International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: https://www.tandfonline.com/loi/tsed20

A scientific creativity test for secondary school students

Weiping Hu & Philip Adey

INT. J. SCI. EDUC., 2002, VOL. 24, NO. 4, 389–403

Taylor & Francis
Taylor & Francis Group

RESEARCH REPORT

A scientific creativity test for secondary school students

Weiping Hu, Shanxi Teachers' University, China and Philip Adey, King's College London, UK

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

International Journal of Science Education ISSN 0950–0693 print/ISSN 1464–5289 online
http://www.tandf.co.uk/journals
DOI: 10.1080/09500690110098912

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,

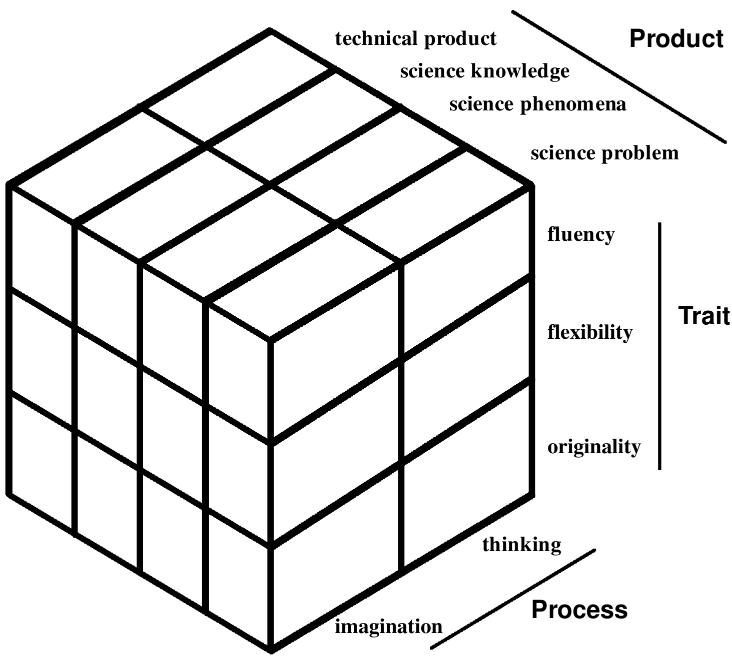

Figure 1. The Scientific Structure Creativity Model (SSCM).

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.

