

Exploring the Relationship between Mathematical Creativity and Mathematical Achievement

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In this study we investigated the relationship between students' creative performance and achievement in the mathematical domain across grade levels. DISCOVER math assessment was used to measure originality, flexibility, and elaboration (OFE), fluency, and total mathematical creativity (TMC) as indexes of students' mathematical creativity. The participants were 78 second- to fourth-grade students, mostly Navajo Indians, from 4 schools in low-income areas in a southwestern state in the US. Students' scores on the Iowa Tests of Basic Skills (ITBS) or Comprehensive Tests of Basic Skills (CTBS), taken as part of their schools' regular program of achievement testing were the measures of mathematical achievement. Using Pearson correlations, authors found significant relationships among all the measures of creativity (fluency, OFE, and TMC) and between all the indices of creativity and both the measures of mathematics achievement. Using multiple regression the authors found that OFE, fluency, and TMC explained from 41% to 60% of the variance in mathematical achievement scores across all indices of creativity and both achievement tests. Using ANOVA, authors found that both mathematical creativity and mathematical achievement increased across grade levels, but the Pearson correlations by grade level showed that these increases were not linear. Recommendations include a greater emphasis on the development of mathematical creativity in the elementary grades and research on the relationships between creativity and achievement using current instruments and theories with a special focus on domain-specific creativity and achievement across domains.

Introduction

The creativity of mathematicians has been accepted as the insurance of the growth of the field of mathematics (Sriraman, 2004).

Some theoreticians and teachers have believed that only creative mathematicians can be successful at contributing to the growth of the field of mathematics (King, 1992). Unfortunately teachers at the elementary and secondary levels have not recognized the importance of creative thinking and problem solving in mathematics. Although creative thinking has been recognized as necessary for participation in high levels of mathematics, mathematical creativity has not been emphasized in school curricula or teaching

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strategies at the elementary and secondary school levels (Jo & Maker, 2011, this issue; Kwon, Park & Park, 2006). Kwon and colleagues concluded that traditional math education was intended to focus mostly on convergent thinking in which a student memorized existing mathematical rules and theorems and then applied them to problems to find one exclusive solution rather than to apply these rules and theorems in new and different ways. Jo and Maker found that when observers recorded the use of teaching strategies to encourage problem solving using the DISCOVER curriculum model, the teaching of mathematics was seldom described. They concluded that this observation could have been due to the fact that teachers spent little time on mathematics instruction in the schools in the study or because teachers did not see the usefulness of the model in mathematics. Because of educators' apparent lack of interest, researchers have not emphasized creativity in mathematics, so the relationship between mathematical creativity and mathematical achievement at the elementary and secondary level has remained unclear.

The relationship between general academic achievement and domain-general creativity has been investigated by numerous studies after Getzels and Jackson's (1962) classic study of the role of creativity in school achievement. While some researchers have found high correlations between academic achievement and creativity (Torrance 1962; Yamamoto, 1964; Asha, 1980; Cicirelli, 1965; Counts, 1971; Murphy, 1973), some have not verified the correlation or have found low correlations between these two variables (Baird, 1985; Edwards & Tyler, 1965; Hoyt, 1966; Krause, 1977; Mayhon, 1966; Marjoribanks, 1976; Nelson, 1975; O'Leary, 1980; Reilly & Chao, 1982; Sierwald, 1989;

Tanpraphat, 1976; Wallach, 1976). Despite the fact that all these studies have revealed informative results, the varied and conflicting conclusions of the studies make understanding the relationships between these two variables, especially in specific domains such as science, art, and mathematics, complicated and difficult. Interestingly, most of the research we found was conducted in the 60s, 70s, and 80s; new research should be initiated to revisit these relationships using current theories and instruments.

Mathematical Creativity and Divergent Thinking

The question "What is creative?" has motivated researchers to seek definitions and manifestations of creativity (Guilford, 1950, 1967; Csikszentmihalyi, 1988; Gardner, 1988; Sternberg, 1999). While Sternberg and Lubart (2000) defined general creativity as the process of producing unusual original work that was useful and adaptive, mathematical creativity usually has been viewed as solving a problem by choosing an original and insightful method regardless of the usefulness of the product (Sriraman, 2004; Erynck, 1991; Haylock, 1987).

