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Creative Scientific Problem Finding and Its Developmental Trend

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Creative Scientific Problem Finding and Its Developmental Trend

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This is a study of the development trend of creative scientific problem finding (CSPF) ability of a sample of 1,367 elementary, middle, and high school students in two Chinese cities. Students were instructed to generate science related questions in both open and closed conditions with responses scored for Fluency, Flexibility, and Originality. Results suggest that CSPF ability has a developmental trend characterized by a significant leap in the 5th grade, followed by a steady advance until it peaked in the 8th grade, and then declined and stabilized in the high school years (9th–11th grades). No difference between male and female students was found. The type of instruction showed significant differential influence on CSPF and its development.

There is a substantial literature on problem-solving, within which the issue of problem finding is somewhat underrepresented, although it is recognized as important (Chand & Runco, 1993; Csikszentmihalyi, 1999). In the present context, problem finding is taken to mean students' ability to generate problems for themselves, either generally or within a particular subject domain (e.g., art, science), and either generally within that domain (e.g., scientific problems) or related to a particular context (e.g., problems related to space travel). Problem finding has been researched in various populations. For instance, Okuda, Runco, and Berger (1991) and Wakefield (1985) did work on children, Chand and Runco (1993) on college students, and Kay (1991) on artists.

Getzels and Csikszentmihalyi (1975) predicted that the creativity of a solution depends on the creativity of the problem being solved. They believed that creative achievements often resulted from problem finding, rather than just problem solving. There is also evidence that students who have been taught to explore different ways to define problems may engage in more creative problem solving over the longer term (Baer, 1988).

Although various studies have been conducted on creativity as a general ability or process, it is a general consensus that domain-specific knowledge and skills are major components of creativity (Hu, Adey, Shen, & Lin, 2004) because creative functioning in one domain may be unique and psychologically different from creative functioning in another. Nickerson (1999) stressed the importance of domain-specific knowledge

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as a determinant of creativity and felt it is generally underestimated. Csikszentmihalyi (1996) interviewed 91 unusually creative people from many domains. He concluded that a person who wants to make a creative contribution not only must work within a creative system, but must also reproduce that creative system within his or her mind. Hence, domain-specific research is necessary in understanding characteristics of the creative process related to that domain. In particular, scientific creativity as a domain has attracted considerable interest (Hu & Adey, 2002; Shi, 1995; Shi, Zha, & Zhou, 1998; Shukla & Sharma, 1986), because it is one of the most important areas contributing to the advancement of human civilization.

Historically, development of creativity attracted many research efforts. Vernon (1948, quoted by Torrance, 1962) was interested in students' ability to understand and explain graphs and or pictures. He found that intellectually and emotionally normal children reach constructional imagination around 11 years old. They can creatively explain a situation when they reach 11 years old, as evidenced by their ability to state causal hypotheses in an Ask-and-Guess test. This shows that creativity in school-aged children steadily develops and reaches a peak at around 11 years old. Barkan (1960, quoted by Torrance, 1962) studied the development of creativity in children by observing art teachers in elementary school. He discovered that there are several periods wherein the creative ability in children takes significant leaps. The first to second grade, growth is faster than that from kindergarten to grade 1. Second grader children are more interested in why and how things change, whereas third and fourth grade children focus more on questioning and further explaining why things change. Hence, it is likely that there is a qualitative leap around the fourth grade from superficial to more in-depth pursuit of understanding how things work.

Q1 Torrance et al. (1962) were among the earliest to research problem finding and how it develops in children. They found that the number of questions children ask increases with age. It reaches a peak at third grade but decreases dramatically in the fourth grade, and then recovers somewhat in the fifth and sixth grades. It then decreases in seventh grade, but increases every year after that. This 1962 study, however, only looked at the frequency of the questions asked by children. One may wonder about the Fluency and Originality of the problems students posed. One study that involved all three properties of creative scientific problem was a cross-cultural comparison of scientific creativity between English and Chinese adolescents (Hu et al., 2004). Problem finding was included as one of the seven dimensions of scientific creativity (the other ones being unusual uses, creative product improvement, scientific imagination, creative problem solving, creative experiment design, and creative product design). Interestingly, the developmental trend of problem finding appeared different from the overall trend of scientific creativity, which shows seventh to eighth grade and ninth to twelfth grade as key periods of rapid development. One may postulate that creative scientific problem finding ability may have its own unique developmental characteristics worthy of exploration. Recently, Hu and Han (2006) started this line of work on a sample of elementary students in China. They asked second, third, fourth, and fifth graders to list questions they are curious about related to natural phenomena around their daily lives. Responses were rated in terms of Fluency, Flexibility, and Originality. Findings suggest there is no difference between second and third grades in creative science question-asking ability; fourth grade shows significant superiority, and fifth graders did better, but not significantly better, than fourth graders. Evidently, this study is limited by the sample size and it only included the four grade levels.

