truly random process will often generate something that is merely original.

So again, originality is not alone sufficient for creativity. Original things must be effective to be creative. Like originality, effectiveness takes various forms. It may take the form of (and be labeled as) *usefulness, fit,* or *appropriateness*. The Inaugural Editorial of the *CRJ,* which appeared nearly 25 years ago, referred to *utility* when describing what kind of research would be published (Runco, 1988). Creative research on creativity would be published, and the standard definition was used: "Originality is vital, but must be balanced with fit and appropriateness" (Runco, 1988, p. 4).

Effectiveness may take the form of value. This label is quite clear in the economic research on creativity; it describes how original and valuable products and ideas depend on the current market, and more specifically on the costs and benefits of contrarianism (i.e., originality; Rubenson, 1991; Rubenson & Runco, 1992, 1995; Sternberg & Lubart, 1991). Value was also recognized by Bethune—in 1839! He described value as:

> The stability of the fabric which gives perpetuity to the decoration. To mingle the useful with the beautiful, is

> the highest style of art. The one adds grace, the other value. It would be a poor summing up of a life upon earth, to find that all the powers of an immortal intellect had been devoted to the amusement of idle hours, or the excitement of empty mirth, or even the mere gratification of taste, without a single effort to make men wiser and better and happier. If the examination be made, it will be found, that those works of Genius are the most appreciated, which are the most pregnant with truth, which give us the best illustrations of nature, the best pictures of the human heart, the best maxims of life, in a word, which are the most useful. (p. 61)

Bethune referred to art, and genius, but he assumed that creativity played a role in each. Continuing,

> Yet familiar as the effects of Genius are, it is not easy to define what Genius is. The etymology of the term will, however, assist us. It is derived from the verb, signifying to engender or create, because it has the quality of originating new combinations of thought, and of presenting them with great clearness and force. Originality of conception, and energy of expression, are essential to Genius. (p. 59)

It was common to conflate creativity and genius in Bethune's (1839) era, and, in fact, that same blend can be seen well into the 1900s.

Bethune (1839) quoted Shakespeare when describing the two facets of genius:

> The poet's eye, in a fine frenzy rolling,
> Doth glace from heaven to earth, from earth to heaven—
> And as imagination bodies forth
> The forms of things unknown, the poet's pen
> Turns them to shape, and gives to airy nothing
> A local habitation and a name. (p. 59)

This is from *A Midsummer Night's Dream* (Act 5, Scene 1, which was probably written after 1590 but before 1596) and not surprisingly is only two lines below what is probably the Shakespearean quotation most often cited in creativity research, namely, "The lunatic, lover, and the poet/Are of imagination all compact."

The poetic description of imagination finding "a local habituation and a name" is as suggestive as it is artful, but it is not a clear statement of originality and effectiveness. Thus, neither Shakespeare nor Bethune (1839) should be credited with the original standard definition of creativity. They seemed to be thinking about two requirements that parallel originality and effectiveness, but their wording leaves a fair bit of ambiguity. In fact, some of the difficulty in finding the first occurrence of the *standard definition* is that the word *creativity* has a fairly short history.

Royce (1898) was on the right track, and, like Bethune (1839), he worked before 1900:

> In general, whether with or without deliberation, the effort to make the unlike results in a pretty constant and subtle modification of the style of the original habits, a modification small, but visible, and due, if you like, to suggestion. Here is a blending of one's own style with the results of outer stimulus. It is just such blending that, in some arts and even in some sort of scientific work, constitutes valuable inventiveness. (p. 145)

Royce's (1898) mention of "variation" is quite interesting, given the ongoing debate about blind variation and selective retention as requirements for the creative process (Gabora, 2011; Runco, 2007a; Simonton, 2007; Weisberg & Hass, 2007), but what is most pertinent is the phrase "valuable inventiveness." Still, Royce did not use the words *originality, creativity*, nor even *usefulness*, and although invention is sometimes associated with creativity, it is certainly not a synonym (Runco, 2007b).