Although creativity might have different forms in different domains, creativity would be expected to be characterized by insight, associative thinking, or divergent thinking regardless of the domain of creativity (Guilford, 1977; Mumford & Gustafson, 1988). In this study, we followed the model developed by Sak and Maker (2006), and defined mathematical creativity as the ability to produce novel solutions to problems and to apply mathematical principles in many different ways to produce mathematically correct solutions. We measured creativity

by assessing the components of divergent thinking using the procedures designed by Sak and Maker: originality, flexibility, and originality (OFE) and fluency in thinking using the DISCOVER assessment model. We added a score for total mathematical creativity (TMC), which was the sum of OFE and fluency scores.

The DISCOVER Assessment Model

The Discovering Intellectual Strengths and Capabilities while Observing Varied Ethnic Responses (DISCOVER) assessment model was developed to identify gifted students from culturally diverse groups by observing the number and the choice of problem solving strategies used by children. The assessment was grounded in the theory of Multiple Intelligences (Gardner, 1984), the theory of the Triarchic Mind (Sternberg, 1989) and studies of creativity (Getzels & Csikszentmihalyi, 1976).

Problem solving has been a key component of the DISCOVER assessment model. Problem solving was conceptualized in the model based upon the problem classification proposed by Getzels & Csikszentmihalyi (1976), who proposed that the method and structure of problems could be used to classify them as measures of knowledge or measures of creativity and to generate problems for students to solve. In this context problems were classified as either closed or open based on the number of alternatives available to the problem solver. For example, a problem was defined as closed if it could be solved in only one way and open if it could be solved in an infinite number of ways.

For the DISCOVER assessment model, problem structure was rated on a scale that ranged from a Type I problem to a Type VI problem. A Type I problem would be

highly structured and closed whereas a Type VI problem would be completely open-ended and ill-defined. All conceivable problems could fall somewhere on the continuum between the two extremes. Sak and Maker (2005) investigated the construct validity of the problem continuum by determining the relationships among the problem types. They found that correlations between the problem types varied according to the proximity of the types to each other. For instance, the correlation between Type I and Type II problems was .49, between Type I and Type III was .41, and between Type I and Type IV was .39. All correlations were statistically significant at the .01 level, showing the validity of the distinctions between problem types.

Table 1 has the problem types in the DISCOVER problem continuum (Maker and Schiever, 2005), a tool used to design assessments and curricula. The six problem types are displayed from Type I through Type VI, along with how much information would be known—how much structure was provided—for both the problem presenter and the problem solver in each Problem Type.

Problem Type Examples

The DISCOVER math assessment included problem Types I, II, IV and V. Type IV and V problems were used to measure the fluency, flexibility, originality, and elaboration components of divergent thinking (Sak & Maker, 2006), which have been considered to be good predictors of creative performance (Runco, 1990).

Type I Problem: The problem was clear, well-defined, and known to both the presenter and the solver. The method and solution also were known to the presenter and to the solver, but the solution had to be

derived by the solver. For example, “Solve this problem: $8 - 4$.” The problem was clear and well-defined. The method would be

subtraction, and the solver needed only to determine that “4” was the correct answer.

Table 1
Problem Types in the DISCOVER Assessment

| Problem Types | Problem | | Method | | Solution | |
|---------------|-----------|--------|-----------|--------|-----------|--------|
| | Presenter | Solver | Presenter | Solver | Presenter | Solver |
| I | K | K | K | K | K | U |
| II | K | K | K | U | K | U |
| III | K | K | R | U | R | U |
| IV | K | K | U | U | U | U |
| V | K | K | U | U | U | U |
| VI | U | U | U | U | U | U |

Note: K = Known; U = Unknown; R = Range, (From Maker and Schiever, 2005)

Type II Problem: This problem was clear, well-defined, and known both to the presenter and the solver. Although the presenter knew the method and solution they both had to be derived by the solver. For example, “If John were paid \$8 per hour for working, how much would he be paid for ten hours working?” The problem was defined clearly. The solver needed to determine that the method was multiplication and that the correct answer was \$80.