Runco and Okuda (1991) found instruction type affects the quality of creativity. They use three sets of instructions: (a) conventional (inexplicit) directions; (b) directions designed to maximize ideational Originality; and (c) directions designed to maximize ideational Flexibility (the thematic variety of ideas). Results showed increased Originality scores in the (b) condition and increased Flexibility scores in (c) condition as expected; yet Flexibility scores were low when Originality instructions were given (b). This finding tells us that instruction type is an important variable in the experimental exploration of CSPF.

This investigation is unique in that it explores the development of the effect of instruction type over the range from grade 3 to grade 11 on problem finding ability, in a population of Chinese students. This, in turn, will allow comparisons with results from other countries, shedding light on educational and cultural impacts on such development.

This investigation is unique in that it explores the development of the effect of instruction type over the range from grade 3 to grade 11 on problem finding ability, in a population of Chinese students that will allow comparisons to be made with results from other countries, shedding light on educational and cultural impacts on such development (Hu et al., 2004; Rudowicz, Tokarz, & Beauvale, 2009).

METHODS

Participants

Participants were 1,367 students from two Chinese cities (see Table 1). One class from each of grades 3 to 11 was randomly selected from the schools in each of the cities.

TABLE 1
Sample Description

		Linfen		*Taiyuan*		
Grade	*Age*	*Male*	*Female*	*Male*	*Female*	*Total*
3rd	8	23	22	29	27	101
4th	9	25	15	33	34	107
5th	10	36	27	28	23	115
6th	11	38	36	55	54	183
7th	12	50	39	63	43	195
8th	13	38	40	66	45	189
9th	14	31	30	55	59	176
10th	15	32	23	67	40	162
11th	16	19	30	50	40	139
Totals		554		813		1367

Measures

We have chosen to use Torrance's basic model of creativity as the basis for assessing students' problem finding ability. The model broadly defines creativity in terms of Fluency (how many ideas), Flexibility (variety of ideas) and Originality (rarity of ideas), and it appears to be a good measure not only for identifying and educating the gifted but for discovering and encouraging everyday life creativity in the general population (Kim, 2006). We have found the Torrance model to be robust and reliable in previous studies (Hu & Adey, 2002) and using it here enables us to make direct comparisons of results with those previous studies.

The influence of instruction type in measures of ideational output has been well researched (Harrington, 1975; Runco, 1986; Runco & Okuda, 1991). Explicit instruction (e.g., "write as many and varied questions as you can . . . ") was consistently found to produce best or maximal performance and hence offers the most reliable indicator of creative ability. The explicit instruction used in this study was adapted from Torrance's Minnesota Creativity Test, which explicitly requires students to write out as many scientific questions as they can and as creatively as they can. In addition, two types of explicit instruction were given. One is described as *open* and asked the subjects to generate scientific questions based on their everyday life experience and observations (*open instruction*). The other is more confined, asking subjects to generate all scientific questions related to a picture of an astronaut standing on the moon (*closed instruction*). The design is intended to capture all potential ability related to scientific problem finding, whether it is based on daily life observation or generated from the imagination and knowledge of specific aspects of science related to the picture. The picture was chosen from three others based on a pretest because it showed adequate sensitivity and stimulating properties and was able to generate adequate responses needed for comparison across all age groups.

Instructions were presented as PowerPoint slides. Open instruction was presented before the Closed instruction to limit a possible response set. Each section was limited to 8 minutes based on pretest experience that a longer time allowance did not change the number of questions generated by students.

