XIANWEI YUAN

BHARATH SRIRAMAN

AN EXPLORATORY STUDY OF RELATIONSHIPS BETWEEN STUDENTS' CREATIVITY AND MATHEMATICAL PROBLEM-POSING ABILITIES

INTRODUCTION

The literature is replete with statements alleging that people in the Western countries are more creative than people in the East Asian countries (Zhao, 2008; Rudowicz & Hui, 1998; Yue & Rudowicz, 2002; Lubart, 1990; Dunn, Zhang, & Ripple, 1988). A typical explanation for those statements is that, citizens of the Western cultures tend to be independent and to find meaning largely by reference to their own internal thoughts, feelings, and actions rather than by those of others; while citizens of the East tend to hold an interdependent perspective of the self in which meaning depends more on interpersonal relationships (Markus & Kitayama, 1991). In other words, in the Western countries, individuals often focus on discovering and expressing themselves and on accentuating differences from others, whereas East Asians tend to organize more into hierarchies in which individuals seek membership in larger communities (Zha, Walczyk, Grifffith-Ross, & Tobacyk, 2006).

In the domain of mathematics, it is widely accepted in China that U.S. students are more creative in mathematics than Chinese students (e.g., National Center for Education Development, 2000; Yang, 2007). According to Mathematics Curriculum Development Group of Basic Education of Education Department (2002), one of the most alleged prominent weaknesses is that Chinese students lack creativity in mathematics. In the professional world, it is said that the publishing activities of Chinese mathematicians in the world-class journals are far from enough (Ye, 2003). At the same time, many Chinese teachers and educators believe that U.S. teachers and educators hold the opinion that it is more important to develop students' creativity in mathematics than to teach students basic mathematical knowledge (Jia & Jiang, 2001). It is also well-known in China that, in the United States, mathematics teachers emphasize students' active involvement in the process of learning and that they also tend to use open problems and various activities in teaching mathematics–which are perceived to benefit students' development of creativity in mathematics (e.g., Bai, 2004; Zhu, Bai, & Qu, 2003).

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Despite the fact that "mathematical creativity ensures the growth of the field of mathematics as a whole" (Sriraman, 2009, p. 13), there is a lack of an accepted definition of mathematical creativity (Mann, 2006). Sriraman (2005) pointed out that most of the extant definitions of mathematical creativity are vague or elusive. For example, according to Sriraman, Hadamard and Poincaré defined mathematical creativity as the ability to discern, or choose; Birkhoff defined mathematical creativity as the ability to distinguish between acceptable and unacceptable patterns; to Ervynck, creativity is the ability to engage in nonalgorithmic decision-making. More recently, according to Chamberlin and Moon (as cited in Shriki, 2010), in the context of mathematics, creativity of students is defined as having "an unusual ability to generate novel and useful solutions to simulated or real applied problems using mathematical modeling". Sriraman (2009), however, argued that in the context of creativity in mathematics, "the results of creative work may not always have implications that are 'useful' in terms of applicability in the real world … it is sufficient to define creativity as the ability to produce novel or original work" (p. 14-15).

In the mean time, there are claims that the ability of posing problems in mathematics is linked to creativity. For example, Jensen (1973) looked at students' ability to pose mathematical questions based on a given scenario as one measure of mathematical creativity. According to Jensen, for students to be creative in mathematics, they should be able to pose mathematical questions that extend and deepen the original problem as well as solve the problems in a variety of ways. Silver (1997) argued that inquiry-oriented mathematics instruction which includes problem-solving and problem-posing tasks and activities can assist students to develop more creative approaches to mathematics. It is claimed that through the use of such tasks and activities, teachers can increase their students' capacity with respect to the core dimensions of creativity, namely, fluency, flexibility, and originality (e.g., Presmeg, 1981; Torrance, 1988). English (1997a) claimed that in her study of a problem posing program, the activities had a strong emphasis on children being creative, divergent, and flexible in their thinking and students were encouraged to look beyond the basic meanings of mathematics with those activities.

In the United States, problem posing has been a goal of school mathematics since at least 1989. According to the National Council of Teachers of Mathematics [NCTM] (1989), students should be given opportunities to solve mathematical problems using multiple solution strategies and to formulate and create their own problems from given situations. In China, problem posing was added to the goals for school mathematics only in the year 2002. In a document entitled the Interpretation of Mathematics Curriculum (Trial Version) (Mathematics Curriculum Development Group of Basic Education of Education Department, 2002), it is pointed out that students' abilities in problem solving and problem posing should be emphasized and that students should learn to find problems and pose problems in and out of the context of mathematics.

At the same time, mathematical problem posing has emerged to be a heated topic (e.g., English a, b, c, 1997; Silver, 1994). Despite the fact that the achievements in mathematics of students in the United States are poorer than those of students in East Asian countries (Stevenson & Stigler, 1992; Stigler &

Hilbert, 1999), studies have shown that when it comes to mathematical problem posing, it is not the case. For example, in Cai and Hwang's (2002) study, the Chinese sixth graders outperformed the U.S. sixth graders on computational tasks, whereas with regard to problem posing, the Chinese students did not outperform the U.S. students. At the college and graduate school level, ability in problem posing also has caught the attention of mathematicians. For example, the Harvard professor Shing-Tung Yau (Sun, 2004), who is the only Chinese-born mathematician to have won the Fields Medal, compared graduate students who studied under him and commented that students from China are very good in basic skills but, in comparison with U.S. students, often lack mathematical creativity and ability in posing research questions.

In sum, the discussion about creativity and mathematical problem-posing abilities suggests that students in the Western countries are more creative than students in the East Asian countries and that the former are better at problem posing in mathematics than the latter. These claims seem to indicate some correlation between creativity and mathematical problem-posing ability. Although there are findings that show the correlations between the two in other fields, such as art (Csikszentmihalyi & Getzels, 1971), there are researchers who claimed that there was an incomplete basis for asserting a relationship in the domain of mathematics (Haylock, 1987).

The present study into U.S. and Chinese students promises to provide a rich and rewarding context for the investigation of the relationship between creativity and mathematical problem-posing ability. Specifically, the following three questions will be addressed in this study:

1. Are there differences in students' mathematical problem-posing abilities in the comparable groups? If so, what are the differences?
2. Are there differences in their creativity? If so, what are the differences?
3. Is there a significant relationship between students' creativity and mathematical problem-posing abilities in the comparable groups?