Type IV Problem: The problem was defined clearly and known to both the presenter and the solver, but was more open-ended than earlier problems. Several correct methods and solutions were possible, all of which were known to the presenter but had to be derived by the solver. For example, “Use these numbers to write as many correct equations as possible (4, 6, 2).” The problem could have four solutions [$4+2=6$, $2+4=6$, $6-4=2$, $6-2=4$], qualifying this problem as Type IV. The solver, when determining the

methods, had to see the possibility of using different operations and number orders to arrive at the maximum quantity of answers.

Type V Problem: The problem was well-defined and known to the presenter and to the solver, but the methods and solutions were unknown to both. For example, “Write as many problems as possible that have 5 as the answer.” Several categories of methods and solutions might be given: [$2+3=5$, $3+2=5$, $4+1=5$]. The Type 4 problem had a clear goal but not necessarily a right answer, requiring the solver to gather as much information as possible so he/she could analyze the potential methods and solutions.

In this study, we used the DISCOVER math assessment to measure originality, flexibility, and elaboration (OFE), fluency, and total mathematical creativity (TMC) as indexes of students’ creativity in the mathematical domain. The purpose of this study was to investigate the relationship between students’ creative

performance in the mathematical domain and their mathematical achievement.

The following research questions guided the study:

- 1) What relationships existed between creative performance in the mathematical domain and mathematical achievement?
- 2) How did these relationships change across grade levels?

Method

Participants

The data in the study were collected during the DISCOVER Project. The total number of participants was 78 students in grades 1 to 4. The participants were from four schools in a southwestern state in the US as presented in Table 2. School A was comprised of 95% Navajo Indian students, School B was comprised of 99% Navajo

Indian students, School C was comprised of 95% Navajo Indian students, and School D was comprised of 99% Navajo Indian students. All schools were located on the Navajo Indian Nation, and all were in rural, low-income areas. Some students were assessed for several consecutive years using the DISCOVER assessment.

Instruments

DISCOVER Assessment: The DISCOVER assessment was used in this study to measure the participants' mathematical creativity. The math section of the assessment included Types I, II, IV and V problems. Mathematical creativity was assessed using Types IV and V problems. The DISCOVER assessment varied in form and implementation according to the age group being assessed. Different forms were developed for Pre-K, K-2, 3-5, 6-8, and 9-12.

Table 2

The Number of Students at Each School and Grade Level

| Number | Grade | Gender | |
|----------|-------|--------|--------|
| | | Male | Female |
| School A | | | |
| 17 | 2 | 8 | 9 |
| 13 | 4 | 8 | 5 |
| School B | | | |
| 15 | 3 | 8 | 7 |
| 11 | 4 | 4 | 7 |
| School C | | | |
| 16 | 2 | 8 | 8 |
| 14 | 3 | 7 | 7 |
| 11 | 4 | 5 | 6 |
| School D | | | |
| 17 | 1 | 7 | 10 |
| 17 | 2 | 7 | 10 |
| 15 | 3 | 7 | 8 |
| Total | 78 | 39 | 39 |

Note: Some students took the assessments more than one year

In this study the forms for grades 1-2 and 3-5 were used. Previous studies of the DISCOVER assessment showed high inter-rater reliability ranging from 80% to 100% (Sarouphim, 1999; Griffiths, 1996). Sak and Maker (2003), investigated the predictive validity of DISCOVER, and showed that it explained 20% of the variance in Stanford 9 Math scores with $p=.007$ and 20% of the variance in AIMS Math scores with $p=.009$. These results have provided evidence for the predictive validity of DISCOVER. The results obtained by Sak and Maker (2004) and Maker (2001) showed that moderate correlations existed between the DISCOVER assessment and math achievement ($r=.30, p<.01$) and IQ scores ($r=.35, p<.01$).