> Slide 1: "The ability to ask creative questions is a very important one. Today you have an opportunity to put your creativity to work. Please try to come up with as many questions as you can, from as many angles as you can, and try to produce as unique questions as you can."
>
> Slide 2: "Based on your life experiences and daily observations of things, write down all science related questions you are curious about."
>
> Slide 3 (shows an astronaut standing on the moon): "This picture contains many science related questions, write down as many as you can think of."

Data Analysis

After elimination of irrelevant answers, responses related to science were rated for their Fluency, Flexibility, and Originality. The Fluency score is simply the number of questions generated. The Flexibility score is the number of categories across which a subject's questions are distributed. The categories are predetermined, before any individual's response is scored, by pooling all responses together and categorizing them based on the nature of all questions. The Originality score is based on the frequency percentage for a given response in the total sample. The student will gain a score of 2 if the response frequency percentage is smaller than 5%; 1 point if response frequency is between 5–10%; and 0 if above 10%. The total CSPF score is simply the sum of scores of the three properties.

Responses were rated by two raters based on a sample of 100 students. The interrater reliabilities (Pearson product–moment coefficients) were .69 for Originality, .76 for Flexibility, and .85 for Fluency for the open instruction, and .74 for Originality, .81 for Flexibility, and .85 for Fluency for the closed instruction condition. Table 2 shows the correlation coefficients between the total creative scientific problem finding score (CSPF) and

TABLE 2
Correlation Coefficients Between Test Components (Open Instruction)

	Fluency		*Flexibility*		*Originality*	
	Open	*Closed*	*Open*	*Closed*	*Open*	*Closed*
Flexibility	.62***	.67***	—	—		
Originality	.79***	.54***	.48***	.52***	—	—
Total	.93***	.91***	.63***	.78***	.96***	.82***

Note. ***$p < 0.001$.

TABLE 3
Result of Repeated Measure ANOVA: Effects of Grade, Sex, Type of Instruction on Creative Scientific Problem Finding (CSPF) Scores (F Values and Effect Sizes, h^2)

	Fluency		*Flexibility*		*Originality*		*CSPF*	
Source	*F*	h^2	*F*	h^2	*F*	h^2	*F*	h^2
Grade ($df = 8$)	26.83***	0.14	18.71***	0.10	32.20***	0.16	27.24***	0.14
Sex ($df = 1$)	0.03	0.00	3.62	0.00	0.47	0.00	0.002	0.00
Type (ins; $df = 1$)	53.52***	0.11	250.30***	0.16	2104.5***	0.61	511.4***	0.28
Type × sex ($df = 1$)	1.12	0.001	2.27	0.002	0.05	0.000	1.32	0.001
Type × grade ($df = 8$)	8.36***	0.10	10.56***	0.10	16.92***	0.09	9.97***	0.11
Sex × grade ($df = 8$)	0.44	0.00	1.09	0.01	0.68	0.00	0.93	0.00
Type × sex × grade ($df = 8$)	0.62	0.00	0.67	0.00	0.75	0.00	0.91	0.00

Note. $^{*}p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$.

the Fluency, Flexibility, and Originality scores of CSPF. The consistently high correlations between the different components suggests that each component is tapping into a common *creative problem finding* construct and this provides some justification for adding the scores of each component to reach a single total score.

RESULTS

Repeated measure analysis of variance was used to test the main and interaction effects of grade (9), sex (2), and type of instruction (2) on CSPF scores. Grade and sex are between group variables; Type of Instruction is within group variable. The results are presented in Table 3.

Table 4 shows the mean and standard deviation scores of Fluency, Flexibility, Originality, and total CSPF scores for all grades.

To determine if differences on CSPF scores between grades are significant, a post hoc Tukey HSD test was used for multiple comparisons. This showed that although there was no significant difference between grade 4 mean CPFS scores and those of grade 3, grade 4 was significantly different from all other grades. There was no significant difference between fifth, sixth, and seventh grades, but they are all significantly different from the eighth grade, which was the highest CSPF score in all grades. The decrease after eighth grade was significant, from which point on, CSPF scores stagnated. There was no significant difference between ninth, tenth, and eleventh grade. Hence, from a statistical point of view, third grade and fourth grade were at the same level; fifth, sixth, and seventh grades were at the same level; the eighth grade was at its own level, and finally, ninth, tenth, and eleventh grades were at one level.