CONCEPTUAL FRAMEWORK

Guilford's Structure of Intellect Model

In the year 1950, Guilford and his associates hypothesized that fluency, flexibility, and originality would be three important aspects of creativity (Guilford, 1959). Such traits were found in Guilford's well-known structure of intellect model. Guilford claimed that the intellectual factors fall into two major groups–thinking and memory factors—and the great majority of them can be regarded as thinking factors. Within this group, a threefold division appears—cognitive (discovery) factors, production factors, and evaluation factors. The production group can be significantly subdivided into a class of convergent thinking abilities and a class of divergent thinking abilities. Guilford defined divergent production as the generation of information from given information, where the emphasis is on variety of output from the same source (information, originality, unusual synthesis or perspective). Included in the divergent thinking category were the factors of fluency, flexibility, originality, and elaboration. Fluency in thinking refers to the quantity of output. Flexibility in thinking refers to a change of some kind: a change in the meaning, interpretation, or use of something, a change in understanding of the task, a change of strategy in doing the task, or a change in direction of thinking, which may mean a new interpretation of the goal. Originality in thinking means the production of unusual, far-fetched, remote, or clever responses. In addition, an original idea should be socially useful. Elaboration in thinking means the ability of a person to produce detailed steps to make a plan work. Guilford saw creative thinking as clearly involving what he categorized as divergent production.

In the present study, *Torrance Tests of Creative Thinking* [TTCT] (Torrance, 1966), which are based on the four factors, namely, Fluency, Flexibility, Originality, and Elaboration, are used to measure participants' creativity. However, only the three factors, namely, Fluency, Flexibility, and Originality, are used to guide the design and data analysis of the whole study, including the mathematical problem-posing test. Elaboration is not used because, in the scoring manual provided by the test designer, the scoring procedure has been greatly streamlined by having the scorer estimate the number of details within the six sets of limits determined by normative data (Torrance, 2008a). In other words, the scoring of the Elaboration is at best an estimate and, therefore, will not provide accurate information on participants' Elaboration ability. Also, the analysis of the problem-posing test (discussed in the next section) will be guided by the three factors mentioned above, too.

Mathematical Problem-Posing Framework

Stoyanova and Ellerton classified a problem-posing situation as free, semi-structured or structured. According to this framework, a problem-posing situation is free when students are asked to generate a problem from a given, contrived or naturalistic situation (see Task 1 below), semi-structured when students are given an open situation and are invited to explore the structure of that situation, and to complete it by applying knowledge, skills, concepts and relationships from their previous mathematical experiences (see Task 2 below), and structured when problem-posing activities are based on a specific problem (see Task 3 below). The first two tasks were adapted from Stoyanova's (1997) dissertation and the third task was adapted from Stoyanova's (1997) dissertation and Cai's (2000) research.

Task 1: There are 10 girls and 10 boys standing in a line. Make up as many problems as you can that use the information in some way.

Task 2: In the picture below, there is a triangle and its inscribed circle. Make up as many problems as you can that are in some way related to this picture.

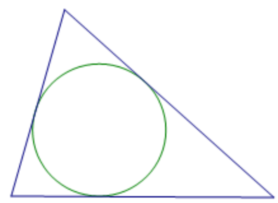

Figure 1. Figure for the semi-structured problem-posing situation example.

Task 3: Last night there was a party at your cousin's house and the doorbell rang 10 times. The first time the doorbell rang only one guest arrived. Each time the doorbell rang, three more guests arrived than had arrived on the previous ring.

(a) How many guests will enter on the 10th ring? Explain how you found your answer.

(b) Ask as many questions as you can that are in some way related to this problem.

STUDY VARIABLES AND DEFINITION OF STUDY TERMS

Definition of Creativity

Although many researchers have attempted to define the concept of creativity, there is no universally accepted definition. However, Plucker and Beghetto (2004), in their literature review on creativity, argued that there are two key elements of creativity, specifically novelty (i.e., original, unique, new, fresh, different creations) and usefulness (i.e., specified, valuable, meaningful, relevant, appropriate, worthwhile creations). Plucker and Beghetto also pointed out that the combination of these two elements serves as the keystone of scholarly discussions and definitions of creativity. The production of something new is included in almost all of the definitions (Torrance, 1988), either explicitly or implicitly. According to Torrance, on the one hand, there are definitions maintaining that the product does not have to be new to the whole society but new to the person; On the other hand, there are definitions that emphasize the newness in terms of the society. In addition to novelty, the second defining component of creativity concerns the extent to which a proposed idea fits within boundaries imported by constraints. In other words, novel productions need to be useful in a given context to quality as being creative. According to Torrance, creativity is defined as the process of sensing difficulties, problems, gaps in information, missing elements, something askew; making guesses and formulating hypotheses about these deficiencies; evaluating and testing these guesses and hypotheses; possibly revising and retesting them; and finally communicating the results (Torrance, 1988, p. 47).

The creativity measurement in this study, *Torrance Tests of Creative Thinking* (Torrance, 1966), comprise test activities that are models of the creative process described in the definition of Torrance. Also, Torrance's definition is to some extent parallel to Polya's (1954) four principles on how to solve problems in mathematics, namely, understand the problem, devise a plan, carry out the plan, and look back/Review/extend. Therefore, in this study, Torrance's definition are adopted.

Definition of Mathematical Problem Posing

There are different terms that are used in reference to problem posing, such as problem finding, problem sensing, problem formulating, creative problem-discovering, problematizing, problem creating, and problem envisaging (Dillon, 1982; Jay & Perkins, 1997). In the present study, mathematical problem posing will be defined as the process by which, on the basis of mathematical experience, students construct personal interpretations of concrete situations and from these situations formulate meaningful mathematical problems (Stoyanova & Ellerton, 1996). In the proposed study, mathematical problem-posing abilities will be measured by means of a mathematical problem-posing test. More details about the test were discussed in the Conceptual Framework section.