Iowa Tests of Basic Skills

Iowa Tests of Basic Skills (ITBS) was a norm-referenced nationally standardized test providing a comprehensive measurement of growth in word analysis, vocabulary, listening, reading, methods of study, the mechanics of writing, and mathematics. The ITBS Math Total score was used as a measure of the participants' mathematical achievement. The mathematics sections included measures of problem solving, data interpretation, math concepts, estimation, and computation. Test-retest stability coefficients over a one-year time interval were measured in the .70 to .90 range and internal consistency and alternate forms reliability coefficients were in the .80s and .90s (Linn & Miller, 2005). The ITBS was used at Schools A and C.

Comprehensive Tests of Basic Skills

Comprehensive Tests of Basic Skills / 4 (CTBS/4) was designed to measure achievement in reading, language, spelling, social studies, study skills, mathematics, and

science. The mathematics sections included math concepts, estimation, and computation. The CTBS/4 Math Total was used in this study as a measure of the participants' mathematical achievement. Reliability coefficients (KR-20) for the levels used by the sample ranged from .88 to .94 (Shepard, 1985). The CTBS/4 was used at Schools B and D.

Procedure

Test Administration

The DISCOVER Assessment was administered by classroom teachers or DISCOVER team members in classroom settings. Students were given a blank sheet and a worksheet containing math problems. Classroom teachers and DISCOVER research team members gave students clear instructions, worked sample problems with them, and made certain all understood the tasks. Students were given as much time as they needed to complete the assessments and were encouraged to use the blank paper they were given to work out problems and solutions.

Test Scoring

Trained researchers and graduate assistants scored students' solutions. Students' solutions were scored in three categories: Originality-Flexibility-Elaboration (OFE), Fluency, and Total Mathematical Creativity (TMC), which was the sum of Fluency and OFE. Students were given one point for each correct answer and they were summed as the Fluency score (Sak & Maker, 2006; Jo & Maker, 2011, this issue).

Students' ways of using mathematical concepts, showing originality, flexibility, and elaboration in their solutions were the criteria for scoring OFE: the use of diverse strategies, the use of several

operations, especially in one problem, and the development of unique problems. Students were given two points for using two different operations, understanding the commutative property, using inverse operations, using number(s) 100 or higher, and using more than two numbers. Five points were given for a clear use of a logical strategy and creation of unique problems or symbolic representations (Sak & Maker, 2004; Jo & Maker, 2011, this issue).

Data Analysis

Pearson correlations, using through SPSS, were performed to determine the relationship between Fluency, OFE, TMC, and mathematical achievement scores of the participants. The relationships were computed separately for each grade level and analyzed on dot graphs to observe the effect of the outliers. As a result of these observations, we removed a few multivariate outliers to assure that the small size of participants at various grade levels did not mislead our analysis. These multivariate outliers were excluded from all analyses, and we merged the data of the students who took the same forms of the DISCOVER assessments to diminish the misleading effect of small sample sizes. Because the DISCOVER math assessment had different forms for Grades K through 2, 3 through 5, and 6 through 8, we analyzed students' data for students in Grades 1 and 2 together and those in Grades 3 and 4 together (Tables 3 & 4).

Two multiple regression analyses were performed to predict students' domain specific math achievement on each test (ITBS and CTBS). In the first multiple regression, we used OFE and fluency scores as the predictor variables, and in the second multiple regression analysis, we used TMC as the predictor variable. Multivariate

analysis of variance (MANOVA) also was conducted to examine differences in students' domain specific test achievement and total mathematical creativity scores across grade levels.

Results

In Table 5 we have shown the means and standard deviations for Fluency, OFE, TMC, and mathematical achievement scores at each grade level. The students at the upper grades scored higher in both achievement and creativity than did students in the lower grades.