There were no significant differences between the mean scores of males and females either overall, nor within any grade or subscale of the CSPF.

Pairwise comparisons were performed for all grades on Fluency, Flexibility, Originality, and total CSPF scores between open and closed instruction conditions (Table 5).

Figures 1–4 show the development trends for Fluency, Flexibility, Originality, and total CSPF scores by grade in the open and closed instruction conditions.

TABLE 4
Creative Scientific Problem Finding (CSPF) Mean and Standard Deviation for All Grades

Grade	*Age*	*Fluency*	*Flexibility*	*Originality*	*CSPF*
3rd	8	14.47 ± 6.10	6.83 ± 2.13	14.34 ± 5.75	35.28 ± 11.77
4th	9	13.46 ± 5.15	6.07 ± 1.95	11.94 ± 5.30	31.53 ± 10.64
5th	10	17.47 ± 6.93	7.11 ± 2.02	18.47 ± 7.84	35.28 ± 40.55
6th	11	16.53 ± 8.13	7.60 ± 2.31	16.56 ± 8.65	40.55 ± 17.44
7th	12	17.52 ± 6.90	7.76 ± 2.35	17.71 ± 8.12	42.48 ± 15.66
8th	13	24.53 ± 9.51	8.88 ± 2.54	25.49 ± 10.12	58.59 ± 20.12
9th	14	18.58 ± 8.12	7.52 ± 2.40	20.01 ± 9.97	46.85 ± 18.39
10th	15	18.96 ± 6.84	8.37 ± 2.37	21.87 ± 8.78	48.74 ± 15.21
11th	16	17.54 ± 7.41	8.00 ± 2.46	19.60 ± 8.01	44.84 ± 15.84

TABLE 5
Effects of Open and Closed Explicit Instructions Creative Scientific Problem Finding Scores

	Fluency		*Flexibility*		*Originality*		*CSPF*	
Grade	*Open*	*Closed*	*Open*	*Closed*	*Open*	*Closed*	*Open*	*Closed*
3	7.49	6.98	3.24	3.64	11.59	2.87	24.46	13.56
	±3.50	±3.78	±1.20	±1.48	±5.12	±2.55*	±23.39	±5.79*
4	6.79	6.61	3.04	3.01	9.87	2.09	19.79	11.78
	±3.29	±2.89	±1.13	±1.42	±4.91	±2.23*	±8.42	±5.52*
5	8.74	8.74	3.33	3.78	13.41	5.07	25.63	17.67
	±4.22	±3.66	±1.22	±1.28	±6.31	±3.34*	±10.19	±6.98*
6	7.98	8.55	3.30	4.30	12.34	4.21	23.82	17.25
	±4.12	±4.81	±1.19	±1.69*	±6.91	±3.43*	±11.18	±8.54*
7	8.55	8.97	3.59	4.19	13.30	4.54	25.42	17.74
	±3.69	±4.41	±1.25	±1.87*	±6.41	±3.54*	±10.26	±8.44*
8	11.81	12.72	4.05	4.83	19.97	5.52	35.83	23.07
	±5.39	±5.30	±1.32	±1.94*	±8.37	±3.60*	±13.66	±9.56*
9	8.19	10.39	3.19	4.33	14.58	5.43	26.29	20.31
	±4.60	±4.66*	±1.23	±1.68*	±8.32	±3.91*	±13.10	±8.62*
10	8.30	10.70	3.38	5.00	14.27	7.63	26.09	23.52
	±4.12	±4.10*	±1.16	±1.82*	±6.78	±4.44*	±10.76	±8.42
11	7.67	9.76	3.34	4.68	13.92	5.47	25.16	19.98
	±3.74	±5.17*	±1.15	±1.69*	±6.63	±3.26*	±10.36	±8.21*

Note. $^{*}p < 0.05$ between open and closed instructions.