RESEARCH DESIGN

In this study, three tests were administered to the students. The first test is the *Torrance Tests of Creative Thinking* (Torrance, 1966). The second is a mathematical problem-posing test, and the third, a mathematics content test. Medians of the first two tests were compared and correlations between the scores of the first two tests were used to explore relationships between creativity and mathematical problem-posing abilities. The third test, the mathematics content test was used to examine students' levels of mathematical knowledge.

Since this study is exploratory and the participants in this study were not randomly selected from well-defined populations, the results will only provide some major attributes of the groups studied so that the researchers will be able to place the study in a larger context in the future. In other words, the findings of this study will not be generalized to the whole high school student population in each county. For that reason, descriptive rather than inferential statistics were used (Vogt, 2007). Spearman correlation coefficients were computed to measure the relationship between the two variables, namely, creativity and mathematical problem-posing ability.

PARTICIPANTS

Participants from China were selected from Shandong province which has a strong root in Confucian culture in the north of China. Participants from the United States were selected from a mid-western town in the United States. In English's (1997b) framework of Key Elements of Problem Posing, students' knowledge and reasoning play an important role in students' problem posing. Therefore, this study selected students who were taking advanced mathematics courses as participants to make sure that the participants have the knowledge and reasoning abilities needed for the problem-posing activities.

Participants from China

Chinese students in this study were from a small city, Jiaozhou, in China. As of the 2008 census, Jiaozhou has an urban population of 450,000 and an area of 45 km^2. As its name indicates, the No.1 High School of Jiaozhou is one of the two best high schools of the five high schools in the city. It currently has 49 staff, 159 teachers and about 3600 students distributed in the 10^{th}, 11^{th}, and 12^{th} grades. In Jiaozhou, high school students are divided into two strands, namely, a science strand and an art strand. Usually, after the first semester in high school, students choose a strand and are assigned to different classes. Science students take more advanced mathematics courses in high school than arts students. In the school in this study in Jiaozhou, in each grade, there are two art strand classes and ten science strand classes, two of which are express science strand classes. Students in these two express science strand classes were admitted according to their achievement (total score of five subjects, namely, mathematics, literature, English, physics, and chemistry) in the high school entrance examination of the city, which they took after the 9^{th} grade immediately before they entered the high school. The class in this study is one of the two 12^{th} grade express science strand classes. Therefore, the participants from Jiaozhou can be considered as advanced in mathematics.

Participants from the United States

Normal is an incorporated town in McLean County, Illinois, United States. As of the 2000 census, it had a population of 45,386. According to the United States Census Bureau, the town has a total area of 13.7 square miles (35.4 km^2). There are three high schools in town. One of them is the University High School, which is a laboratory school of the College of Education at Illinois State University. University High School has about 600 students in grades 9 through 12. The U.S. students in this study were from two Advanced Placement Calculus classes and two Pre-Calculus classes. Those students were in the11th or 12th grade.

In conclusion, although participants in this study are from two very different locations, by choosing students from advanced classes in advanced schools in each of the two locations, the researchers managed to focus on mathematically advanced high school students in each of the two locations. Initially, 68 Chinese students and 77 U.S. students agreed to participate in this study. However, since some students had to miss one or two of the three tests, not all the participants' test papers were analyzed. In the end, 55 Chinese participants and 30 U.S. participants were present for all the tests. Among the 30 U.S. students, 17 were female and 13 were male; 17 were AP Calculus Course students and 13 were from Pre-Calculus Course students. Among the 55 Chinese students, 18 were female and 37 were male; all of the Chinese students were in the 12^{th} grade. The Chinese students in this study were from one class; while the U.S. students were from four different classes. That is one of the reasons why more U.S. students than Chinese students missed some of the tests and ended up dropping out from this study.

MEASURES AND INSTRUMENTATION

The measures and instrumentation in this study include the mathematics content test, the Figural Torrance Test of Creative Thinking, the Verbal Torrance Test of Creative Thinking, and the mathematical problem-posing test. Since the researchers were based in the United States, all three tests were administered in Chinese by the mathematics teacher of the class in China. With the U.S. students, the first author conducted all of the tests in person, except the mathematics content test, which was given by the mathematics teacher of the class due to a time conflict.

The Mathematics Content Test

The purpose of the mathematics content test in this study is to measure the participants’ basic mathematical knowledge and skills. Instead of developing a test for this study, the researchers adapted the National Assessment of Educational Progress (NAEP) 12^{th} grade Mathematics Assessment as the mathematics content test. The 2005 mathematics framework focuses on two dimensions: mathematical content and cognitive demand. By considering these two dimensions for each item in the assessment, the framework ensures that NAEP assesses an appropriate balance of content along with a variety of ways of knowing and doing mathematics. The 2005 framework describes five mathematics content areas: number properties and operations, measurement, geometry, data analysis and probability, and algebra. Although the NAEP assessment seems to fit the purpose of this study, the researchers conducted several pilot tests and made several changes to make sure that the items were cultural fair and that all the participants had learned the content.

The Torrance Tests of Creative Thinking

The Torrance Tests of Creative Thinking (TTCT) includes two tests, namely, the Figural TTCT, Thinking Creatively with Pictures, and the Verbal TTCT, Thinking Creatively with Words. According to the Scholastic Testing Service (2007), the Figural TTCT is appropriate at all levels, kindergarten through adult. It uses three picture-based exercises to assess five mental characteristics, fluency, resistance to premature closure, elaboration, abstractness of titles, and originality. Appropriate for first graders through adults, the Verbal TTCT uses six word-based exercises to assess three mental characteristics: fluency, flexibility, and originality. Both the Figural TTCT and the Verbal TTCT were used in this study, but only three mental characteristics, namely, fluency, flexibility, and originality, were analyzed.

The Mathematical Problem-Posing Test

Using Stoyanova and Ellerton's (1996) framework of mathematical problem posing, three situations were included in the mathematical problem-posing test, namely, free situation, semi-structured situation, and structured situation. Using Guilford's structure-of-intellect model, the problem-posing test was also analyzed using the three characteristics: fluency, flexibility, and originality.