Correlations between OFE, Fluency, TMC, and Mathematical Achievement

As shown in Tables 3 and 4, a strong, significant correlation was found between OFE, fluency, TMC, and mathematical achievement on both ITBS and CTBS tests for each grouped grade level. Correlations between Fluency, OFE, and TMC also were statistically significant. The correlation between Fluency and TMC was higher than the correlation between OFE and TMC (Tables 3 and 4).

Fluency and mathematical achievement

Fluency scores correlated significantly with mathematical achievement as measured by the ITBS (Grades 1 and 2, $r=.674$, $p<0.01$; Grades 3 and 4, $r=.584$, $p<0.01$). Fluency scores also correlated significantly with mathematical achievement as measured by the CTBS (Grades 1 and 2, $r=.656$, $p<0.01$; Grades 3 and 4, $r=.618$, $p<0.01$).

OFE and mathematical achievement

OFE scores correlated significantly with mathematical achievement as measured by the ITBS (Grades 1 and 2, $r=.554$, $p<0.01$; Grades 3 and 4, $r=.549$, $p<0.01$). OFE scores

also correlated significantly with the CTBS (Grades 1 and 2, $r=.609$, $p<0.01$; mathematical achievement as measured by Grades 3 and 4, $r=.695$, $p<0.01$).

Table 3

Pearson Correlations between Fluency, OFE, Total Mathematical Creativity (TMC), and Mathematical Achievement Scores on the ITBS

| | Fluency | OFE | TMC | ITBS |
|-------------------|---------|--------|--------|--------|
| Grades 1 & 2 N=17 | | | | |
| Fluency | | .585** | .857** | .674** |
| OFE | | | .666** | .554** |
| TMC | | | | .771** |
| ITBS | | | | |
| Grades 3 & 4 N=38 | | | | |
| Fluency | | .643** | .924** | .584** |
| OFE | | | .821** | .549** |
| TMC | | | | .601** |
| ITBS | | | | |

Note: OFE= originality, flexibility, elaboration, TMC=total mathematical creativity, ITBS= Iowa Tests of Basic Skills **Correlation is significant at the 0.01 level (2-tailed).

Table 4

Pearson Correlations between Fluency, OFE, Total Mathematical Creativity (TMC), and Mathematical Achievement Scores on the CTBS

| | Fluency | OFE | TMC | CTBS |
|-------------------|---------|--------|--------|--------|
| Grades 1 & 2 N=34 | | | | |
| Fluency | | .883** | .985** | .656** |
| OFE | | | .949** | .609** |
| TMC | | | | .655** |
| CTBS | | | | |
| Grades 3 & 4 N=41 | | | | |
| Fluency | | .776** | .985** | .618** |
| OFE | | | .873** | .695** |
| TMC | | | | .670** |
| CTBS | | | | |

Note: OFE= originality, flexibility, elaboration, TMC=total mathematical creativity, CTBS= Comprehensive Tests of Basic Skills, **Correlation is significant at the 0.01 level (2-tailed).

TMC and mathematical achievement

TMC scores correlated significantly with mathematical achievement as measured by the ITBS (Grades 1 and 2, $r=.771$, $p<0.01$;

Grades 3 and 4, $r=.601$, $p<0.01$). TMC scores correlated significantly with mathematical achievement measured by the CTBS (Grades 1 and 2, $r=.655$, $p<0.01$; Grades 3 and 4, $r=.670$, $p<0.01$).

OFE and Fluency Contribution to Mathematical Achievement

A multiple regression analysis was performed to predict the contribution of students' OFE and fluency performance on mathematical achievement scores. The dependent variable was mathematical achievement scores measured by both ITBS and CTBS, and predictor variables considered for the analysis were OFE and fluency (Table 6). For Grades 1 and 2, the variables as a whole explained 41% and 49 %

of the variance in the mathematical achievement scores on the ITBS and CTBS, respectively, which means that the model was definitely meaningful (ITBS, $R = .64$; $F(2, 32) = 11.91$; $p < .001$; CTBS, $R = .70$; $F(2, 32) = 14.582$; $p < .001$). For Grades 3 and 4, the variables as a whole explained 60% and 50% of the variance in the mathematical achievement scores on the ITBS and CTBS, respectively, which means that the model was definitely meaningful (ITBS, $R = .78$; $F(2, 24) = 16.139$; $p < .001$; CTBS, $R = .71$; $F(2, 39) = 18.38$; $p < .001$).