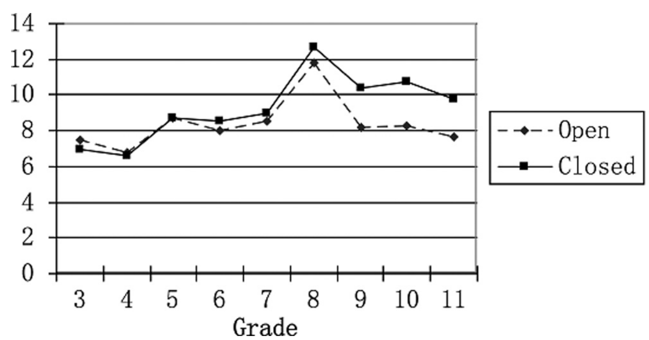

FIGURE 1 Effect of type of instruction on creative scientific problem finding fluency.

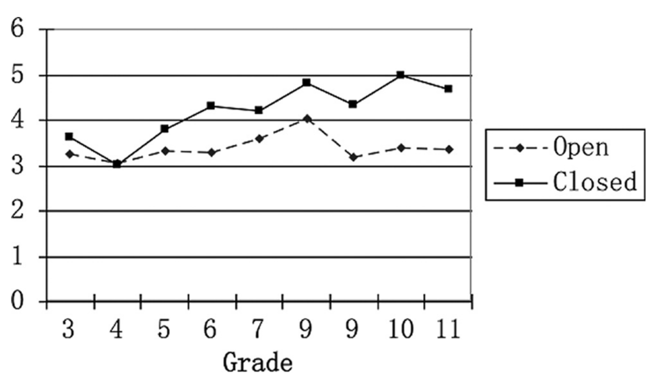

FIGURE 2 Effect of type of instruction on creative scientific problem finding flexibility.

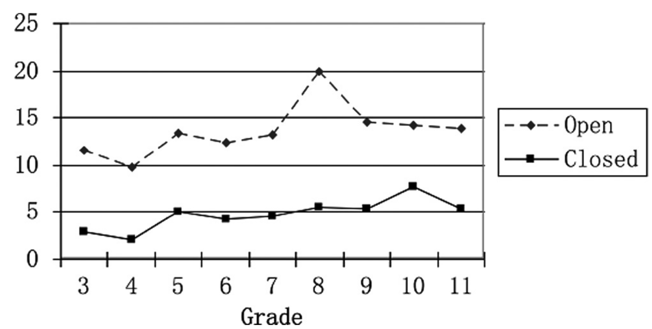

FIGURE 3 Effect of type of instruction creative scientific problem finding originality.

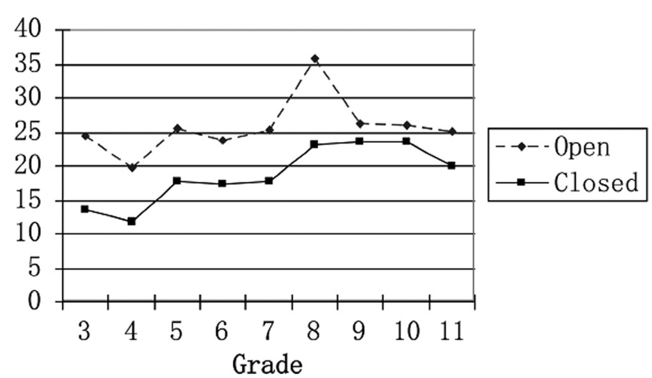

FIGURE 4 Effect of type of instruction on total creative scientific problem finding scores.

DISCUSSION

There was a clear development of CSPF ability starting from the third grade, with a slight but nonsignificant dip at fourth grade followed by a steady advance toward a spectacular peak at the eighth grade level, and then a significant drop at ninth grade, from which it appears to stagnate for the next 2 years. The initial decrease in CSPF ability at fourth grade is consistent with the findings of Torrance (1962) and Hu and Han (2006; after allowing for a change in grading system which means that their third grade is equivalent to our fourth grade.). The drop between sixth and seventh grades described by Torrance is not obvious in this study. The seventh grade was actually higher in CSPF ability but the difference is insignificant. The same pattern appeared in Hu et al.'s (2004) study with the English sample. Hence, it is likely that the absence of a dip between sixth and seventh grade is specific to CSPF (problem finding) ability, which may be different from that of the general development of creativity described by Torrance.