The Translation of the Tests from English to Chinese

In the translation of the mathematics content test, two translation and back translation circles were done. The test was first translated into Chinese by the first author and then translated back into English by two mathematics education researchers in China. The two Chinese researchers held Ph.D degrees in mathematics education and had a high level of English proficiency. After a few changes were made, the test was then translated from Chinese into English by a science professor in the United States who is fluent in both Chinese and English. More details were discussed in the test development section. Instead of translating the TTCT, the Chinese versions of TTCT were purchased from the Taiwan Psychological Publishing Co., Lid. The Chinese versions of TTCT were not only translated by Li (2006a, 2006b) in Taiwan, but were also checked for validity and reliability in the context of Chinese students in Taiwan. Since the mathematical problem posing-test only included four tasks, the translating work was done be the first author and was then translated from Chinese into English by a mathematics education researcher in China. One translation and back translation circle was conducted.

DATA ANALYSIS

The Scoring of the Mathematics Content Test

Since the mathematics content test only includes multiple-choice problems and short answer problems, the scoring procedures are very straight forward. The first author scored all the mathematics content test and no inter-rater reliability was needed.

The Scoring of the TTCT Tests

The Figural TTCT was rated according to the *Streamlined Scoring Procedure* (Torrance, 1988). Similarly, the Verbal TTCT was rated according to the *Manual for Scoring and Interpreting Results* (Torrance 1988). As for the Chinese version of the TTCT, both the Figural TTCT and the Verbal TTCT were scored by the first author and an assistant researcher who speaks both English and Chinese.

The Scoring of the Mathematical Problem-Posing Test

The problems posed by the participants in the mathematical problem-posing test were first judged as to their appropriateness. Responses that are non-appropriate were eliminated from further consideration. For example, for the first task, responses such as “How old are the children?” or “Do they know each other?” were eliminated. In addition, problems that lacked sufficient information for them to be solved were also eliminated from further analysis. For example, for the second task, responses such as “Find the area of the circle” and, for the third task, responses such as “How many girls and how many boys are there at the party?” were eliminated. The remaining responses that are appropriate and viable were scored according to the rubrics in terms of their fluency, flexibility, and originality. The rubrics were developed by the researchers following these steps:

1. Typed all the responses into a Microsoft Word document and recorded the frequency with which each of the responses occurred. The responses generated by the two groups of students were separated so that the researchers could see the differences among the groups.

2. Categorized the responses. The two groups of students’ responses to the mathematical problem-posing test were categorized. It turned out that the categories are not the same for the two samples. For example, in the second problem posing task, the Chinese students have a category of “Dilation” but the U.S. students do not have this category. After the responses generated by each group of students were categorized, all the categories were combined to make a common rubric for both the two groups.

3. Determined the originality of each of the responses. The originality of the responses in this test was determined by their rareness. Since students in the two groups have different textbooks and instruction, one rare response in one group might not be rare in the other group. Therefore, the originality of the responses was relative to other students in the same group. For that reason, the originality was analyzed separately among the two groups. For the U.S. group, 30 participants finished all the tests. The researchers decided that if one response was posed by three or more than three participants, which is more than but including 10 percent of the 30 participants, then it is considered as not original. For the Chinese group, in which there are totally 55 participants, the researchers decided that if one response was posed by six or more than six participants, which is about 10 percent of the 55 students, then it is considered as not original. In addition, there are problems that were posed by less than 10 percent of the total number of participants but were not considered as original, for example, the following problem is not considered as original because the mathematics involved in the problem is at a very low level to a high school student.

If there are four girls with brown hair and two more boys with brown hair than girls, how many people do not have brown hair?

RESULTS

Comparison of the Mathematics Content Test Scores

The purpose of the mathematics content test was to measure the participants' basic mathematical knowledge and skills. Table 1 shows the results for the two groups. Clearly, Chinese students achieved more highly on the mathematics content test than the U.S. group.

Table 1. Mathematics Content Test Results

Groups	Average (out of 50)	Median (out of 50)
U.S. students	36.5 (73%)	36
Chinese students	45.8 (91.6 %)	46

Comparison of TTCT Scores

The following two tables show the results of the Figural TTCT and Verbal TTCT. In the Figural TTCT: Norms-Technical Manual (Torrance, 2008b) and the Verbal TTCT: Norms-Technical Manual (Torrance, 2008c), Torrance and his colleagues listed the national percentiles for different grade levels of students based on surveys among the U.S. students. Li (2006 a, 2006b), who translated the TTCT, conducted surveys among Taiwan students and also listed the national percentiles for different grade levels students based on the data in Taiwan. In both manuals, the percentiles were given by grades. For example, in Table 2, in the U.S. manual, for both 11th graders and 12th graders, 24 is at the 81st percentile. In this study, however, in order to compare the two groups' performances, the U.S. manual was used for all two groups of students. Table 13 shows that, in the Figural TTCT test, Chinese students provided more responses than the U.S. students. In terms of originality of the responses, Chinese students and U.S. students had the same median.

Table 2. Figural TTCT Results

Groups	Fluency median[a] (National percentile[b])	Originality median[a] (National percentile[b])
U.S. students (30 students)	24 (81%)	18 (75%)
Chinese students (55 students)	25 (84%)	18 (75%)

[a] The scores are medians in each group.
[b] The percentiles are obtained from the Figural TTCT Norms-Technical Manual (Torrance, 2008b).

Table 3 shows the results of the Verbal TTCT test. These are different from the results of the Figural TTCT test. In this test, U.S. students scored much more highly than the Chinese group. In addition, Chinese students' National percentile dropped to 55% on Fluency score and Flexibility score. It seems that U.S. students in this study achieved more highly in the Verbal TTCT than Chinese students.

Table 3. Verbal TTCT Results

Groups	Fluency median[a] (National percentile[b])	Flexibility median[a] (National percentile[b])	Originality median[a] (National percentile[b])
U.S. students (30 students)	105 (78%)	54 (84%)	68 (84%)
Chinese students (55 students)	83 (55%)	43.5 (55%)	58 (75%)

[a]The scores are medians in each group.
[b]The percentiles are obtained from the Verbal TTCT Norms-Technical Manual (Torrance, 2008c).

Comparison of the Mathematical Problem-Posing Test Scores

It is important to point out that, in counting the number of problems generated by the students in each group, the same problems generated by the same group of students were counted once. For example, the following two problems were counted as one problem and were categorized as "Given the three sides of the triangle, find the area of the inscribed circle".