Table 5

Means and Standard Deviations for Fluency, OFE, Total Mathematical Creativity (TMC), and Mathematical Achievement Scores

| | Fluency | OFE | TMC | CTBS/4 | ITBS |
|----|---------|-------|--------------|--------|--------|
| | | | Grade 1 N=17 | | |
| M | 11.94 | 7.29 | 19.35 | 466.00 | |
| SD | 3.63 | 2.69 | 6.10 | 26.39 | |
| | | | Grade 2 N=33 | | |
| M | 24.53 | 17.00 | 37.82 | 610.18 | 69.97 |
| SD | 10.49 | 13.39 | 15.64 | 31.48 | 8.67 |
| | | | Grade 3 N=44 | | |
| M | 11.55 | 5.97 | 17.23 | 658.77 | 84.64 |
| SD | 9.26 | 5.23 | 13.72 | 20.62 | 13.51 |
| | | | Grade 4 N=35 | | |
| M | 22.73 | 8.82 | 31.55 | 702.45 | 101.00 |
| SD | 23.96 | 5.51 | 28.82 | 34.04 | 12.14 |

Note: OFE= originality, flexibility, elaboration, TMC=total mathematical creativity, CTBS/4 = Comprehensive Tests of Basic Skills/4, ITBS= Iowa Tests of Basic Skills

TMC Contribution to Mathematical Achievement

A simple regression analysis was performed to predict the contribution of students' TMC performance to mathematical achievement scores. The dependent variable was mathematical achievement scores on both ITBS and CTBS, and the predictor variable considered for the analysis was mathematical achievement (Table 6). TMC explained 60% and 43% of the variance in the mathematical achievement scores

respectively on the ITBS and CTBS for Grades 1 and 2, which means that the model was definitely meaningful (ITBS, $R = .77$; $F(2, 32) = 45.56$; $p < .001$; CTBS, $R = .66$; $F(1, 33) = 24.09$; $p < .001$). TMC also explained 54% and 45% of the variance in the mathematical achievement scores on the ITBS and CTBS, respectively, for Grades 3 and 4, which means that the model was definitely meaningful (ITBS, $R = .73$; $F(1, 24) = 26.92$; $p < .001$; CTBS, $R = .67$; $F(1, 39) = 30.52$; $p < .001$).

Grade Level Differences in TMC and Mathematical Achievement

A one-way, between-groups MANOVA was conducted to investigate performance

differences in mathematical achievement and TMC at different grade levels on both the ITBS and the CTBS. The analysis showed that a statistically significant difference existed among grade groups

Table 6

Summary of Multiple Regression Analysis for Variables Predicting Mathematical Achievement

| Grade | Model | ITBS | | | CTBS | | |
|-------|-------------|------|----------------|------|------|----------------|------|
| | | R | R ² | SE | R | R ² | SE |
| | | | N=32 | | | N=39 | |
| 1 & 2 | OFE-Fluency | 0.64 | 0.41 | 6.43 | 0.70 | 0.49 | 6.37 |
| | TMC | 0.77 | 0.60 | 3.17 | 0.66 | 0.43 | 5.78 |
| | | | N=22 | | | N=39 | |
| 3 & 4 | OFE-Fluency | 0.78 | 0.60 | 4.45 | 0.71 | 0.50 | 4.98 |
| | TMC | 0.73 | 0.54 | 5.19 | 0.67 | 0.45 | 6.76 |

Note: OFE=originality, flexibility, elaboration, TMC=total mathematical creativity, CTBS = Comprehensive Tests of Basic Skills, ITBS= Iowa Tests of Basic Skills, SE= Standard deviation.