The apparent stagnation of CSPF scores in the late middle and high school (grades 9, 10, 11) is different from the result in Hu et al. (2004). For the English sample, the developing trend of problem finding ability showed a steady increase from sixth to eighth grade, then a slight dip at ninth grade. However, their tenth grade reached a new high. Unfortunately, no data were collected after 15 years old for the English sample. For the Chinese sample, there was a steady trend up to a peak at grade 11 followed by a dip to the twelfth grade.

One possible explanation for this inconsistency involves differences between open and closed instruction. Inclusion of both in the measurement of CSPF intended to capture the variety of creative scientific problems students may have available in cognition. Open instruction presumably taps into daily observations and vicarious learning and discovery through daily activities, and closed instruction taps into what is similar to the problem finding dimension referred by Hu et al. (2004). The key difference is that the instruction was essentially pictorial for this study, but the instruction in Hu et al. was given verbally. Logically, developmental trends revealed by a picture instruction and a verbal instruction ought to be similar to each other, at least for students who have gained some level of literacy. This is confirmed by observing the developmental trend under closed instruction for Fluency, Flexibility, Originality, and total CSPF (Figures 1–4). Under the closed instruction condition, total CSPF ability for grade 9 had a slight dip, but reached a new high at tenth grade (Figures 2–4) except for CSPF Fluency (Figure 1). CSPF total ability and all its components showed a similar dip at eleventh grade the same way as the Chinese sample in Hu et al.'s study (2004).

One may question whether peaking of CSPF ability at eighth grade is specific to the Chinese sample due to the intense and dominant demand of the National College Entrance Examination. The significant decline of CSPF ability at ninth grade coincides with an acute transition of middle-school students being geared up to prepare for the high school entrance exam. The ninth grade can be seen as a period when the focus of students transits from adventure and curiosity toward more practical and vocationally related issues. This may be one of the reasons that Chinese students show less creativity than their counterparts in the Western world (Hu et al., 2004).

Sex Differences in CSPF Ability

The absence of any sex differences in CSPF ability is consistent with the previous investigations (Hu et al., 2004; Hu & Han, 2006) although the latter did find main sex effects on scientific imagination, creative problem solving, creative experiment design, and creative product design. This may suggest that CSPF ability is not affected by sex, is different from other aspects of scientific creativity, and is a separate and necessary dimension in scientific creativity. Hence, it supports the assertion by Chand and Runco (1993) that problem finding is an important and distinct component in the creative process.

Effect of Type of Instruction on CSPF Ability

As expected, Originality scores increase under open instruction and decrease under closed instruction for all grades. Interestingly, Flexibility and Fluency scores are affected differentially, dependent on grade level. Lower graders tend not be affected by instruction type; for higher graders, Flexibility and Fluency scores decrease under open instructions but increase under closed instruction. This appeared counterintuitive.

Runco and Okuda (1991) found similar results. They concluded that explicit instructions do not influence ability to generate ideas, but rather manipulate the choice of ideational strategies. In this study, it is likely that the open instruction condition allowed students to focus on producing more original questions because there is a bigger pool of ideas they can draw from. Under the closed instruction condition, students may have been forced to produce as many questions as they "know" about one topic.

The finding of grade differential reactions to open and closed instructions is truly developmental. Lower grades might be limited first by their scientific knowledge and experiences, and then by their *ideational strategies* in making responses to the problem finding task. To the higher grade students, they have more knowledge and experiences to draw responses from relevant to the subject matter, and, therefore, might have been more subject to influences by the ideational strategies directed by type of instructions.

At any rate, measurement of CSPF should include both open and closed conditions to capture different aspects of this construct. The open condition asks the student to list all science-related problems that they may have thought about up to the point of testing, so it is not limited to any particular area of science. Perhaps it taps into how observant a student is in general and how much attention they pay to science-related problems in everyday life. However, the closed instruction taps into how quickly and creatively a student can use existing knowledge to find science related problems. Both dimensions need to be included in the measurement of CSPF ability.

Because of the time available for students to take the tasks, only two items were included in this study. This is a limitation and it would be interesting to add more items to test whether it influences the result.

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