Problem 1: Given that the three sides of the triangle are 3, 4, and 5, find the area of its inscribed circle.

Problem 2: Given that the three sides of the triangle are 5, 6, and 7, find the area of the circle.

Task 1. Table 4 and Figure 2 show the number of problems that each group of students posed for the different categories for task 1 in the mathematical problem-posing test. Notice that there is no zero in the numbers. In other words, each of the two groups' responses covered all the 8 categories.

Table 4. Summary of Results on the Mathematical Problem-Posing Test–Task 1

Group	1[a]	2	3	4	5	6	7	8	Total
U.S. (%)	27 (24.1[b])	13 (11.6)	42 (37.5)	8 (7.1)	3 (2.7)	10 (8.9)	3 (2.7)	6 (5.4)	112

Chinese (%)	143 (50)	74 (25.9)	30 (10.5)	5 (1.7)	5 (1.7)	14 (4.9)	4 (1.4)	11 (3.8)	286

[a] Category 1 in Figure 2
[b] The percentage of the number of responses in each category

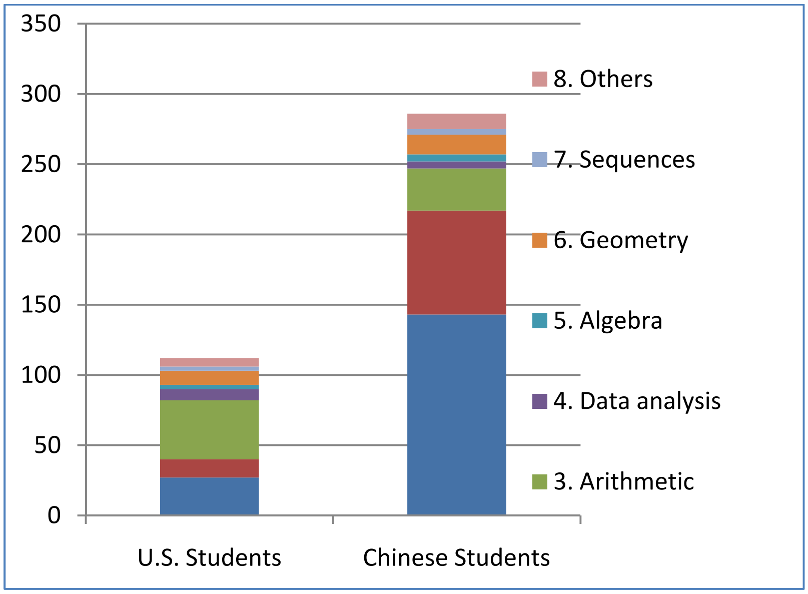

Figure 2. Summary of results on the mathematical problem-posing test, Task 1.

Figure 2 shows the distribution of different categories in each of the two groups. Each of the bars represents the total number of problems students posed for Task 1 in the mathematical problem-posing test. A closer look at the percentages of the categories shows that 50% of Chinese students' responses for the first task are about Combination and Permutations; 29.5% are about Probability. The results for the U.S. students are very different from those for Chinese students. 37.5% of the responses are about Arithmetic problems and 24% are about Combination and Permutation. Among the 30 U.S. students, 11 were taking Pre-Calculus and 19 were taking AP Calculus. Students in the Pre-Calculus course had not learned the probability topic either.

Task 2. Table 5 and Figure 3 show the distribution of the different categories posed by different groups of students. Consistently, for the two groups, the biggest two categories are Length and Area. For U.S. students and Chinese students, the Area category is the largest one and the Length category is the second one. Another observation is that Chinese students posed more problems that involve auxiliary figures (12%); while not many problems of that category were posed by the U.S. students (2.8%).

However, not both the two groups posed problems in all 10 categories. The 30 U.S. students whose tests were analyzed did not pose problem involving categories 5 and 9, which are Transformation and Proof. The 55 Chinese students whose tests were analyzed posed problems that covered all the ideas in the 10 categories. These results suggest that Chinese students are stronger in posing problems in geometry.

Table 5. Summary of Results on the Mathematical Problem-Posing Test–Task 2.

Groups	1	2	3	4	5	6	7	8	9	10	Total
U.S.	1	39	44	3	0	3	6	3	0	7	106
(%)	(0.9)	(36.8)	(42)	(2.8)	(0)	(2.8)	(5.7)	(2.8)	(0)	(6.7)	
inese	11	48	61	8	1	24	14	8	10	15	200
(%)	(5.5)	(24)	(30.5)	(4)	(0.5)	(12)	(7)	(4)	(5)	(7.5)	

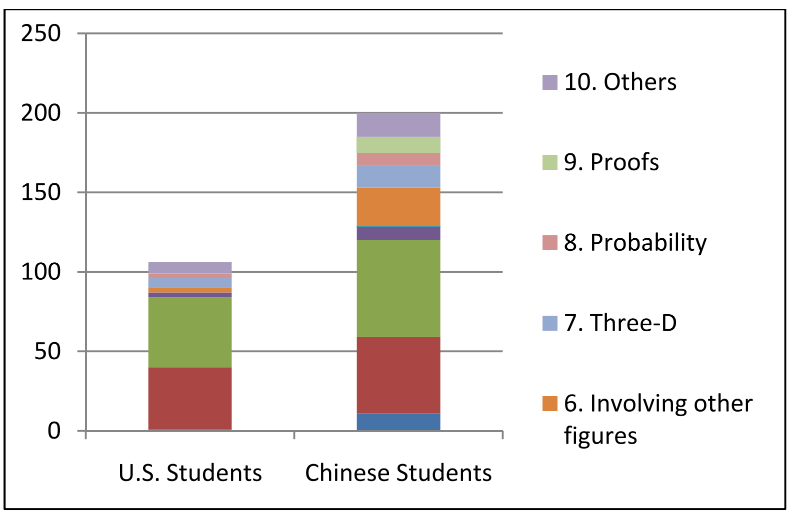

Figure 3. Summary of results on the mathematical problem-posing test, Task 2.