Hutchinson (1931, p. 393) did use the word *creativity* and included "practicality" in his view of it. In his words, "In general. such contributions bear on the implications of creative thought for ethics, rather than on the technique of attaining creativeness itself. From *a more practical standpoint*... creative thought makes transformations in the world" (emphasis added). That "practical standpoint" could be the perspective of the author (and not the practicality of the creative act), but Hutchinson tied it to events "in the world." Presumably, these are realistic or useful in or for our lives. It could be that he was referring to a method for finding creative ideas (the transformation of what already exists "in the world"), in which case we still do not have an unambiguous proposal for the standard definition of creativity.

It is often a good tactic to work backwards. With that in mind: The two-criterion view was already the standard definition in the 1960s. Bruner (1962), for example, in one of the true classics in the field, described how creativity requires "effective surprise" (p. 18). Cropley (1967) pointed to the need for creative things to be "worthwhile" (p. 67) and reflect some "compelling" property (p. 21). Jackson and Messick (1965, p. 313) felt that products must be "appropriate" and Kneller (1965, p. 7) stated that products must be "relevant." Cattell and Butcher (1968) and Heinelt (1974) used the terms *pseudocreativity* and *quasicreativity* to describe products that were not worthwhile or effective. Thus we must look for the first presentation of the standard definition before 1960.

A second good tactic is to use base rates. This suggests a close examination of Institute for Personality and Social Research and the first generation of scholars committed to scientific research on creativity (see Helson, 1999). Indeed, it will come as no surprise to serious students of creativity research that Barron (1955) mentioned the standard definition over 50 years ago. He wrote,

> A second criterion that must be met if a response is to be called original is that it must be to some extent adaptive to reality. The intent of this requirement is to exclude uncommon responses which are merely random, or which proceed from ignorance or delusion. (p. 479)

This quotation might be enough to credit Barron (1955) with the first explicit statement of the standard definition, but then again, "adaptation to reality" was in his discussion of originality and not creativity per se. In fact, Barron referred to two criteria, but one was a criterion for originality, not creativity. He wrote,

> The first criterion of an original response is that it should have a certain stated uncommonness in the particular group being studied. A familiar example of this in psychological practice is the definition of an original response to the Rorschach inkblots, the requirement there being that the response should, in the examiner's experience, occur no more often than once in 100 examinations. (pp. 478–479)

The title of Barron's (1955) paper was "The Disposition Towards Originality," and the two criteria he discussed were uncommonness and adaptation to reality. He was therefore right on target for effectiveness (or usefulness, utility, and value) but he was not explicit about how this all fits with creativity! Creativity was a concern for Barron (1955); he opened this article by criticizing the tendency

> to disembody the creative act and the creative process by limiting our inquiry to the creator's mental content at the moment of insight, forgetting that it is a highly organized system of responding that lies behind, the particular original response which, because of its validity, becomes an historical event. (p. 479)

He was interested in creativity, but did not define it. He defined originality instead.

Guilford (1950) is often credited with publishing the first compelling argument that creativity can be studied scientifically. How did he define creativity? In his own words:

> In its narrow sense, creativity refers to the abilities that are most characteristic of creative people. Creative abilities determine whether the individual has the power to exhibit creative behavior to a noteworthy degree. Whether or not the individual who has the requisite abilities will actually produce results of a creative nature will depend upon his motivational and temperamental traits. To the psychologist, the problem is as broad as the qualities that contribute significantly to creative productivity. In other words, the psychologist's problem is that of creative personality. (p. 444)

That is probably best viewed as a recommendation of what to study. It does not define creativity, other than tautologically "creativity is the characteristic of creative people."

Guilford (1950) did point to criteria for creativity when he stated that "the creative person has novel ideas. The degree of novelty of which the person is capable, or which he habitually exhibits... can be tested in terms of the frequency of uncommon, yet acceptable, responses to items" (p. 452). He thus emphasized originality and operationalized it as novelty and, even more precisely, in terms of uncommon behaviors.