(Grades 1 & 2 and Grades 3 & 4) on both dependent variables. The grade level differences contributed to performance differences in mathematical achievement (ITBS, $F(2, 70) = 30.93$, $p < .001$; CTBS, $F(2, 74) = 18.76$, $p < .001$) and total creativity scores (ITBS, $F(2, 70) = 25.87$, $p < .001$; CTBS, $F(2, 74) = 20.32$, $p < .001$). Although differences in grade level groups contributed significantly to performance differences in TMC and mathematical achievement scores, the grade level differences contributed more to the performance differences in mathematical achievement than did differences in total mathematical creativity scores.

Discussion

The first purpose of the study was to find out the relationship between mathematical creativity and mathematical achievement. In

the early 1960s and 1970s, researchers studied the relationship between general achievement and general creativity, and found different results depending on the instruments used and the populations studied. However, the general perception that has remained in the field is that creativity and achievement are two different constructs, especially at the higher levels of both. We decided to re-investigate this question, but in a domain-specific context and in a subject in which creativity seems not to be emphasized at the elementary and secondary levels.

Using the DISCOVER math assessment, which includes the solving of both closed and open-ended problems and the mathematics sections of two nationally standardized tests of achievement, the CTBS/4 and the ITBS, we found significant correlations between all measures of creativity and math achievement on both tests. We separated the scores on the open-ended questions of the DISCOVER assessment into a combined score for

originality, flexibility, and elaboration (OFE) and fluency. We also combined these two scores to arrive at a score for total mathematical creativity (TMC). All sub scores had a significant correlation ($p > .01$) with mathematics achievement at Grades 1 and 2 and at Grades 3 and 4. Correlations ranged from .549 to .771 and most were in the .5 and .6 range. These results are consistent with those of Sak and Maker (2006) who found significant relationships between mathematical knowledge and mathematical creativity (.34 between knowledge and fluency and .38 between knowledge and OFE). The fact that our correlations were higher than those of Sak and Maker are understandable because mathematics achievement as measured by these instruments is a more general construct because it includes the use of problem solving and other mathematical operations that could be influenced by a student's creative abilities in mathematics more than knowledge would be affected by creativity.

Also important in this discussion is that the multiple regression analysis showed that both fluency and OFE were significant predictors of mathematical achievement. At grades 1 and 2, these two variables explained 41% (ITBS) and 49% (CTBS) of the variance in mathematical achievement. At Grades 3 and 4, the variables as a whole explained 60% (ITBS) and 50% (CTBS) of the variance in mathematical achievement. The scores for Total Mathematical Creativity (TMC) also predicted mathematical achievement, explaining 60% (ITBS) and 54% (CTBS) of the variance at Grades 1 and 2 and 54% (ITBS) and 45% (CTBS) of the variance in mathematical achievement. These results are consistent with those of Sak and Maker (2004), who found in a predictive validity study that DISCOVER math assessment scores

explained 20% of the variance in math scores on both a nationally normed test of mathematics achievement and a State test of mathematics achievement. Taken together, these results can be used to lend support to the belief that teachers in elementary schools can enhance their students' achievement by developing their creative thinking in mathematics.

The second purpose of the study was to find out if the relationships between mathematical achievement and mathematical creativity changed as children progressed through school, or if perhaps the relationships were different at different grade levels as suggested by research showing peaks and slumps in domain-general creativity across the years (c.f., Maker, Jo, & Muammar, 2008). To minimize the effects of the small sample size and because DISCOVER has the same form at more than one grade level, we combined Grades 1 and 2 and Grades 3 and 4 in the analysis. The differences between grade level groups were significant ($p > .001$) on both achievement tests and on both variables: total mathematical achievement and total creativity. The differences between grade levels can be seen more clearly, however, by examining the means and standard deviations for the individual variables across each grade level (Table 5). As would be expected, the achievement scores increased gradually from Grade 1 to Grade 4, with the largest difference between Grades 1 and 2. However, the mean scores for fluency were low at grade 1, higher at grade 2, low again at grade 3, and high again at Grade 4. The mean for Grade 2 was higher than the mean for Grade 4. The means for OFE and TMC had similar patterns, with even higher peaks at Grade 2 than for fluency. Interestingly, these results are consistent with the findings of Maker