Task 3

Table 6 and Figure 4 show the distribution of the categories for Task 3. Consistently, for the two groups, Category 1, which is the Total number of people category, is one of the two top categories. For the U.S. group and the Chinese group, Category 8, which is the Number of things involved category, is the second largest category. Notice that 55 Chinese students' responses were analyzed, but only 30 U.S. students' responses were analyzed. Therefore, it may not be that surprising that Chinese students posed more number of different problems.

Table 6. Summary of Results on the Mathematical Problem-Posing Test–Task 3

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
U.S. (%)	23 (25.3)	10 (11)	8 (8.8)	9 (9.9)	6 (6.6)	6 (6.6)	2 (2.2)	17 (18.7)	0 (0)	2 (2.2)	1 (1.1)	2 (2.2)	5 (5.5)	91
Chinese (%)	36 (17.4)	14 (6.8)	11 (5.3)	12 (5.8)	7 (3.4)	19 (9.2)	15 (7.2)	43 (20.8)	14 (6.8)	14 (6.8)	4 (1.9)	7 (3.4)	11 (5.3)	207

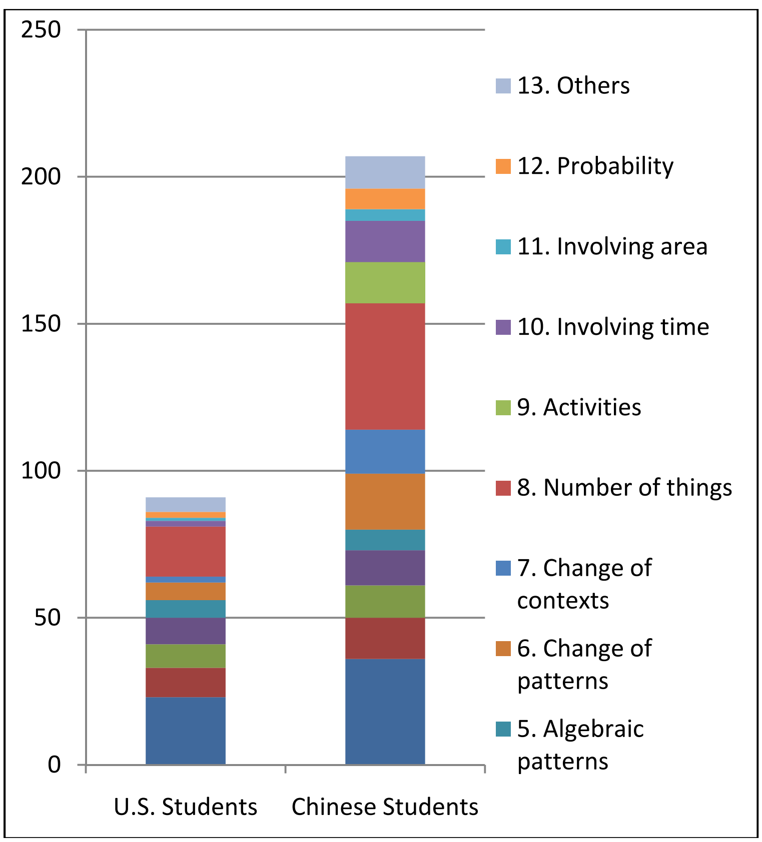

Figure 4. Summary of results on the mathematical problem-posing test, Task 3.

Table 7 and Table 8 show the average number and medians of problems posed in each task by the two groups of students. As mentioned earlier, the originality of the problem posing test was determined relatively within each group. Therefore, originality should not be compared across groups. Comparison of the means indicates that, on average, Chinese students and U.S. students generated similar number of problems and the problems generated involved similar number of categories.

Table 7. Means of the Fluency, Flexibility, and Originality of the Mathematical Problem-Posing Test

	Problem posing Fluency mean	Problem posing Flexibility mean
U.S. students	13.1	10.2
Chinese students	14.1	11.5

Table 8. Medians of the Fluency and Flexibility of the Mathematical Problem-Posing Test

	Problem posing Fluency median	Problem posing Flexibility median
U.S. students	13	10
Chinese students	15	12

Correlations between TTCT and the Mathematical Problem-Posing Test

The scores in the TTCT and the mathematical problem-posing test were first converted to ordinal data before the correlations were calculated. Spearman's rho was calculated among the following variables:

a) fluency of the Figural TTCT and the fluency of the problem-posing test;
b) fluency of the Verbal TTCT and the fluency of the problem-posing test;
c) originality of the Figural TTCT and originality of the problem-posing test;
d) originality of the Verbal TTCT and originality of the problem-posing test;
e) flexibility of the Verbal TTCT and flexibility of the problem-posing test.

Table 9 suggests that among the fluency variables, there is no statistically significant correlation between problem-posing fluency and Figural TTCT fluency or Verbal Fluency. This result suggests that the numbers of responses produced for the two TTCT tests and the mathematical problem-posing test are weakly correlated according to Spearman's rho.

Table 9. Correlation between Mathematical Problem-Posing Fluency and TTCT Fluency–U.S. Students

	Figural TTCT Fluency	Verbal TTCT Fluency	Problem Posing Test Fluency
Figural TTCT Fluency	1.00		
Verbal TTCT Fluency	.55(**)	1.00	
Problem-Posing Test Fluency	0.29	0.34	1.00

** significant with $p < 0.01$

Table 10. Correlation between Mathematical Problem-Posing Flexibility and TTCT Flexibility–U.S. Students

	Verbal TTCT Flexibility	Problem Posing Test Flexibility
Verbal TTCT Flexibility	1.00	
Problem Posing Test Flexibility	0.18	1.00

In the TTCT, only the Verbal TTCT has the variable flexibility. Table 10 shows that Verbal TTCT flexibility is weakly correlated to mathematical problem-posing test flexibility ($p < 0.05$). This result suggests that the numbers of categories U.S. students' responses in the Verbal TTCT are weakly correlated to those in the mathematical problem-posing test according to Spearman's rho.

Table 11. Correlation between Mathematical Problem-Posing Originality and TTCT Originality–U.S.

	Figural TTCT Originality	Verbal TTCT Originality	Problem Posing Test Originality
Figural TTCT Originality	1.00		
Verbal TTCT Originality	0.53(**)	1.00	
Problem Posing Test Originality	0.32	0.22	1.00

** significant with $p < 0.01$

Table 11 shows that for the U.S. group, among the originality variables, there is no statistically significant correlation among the problem posing originality and the Figural TTCT originality or the Verbal TTCT originality. This result suggests that the originality of students' responses produced in the two TTCT tests and those in the mathematical problem-posing test are again weakly correlated according to Spearman's rho.