What of the second part of the standard definition? Guilford (1950) did refer to *acceptable* ideas, the implication being that novelty by itself is not sufficient for creativity. He explored this point further when he wrote, "Creative work that is to be realistic or accepted must be done under some degree of evaluative restraint. Too much restraint, of course, is fatal to the birth of new ideas. The selection of surviving ideas, however, requires some evaluation" (p. 453). Thus, Guilford seemed to be assuming that creativity requires originality and effectiveness. He used the terms *realistic* and *acceptable* for the latter, which is slightly problematic, but still he was thinking about creativity in a fashion that is entirely consistent with the standard definition.

The reason *acceptable* is a problematic way of labeling the criterion of effectiveness is that it begs the question, "Acceptable for whom?" Long ago, Murray (1958) asked, "Who is to judge the judges? And the judges of the judges?" Simonton (in press) and Runco (2003) also saw the question of judges to be a part of issues of definition. Stein (1953) seemed to be aware of this issue and, for this reason, distinguished between the *internal and external frames of reference* that might be used when defining creativity.

As a matter of fact, to our reading, the first clear use of the standard definition seems to have been in an article on creativity and culture, written by Stein (1953). In his words,

> Let us start with a definition. The creative work is a novel work that is accepted as tenable or useful or satisfying by a group in some point in time .... By "novel" I mean that the creative product did not exist previously in precisely the same form .... The extent to which a work is novel depends on the extent to which it deviates from the traditional or the status quo. This may well depend on the nature of the problem that is attacked, the fund of knowledge or experience that exists in the field at the time, and the characteristics of the creative individual and those of the individuals with whom he [or she] is

> communicating. Often, in studying creativity, we tend to restrict ourselves to a study of the genius because the "distance" between what he [or she] has done and what has existed is quite marked .... In speaking of creativity, therefore, it is necessary to distinguish between internal and external frames of reference. (pp. 311–312)

Stein (1953) was the first to offer the standard definition in an entirely unambiguous fashion, and unlike his predecessors, he was without a doubt talking about creativity *per se*. He was not discussing originality, although novelty, and therefore originality, are vital for creativity, and he was not discussing genius, although he offered a useful perspective on it (the "distance").

Stein (1953) is also quoted in detail because he offered several other ideas that are still in use and were well ahead of their time. These include his ideas that (a) creative work tends to be useful for some group, and thus that social judgment is involved; (b) a creative insight "arises from a reintegration of already existing materials or knowledge, but when it is completed it contains elements that are new" (p. 311); and (c) it is important to separate personal from historical creativity (cf. Boden, 1994; Runco, 1996). Stein also foresaw that environments never have a completely predictable impact. Their influence is always dependent on the individual's perception. This view is usually described as a trait × state interaction and was clearly apparent in the early definition of *press* (one of the four strands of research identified by Rhodes, 1961). Stein was aware of the role of both sensitivity and problem finding ability ("The creative person has a lower threshold, or greater sensitivity, for the gaps or the lack of closure that exist in the environment" [p. 312]), recognized the benefits of broad attention and loose associations (cf. Dailey A. et al., 1997), and in 1953 was already studying domain differences, as is so common in creativity research today. Stein reported data from artists and chemists and concluded that creativity benefits from permeable cognitive structures, "for persons in one area (physics, for example) it may mean greater flexibility in the intellectual sphere, while for other... the artist, it appears as a greater flexibility in the emotional or affective sphere" (p. 313).

CONCLUSIONS

Although there were hints that creativity requires originality and usefulness in publications before 1900, it seems to us that Barron (1955), and especially Stein (1953), should be cited whenever the standard definition is used.

This does not imply that no further work is needed and that the standard definition is completely adequate. Important research is being done on several fronts. One involves the basis of judgments. The standard definition only pinpoints which criteria must be used; it does not say anything about who is to judge each, and who is to judge the judges.

Then there are questions about the number of criteria that should be used in a definition of creativity. The standard view points to two criteria, but perhaps there are more—or fewer! Simonton (in press) made a strong case for three criteria—*surprise* being the third—and Runco (in press) raised the possibility that only one criterion is needed. Simonton based his argument on guidelines from the U.S. Patent office; Runco felt that parsimony was the best guide. These two theories of creativity are easy to find in other issues of the *CRJ*.

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