and her colleagues (2008) in their study of the development of domain-general creativity as measured by the Test of Creative Thinking-Drawing Production (TCT-DP). In classes of teachers who used traditional methods of teaching, children's creative performance showed a "slump" at Grades 1 and 3, with a peak at Grade 2. Although the populations of the studies were somewhat different in that the current study includes mostly Navajo Indian students and the other study included Navajo, Mexican American, Caucasian, and African American children, all students attended schools in low-income areas. Most of the students came from low-socioeconomic levels. Perhaps in this population, Grade 3 is a particularly vulnerable age for the development of creativity, and is a time for teachers to be especially attentive to encouraging creativity in their students. We would argue that this is a time in which creativity in math also should be a priority.

This study does have some limitations, and these should be considered by readers as they interpret the results. First, and perhaps most obvious, is the small sample size, which can contribute to inconsistent findings or findings affected by extreme scores. We attempted to correct for this problem by eliminating the outliers in all analyses, but still the small sample size limits the generalizability of the results. A second limitation is the use of two achievement tests. This was unavoidable due to the fact that we were required to use the tests normally given in the schools in which we were working. Generally, these tests are seen as being similar, but exact differences between the tests is unknown because the actual items are unavailable for inspection. Another limitation could be that the DISCOVER math assessment has two forms, and that these forms are used at more

than one grade level. The same form is administered at Grade 1 and Grade 2, and at Grades 3, 4, and 5. Perhaps the reason for the third graders' lower performance than second graders on all measures of creativity is due to the fact that the Grade 1-2 form was easier than the Grade 3-5 form. Although Maker et al (2008) found a similar pattern in overall creativity using a different instrument, we still have some questions about the potential influence of the different forms on the results.

To teachers and other educators, we would say that creativity in mathematics is just as important at the elementary school level as it is in the higher levels of mathematical performance. Perhaps this is a bold statement and one that does not seem to be justified by the results of this small study. However, when combined with the results of other studies (Jo & Maker, 2011, this issue; Sak and Maker, 2004; 2005; 2006), the evidence is stronger than when this study is considered in isolation. Children enjoy creative thinking experiences, and they can learn mathematical concepts and processes while also applying their creative thinking in the use of mathematical principles. If creativity were emphasized in mathematics at the early levels, perhaps more girls would be interested in mathematics, and we would not find the extreme differences between interest levels of boys and girls in this important content area. Maker (2005) for example, found that although the scores of boys and girls on the DISCOVER math assessment was not significantly different, the major difference between boys and girls was that boys tended to write long strings of very similar examples in their response to the open-ended problems, while girls tended to write many different examples and only write a few of each. Using the scoring system developed by Sak and Maker (2006)

and employed in this study, girls would score higher in OFE while boys would score higher in fluency. In this study, we found a significant correlation between both fluency and OFE and achievement in mathematics. The relationships between fluency and mathematical achievement and OFE and mathematical achievement were almost identical. If girls were encouraged to develop their tendencies toward flexible and original thinking in mathematics, they could perhaps progress at a pace equal to that of boys.

For researchers, we recommend further study of the relationships between mathematical creativity and mathematical achievement. The results of this study are thought-provoking, and when combined with the results from Sak and Maker (2006), Jo and Maker (2011, this issue), and Maker and colleagues (2008), are suggestive of a new perspective on an old argument about the relationship(s) between creativity and achievement. Not only do we recommend more studies of mathematical creativity and mathematical achievement, but we also recommend more studies of domain-general creativity and overall achievement as well as studies of domain-specific achievement and creativity in various domains. During the last 40 years, many educators, especially in the field of education for the gifted, have relied on the classic research of Getzels and Jackson (1962), Wallach (1976), and Torrance (1962) to shape their beliefs about the relationships between creativity and school achievement. Perhaps the time has come to re-examine these beliefs by conducting research using current instruments with children in the schools of the 21st century.

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