Tables 12, 13, and 14 show the correlations for the Chinese students. In Table 12, the Spearman's rho shows that Chinese students' mathematical problem posing fluency is significantly correlated to Figural TTCT fluency ($p < 0.05$) and to Verbal TTCT fluency ($p < 0.01$). In other words, students who posed more problems in the mathematical problem-posing test also gave more responses in the Figural TTCT and the Verbal TTCT. As mentioned earlier, Figural TTCT does not have the flexibility variable. In Table 13, Spearman's rho shows that Chinese students' Verbal TTCT flexibility and problem posing flexibility are significantly correlated ($p < 0.01$). In other words, students who posed more categories of problems in the mathematical problem-posing test also gave more categories of responses in the Verbal TTCT. In Table 14, Spearman's rho shows that Chinese students' problem posing originality is significantly correlated with their Verbal TTCT originality ($p<0.01$) but not Figural TTCT. In other words, students who posed more original problems in the mathematical problem-posing test also gave more original responses in the Verbal TTCT. But there is a weak correlation between problem posing and the Figural TTCT.

Table 12. Correlation between Mathematical Problem Posing Fluency and TTCT Fluency—Chinese Students

	Figural TTCT Fluency	Verbal TTCT Fluency	Problem Posing Test Fluency
Figural TTCT Fluency	1.00		
Verbal TTCT Fluency	0.59**	1.00	
Problem-Posing Test Fluency	0.27*	0.53**	1.00

** significant with p < 0.01
* significant with p < 0.05

Table 13. Correlation between Mathematical Problem Posing Flexibility and TTCT Flexibility—Chinese Students

	Verbal TTCT Flexibility	Problem Posing Test Flexibility
Verbal TTCT Flexibility	1.00	
Problem Posing Test Flexibility	0.48**	1.00

** significant with $p < 0.01$

Table 14. Correlation between Mathematical Problem-Posing Originality and TTCT Originality–Chinese Students

	Figural TTCT Originality	Verbal TTCT Originality	Problem-Posing Test Originality
Figural TTCT Originality	1.00		
Verbal TTCT Originality	0.56**	1.00	
Problem-Posing Test Originality	0.18	.52**	1.00

** significant with p < 0.01

In summary, Spearman's rho in the tables above suggests that the correlations between TTCT and problem posing are not consistent among the two groups. For the Chinese students in this study, significant correlations occurred in fluency, flexibility, and originality between problem posing and Verbal TTCT; significant correlations occurred in fluency and flexibility, but not originality between problem posing and Figural TTCT. For U.S. students, no significant correlations were observed between problem posing and the two TTCT tests. However, although not all the correlations were statistically significant, notice the correlations between TTCT scores and problem posing scores were between 0.18 to 0.53 between the two groups. No negative correlation was observed. The correlations among the Chinese group were stronger than the U.S. group. Chinese students in this study also performed better than the U.S. group on the content test.

DISCUSSION

This study investigated the relationships between creativity and mathematical problem posing-abilities. Two groups of students from the United States and China were included. Three questions were addressed in this study. In this section, the findings in regard to the three questions are discussed.

Research Question 1: Are there differences in the mathematical problem-posing abilities in the two groups? If so, what are the differences?

A comparison of the means and medians of the students' scores on the mathematical problem-posing test showed that Chinese students and U.S. students' fluency and flexibility are similar. Since the originality rubric was different for different groups, the originality was not compared.

In the task involving the free problem-posing situation, U.S. students tended to pose combinations and permutations problems and arithmetic problems. Chinese students' responses focused more on combinations and permutations, and probability. Consistently, both groups of students posed problems on combinations and permutations because the task scenario "ten boys and ten girls stand in a line" can very easily lead students to think of the different ways of arranging the 20 students. The fact that Chinese students posed many probability problems is because those students were in their senior year of high school and had learned the topic of probability by the time they took the problem-posing test. Among the 30 U.S. students, 11 were taking Pre-Calculus and 19 were taking AP Calculus. The AP Calculus students had learned probability in high school but probability was not a big category for the U.S. group. The differences in the free problem-posing situation among the two groups indicate that students' content knowledge does have a great influence on their problem posing.

In the task designed as a semi-structured problem-posing situation, consistently, the distribution of the problems in all two groups focused on the lengths category and the areas category. That may be because that lengths and areas are the two most familiar and basic topics in geometry. But the Chinese group also posed more problems involving auxiliary figures, while very few U.S. students did so. This difference might be due to the greater focus on geometry in the mathematics curriculum in China than that in the United States. In other words, students in Chinese might have seen or done more problems involving auxiliary figures in solving or proving geometry problems than the U.S. students.

In the task involving the structured problem-posing situation, for the U.S. group and the Chinese group, the largest category was the one involving total number of people (25.3% and 17.4% respectively) and the second largest category was the one involving numbers of things (18.7% and 20.8% respectively). It is not surprising that both groups posed more problems involving the number of people because in the part a of the task, it was asked "How many guests will enter on the 10th ring?" and most students posed similar problems to this one. Also, it is very easy to think of the amount of food, drinks, gifts, etc. because that is what happens in real life.

Research Question 2: Are there differences in the creativity of high school students taking advanced courses in the two groups? If so, what are the differences?

To answer the second research question, the Figural TTCT and Verbal TTCT were administered and the medians of the fluency, flexibility, and originality in the two different groups were compared. The comparison showed that the students in the two groups are not very different in the fluency and originality of the Figural TTCT. But U.S. students did much better than Chinese students on the fluency, flexibility, and originality on the Verbal TTCT. In the Figural TTCT, students were asked to express their ideas by drawing pictures. In the Verbal TTCT, students were asked to think with words. Therefore, the results of the TTCT suggested that although U.S. students and Chinese students are similar in their ability of drawing their ideas, U.S. students are more capable of expressing their ideas in words.

Research Question 3: Is there a significant relationship between creativity and mathematical problem-posing abilities of students in the two groups?