References

ALBERT, R. S. (ed.) (1983) *Genius Eminence* (New York: Pergamon).
ALEXANDER, P. A. (1992) Domain knowledge: Evolving themes and emerging concerns. *Educational Psychology*, 27, 33–51.
AMABILE, T. M. (1987) The motivation to be creative. In S. G. Isaken (ed.) *Frontiers of Creativity Research: Beyond the Basics* (Buffalo, NY: Bearly) pp. 223–254.
BARRON, F. and HARRINGTON, D. M. (1981) Creativity, intelligence, and personality. *Annual Review of Psychology*, 32, 439–476.
CATTELL, R. B. (1971) *Abilities: Their Structure, Growth and Action* (New York: Houghton Miflin).
CHEIN, M. F. (1982) Creative thinking abilities of gifted children in Taiwan (Chinese). *Bulletin of Education Psychology*, 15, 97–110.
EINSTEIN, A. (1952) Letter to Jacque Hadamard. In B. Ghiselin (ed.) *The Creative Process* (Berkeley, CA: University of California Press), pp. 43–44.
EINSTEIN, A. and INFIELD, L. (1938) *The Evolution of Physics* (New York: Simon & Schuster), p. 91.
FELDHUSEN, J. F. (1995) Creativity: A knowledge base, metacognitive skill, and personality factor. *Journal of Creative Behavior*, 29, 255–268.
FELDMAN, D. H. (1986) *Nature's Gambit* (New York: Basic Books).
FINDLAY, C. S. and LUMSDEN, C. J. (1988) The creative mind: Toward an evolutionary theory of discovery and innovation. *Journal of Social and Biological Structures*, 11, 3–55.
FRIEDLANDER, M. (1983) A natural science creativity as a prediction of creative thinking in science. *Creative Child and Adult Quarterly*, 8, 211–215.
GARDNER, H. (1983) *Frames of Mind: The Theory of Multiple Intelligence* (NewYork: Basic Books).
GUILFORD, J. P. (1950) Creativity. *American Psychologist*, 5, 444–454.
GUILFORD, J. P. (1956) The structure of intellect. *Psychological Bulletin*, 53, 267–293.
GUILFORD, J. P. (1967) Some theoretical views of creativity. In H. Helson and W. Bevan (eds) *Contemporary Approaches to Psychology* (Princeton, NJ: Van Nostrand), pp. 419–459.
HOCEVAR, D. and BACHELOR, P. (1989) A taxonomy and critique of measurements used in the study of creativity. In J. A. Glover, R. R. Ronning and C. R. Reynolds (eds) *Handbook of Creativity* (New York: Plenum), pp. 53–75.
HORN, J. and CATTELL, R. B. (1966) Refinement and tests of the theory of fluid and crystallised intelligence. *Journal of Educational Psychology*, 57, 253–270.
HUDSON, L. (1966) *Contrary Imaginations* (London: Methuen).
JOHNSON-LAID, P. N. (1987) Reasoning, imagining, and creating. *Bulletin of the British Psychological Society*, 40, 121–129.
KITTO, J., LOK, D. and RUDOWICZ, E. (1994) Measuring creative thinking: an activity-based approach. *Creativity Research Journal*, 7, 59–69.
KLINE, P. (1993) *The Handbook of Psychological Testing* (London: Routledge).
LUBART, T. I. (1994) Creativity. In R. J. Sternberg (ed.) *Thinking and Problem Solving* (London: Academic Press), pp. 289–332.
MAJUMDAR, S. K. (1975) A systems approach to identification and nurture of scientific creativity. *Journal of Indian Education*, 1, 17–23.
MUMFORD, M. D., MOBLEY, M. I., UHLMAN, C. E., REITER-PALMON, R. and DOARES, L. M. (1991) Process analytic of creative capacities. *Creativity Research Journal*, 4, 91–122.
OCHSE, R. (1990) *Before the Gates of Excellence: The Determinants of Creative Genius* (Cambridge: Cambridge University Press), p. 187.
OKUDA, S. M., RUNCO, M. A. and BERGER, D. E. (1991) Creativity and the finding and solving of real-life problems: *Journal of Psychoeducational Assessment*, 9, 45–53.
ROSSIMAN, T. and HORN, J. (1971) Cognitive, motivational and temperamental indicants of creativity and intelligence. *Journal of Educational Measurement*, 9, 265–286.
RUNCO, M. A. (1991) *Divergent Thinking* (Norwood, NJ: Ablex).
SCHUBERT, A. (1973) Intelligence as necessary but not sufficient for creativity. *Journal of Genetic Psychology*, 122, 45–47.

Simonton, D. K. (1983) Formal education, eminence and dogmatism: The curvilinear relationship. *Journal of Creative Behavior*, 17, 149–162.

Sinha, A. K. and Singh, C. (1987) Measurement of scientific creativity. *Indian Journal of Psychometry and Education*, 18, 1–13.

Sternberg, R. J. and Lubart, T. I. (1991) An investment theory of creativity and its development. *Human Development*, 34, 1–31.

Sternberg, R. J. (1996) *Successful Intelligence* (New York: Basic Books).

Torrance, E. P. (1962) *Building Creative Talent* (Englewood Cliffs, NJ: Prentice-Hall).

Torrance, E. P. (1990) *Torrance Tests of Creative Thinking* (Beaconville, IL: Scholastic Testing Services).

Welsch, P. K. (1981) The nurturance of creative behavior in educational environments: A comprehensive curriculum approach. *Dissertation Abstracts International,* 41 (9), 3870A (University Microfilms No. 81-06456).

Zheng, R. and Xiao, B. (1983) A study on the creativity of high school students (Chinese). *Acta Psychologica Sinica*, 15, 445–452.