To answer the third research question, Spearman correlation coefficients were calculated among the fluency, flexibility, and originality of the Figural TTCT and Verbal TTCT scores and the mathematical problem-posing test scores. In the Chinese group, mathematical problem-posing fluency is significantly correlated with Figural TTCT fluency ($p<0.01$) and with Verbal TTCT fluency ($p<0.05$); mathematical problem-posing flexibility is significantly correlated with Verbal TTCT flexibility ($p<0.01$); and mathematical problem-posing originality is significantly correlated with Verbal TTCT originality ($p<0.05$) but only weakly with Figural TTCT originality. However, in the U.S. group, no significant correlation was observed between the TTCT scores and mathematical problem posing test scores.

Although the TTCT scores and the mathematical problem-posing test scores were not all significantly correlated, all the Spearman's rho correlations were positive and were between 0.18 and 0.53. That suggests that there are trends in the correlations between creativity and mathematical problem-posing abilities.

To summarize, there is a significant relationship between creativity and mathematical problem-posing abilities of high school students taking advanced courses in the Chinese group but not in the U.S. group. Therefore, the relationship between creativity and mathematical problem-posing abilities is not consistent among the two groups. The consistent findings are that the correlations between the TTCT scores and the mathematical problem-posing test scores were all positive, which suggests in the practical sense, there are correlations between creativity and mathematical problem-posing abilities. Also, Chinese students greatly outperformed the U.S. students in this study and the correlations in the Chinese group were the strongest. That indicates that problem-posing abilities in mathematics might have something to do with students' mathematical knowledge and skills. But this is just a conjecture and needs further research to prove or disprove.

LIMITATIONS OF THIS STUDY

The Participants

In this study, participants were selected from two locations, a city in China and a town in the United States. The Chinese students were in the 12th grade. Some of the U.S. students were in the 11th grade and some were in the 12th grade. The students in the two locations do not have the same mathematics curriculum. The Chinese students had not taken calculus in high school. Thus the differences in the mathematical background and contexts of the two groups constituted a limitation of this research. In addition, the students were not selected randomly within the two student populations. Therefore, the findings of this study cannot be generalized to other students in the two locations.

The translation of the instruments

Since this study involved participants who spoke different languages, namely, English and Chinese, the instruments were translated into two versions. Despite several pilot tests, there were still several problems affected by translation and those problems were excluded from analysis.

The time and distance restrictions

Since four separate tests were to be administered, the researchers decided that in order to avoid interfering with students' regular learning, she had to work around the students' schedules. So far as the U.S. students were concerned, the four tests were given over two semesters. For the Chinese students, two tests were given at the beginning of the semester and two were given before the final examinations.

CONCLUSIONS AND IMPLICATIONS

In conclusion, the findings of this study suggested that there are differences in the mathematical problem posing abilities among the two groups. Although the number of Chinese students almost doubles the number of U.S. students in this study, the results of the problem posing test shows that as a group Chinese students posed almost twice as many or more different problems that the U.S. group. Given that the median of fluency and flexibility of students in the two groups are similar, that indicates that Chinese students were able to pose problems from their peers in the group. This result contradicts those found by Cai and Hwang (2002), who studied sixth-graders' mathematical problem posing and found out that although Chinese students did better in computation skills and solving routine problems, U.S. students performed as well as or better than those Chinese students in problem-posing tasks. This result may imply that, in this study, because students have spent 11 or 12 years learning mathematics, problem posing might involve more than posing but also recalling the problems learned in the past. Younger students, like sixth graders, have not been exposed to many problems in mathematics and, therefore, are more likely to create their own problems based on their prior knowledge.

Another implication is that students' problem posing abilities might be affected by their mathematical knowledge. Students from China in this study scored much more highly than the U.S. group in the mathematics content test and the Chinese students also did much better in the mathematical problem-posing test. The superior performances of Chinese students in the mathematics content test and the mathematical problem-posing test suggest that there might be some correlation between the two. In fact, in China, educators (e.g., Zhang, 2005) have reflected on mathematics education in the past and claimed that the basic knowledge and basic skills in mathematics could be highly related to creativity in mathematics, but there is definitely a kind of balance between them. Wong (2004, 2006), who summarized the characteristics of Confucian Heritage Culture (CHC) learners, pointed out that the Chinese students' focus on the basics might be related to the ancient Chinese tradition of learning from "entering" to "transcending the way." Wong's observation echoes that of Gardner (1989, as cited in Wang, 2008) that imitating the master is the starting point of the path to becoming the master one day. Ellerton (1986) and Leung (1993) both found a clear link between mathematical competence and problem posing, with the more able students being better able to generate problems. This study confirmed the link between the two. Also, this finding also verifies the framework of English (1997b) that, in generating new problems, students must recognize the critical items of information that are required for problem solution. Brown and Walter (2005) also claimed that knowledge is necessary for determining whether or how a posed problem structure constitutes a solvable problem, a basic element of problem posing.

As to creativity, U.S. students did much better in the Figural TTCT than the other two groups but on the Verbal TTCT there was not much difference between the two groups. Although statistically significant correlations between creativity and mathematical problem posing were found in the Chinese group, no such statistically significant correlation was found in the other two groups. This finding seems to suggest that there might not be consistent correlations between creativity and mathematical problem-posing abilities or at least that the correlations between creativity and mathematical problem-posing abilities are complex.

Nevertheless, the authors wanted to emphasize that Silver's (1997) statement suggests any relationships between creativity and problem posing might be the product of previous instructional patterns. Haylock (1987) and Leung (1993), who did not agree that there was correlation between creativity and problem posing in mathematics, did not take instruction into consideration. In other words, if the participants were students who had formal instruction on posing problems in mathematics before this study, the results might be very different, but this conjecture requires further research. In conclusion, this exploratory study revealed some of the characteristics of creativity, mathematical problem-posing abilities, and the correlations between the two among high school students who were taking advanced mathematics in United States and China. The different findings from the two different groups of students suggest that both creativity and mathematical problem-posing abilities and the correlations between them are complex entities to explore.

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AFFILIATIONS

Xianwei Yuan
Dept of Mathematics
Illinois State University
USA

Bharath Sriraman
Dept of Mathematical Sciences
The University of Montana
USA