The Effect of the DISCOVER Curriculum Model On Mathematical Knowledge and Creativity

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The purpose of the research was to investigate the impact of the use of the Discovering Intellectual Strengths and Capabilities while Observing Varied Ethnic Responses (DISCOVER) curriculum model on students' mathematical knowledge and mathematical creativity. Participants were 835 students and 51 teachers from 4 elementary schools. Teachers were divided into three groups (high, middle, and low implementation levels) according to their understanding and application of the DISCOVER curriculum model. Using MANOVA, we found no overall significant differences among scores of students in classrooms of teachers at different levels of implementation. However, at grades 2 and 3, the results were significant. Grade 2 students in the classrooms of high implementers had significantly higher scores on mathematical creativity, measured by a combined score for originality, flexibility, and elaboration (OFE), than did the students in the classrooms of middle level implementers. In grade 3, all scores of students in the classrooms of high, middle, and low implementers were significantly different: mathematical knowledge and creativity (both fluency and OFE). No significant differences were found in the grade 1, 4, and 5 students' performance on mathematical knowledge or creativity in classes of low, middle, and high implementer teachers. Because of these results, the authors recommend that teachers implementing the DISCOVER curriculum model place more emphasis on math and that researchers study the effects of various teaching strategies on the children's domain specific creativity. Grade 3 may be a particularly important time for teachers to pay special attention to strategies for enhancing creativity.

Introduction

In recent years, researchers on creativity have questioned whether creativity was the same across varied domains or whether it was different in each domain. If a child were creative in academic subjects such as math and science, would the same child also be creative in the arts? Would a child usually be creative in one subject or domain but not in others? During the last 50 years, the belief that people's intelligence and creativity were generalized abilities guided much of the research and theory development in the study of creativity (Barron, 1988; Han, 2000). However, empirical studies have shown that creativity in one domain did not predict creativity in another domain nor did it transfer to a different domain, even when the domains were similar. For instance, high levels of creativity in mathematics did not predict the transfer of such creativity to language arts, social studies or even science. Baer's (1996) studies showed that creative training in poetry writing may not even transfer to different tasks in the same domain such as writing novels.

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Educators' beliefs about whether creativity is domain-general or domain-specific have affected educational practices and educational programs to develop children's creative abilities (Baer, 1998). If creativity were domain-general, instruction to develop general creative skills such as brainstorming would be the best way to improve children's creative abilities. If creativity were domain specific, children's creative abilities would be fostered only in those specific areas in which the children were receiving training (Han, 2000).

Although many psychologists and educators have studied the relationship between domain-general and domain-specific creativity, teachers who wanted to support improvement of children's creativity in their classrooms have been confused about whether they should use teaching strategies with a focus on domain-general creativity or domain-specific creativity. Researchers have acknowledged that educators need to have a new approach to creativity in educational contexts. According to Plucker and Beghetto (2004), the separation between general and specific approaches should not be as important as the integration of general and specific approaches to the development of children's creativity.

With integration in mind, Baer and Kaufman (2005) invented the Amusement Park Theoretical (APT) model of creativity to fill the gap between general and specific approaches to the development of creativity. They used the metaphor called the amusement park trip to explain a model for integrating both domain generality and domain specificity. The APT model had four levels: initial requirements, general thematic areas, domains, and micro-domains. One of the APT model's strengthens might be that the problems that resulted from focusing on just one area were solved at the integrated domain level. Like the APT model, the Discovering Intellectual Strengths and Capabilities while Observing Varied Ethnic Responses (DISCOVER) curriculum model was designed as a way to integrate the development of domain general and domain specific creativity. In previous studies, we have investigated the effects of the DISCOVER curriculum model on domain-general creativity (Maker, Muammar, Serino, Kuang, Mohamed, & Sak, 2006; Maker, Jo, & Muammar, 2008). In this study, we investigated its effects on children's domain specific knowledge and creativity.

The DISCOVER Curriculum and Assessment Model

The DISCOVER curriculum and assessment model was based on the ideas of Gardner (1983; 1999) and Sternberg (1985), and incorporated the problem-solving continuum of Getzels and Csikszentmihalyi (1967). Maker and Schiever (Schiever & Maker, 2002; Maker & Schiever, 2004) extended the work of Getzels and Csikszentmihalyi to create a continuum with five Schiever & Maker, 2001) and later six (Maker & Schiever, 2004) problem types ranging from closed (requiring mostly knowledge and convergent thinking) to open (requiring mostly the creative application of knowledge and divergent thinking). The continuum of problem types served as a guide for researchers (Maker, 1996; Maker, 2005) to develop domain-specific assessments of problem solving and as a framework for teams of researchers and teachers to develop teaching methods (Maker, 2005).

In studies of the effect of the DISCOVER model on domain general creativity, Maker and her colleagues found a significant increase in students' creativity in classrooms of high and middle implementers of the DISCOVER curriculum model when compared with the creativity of students in classrooms of low level implementers, who basically used a traditional teaching approach (Maker, et. al, 2006). In this study, creativity was measured by the Test of Creative Thinking-Drawing Production (TCT-DP), considered a measure of domain general creativity. Urban and Jellen's TCT-DP (1996) was deemed to be a fair assessment across cultures because of the use of drawings rather than language as a way for students to express their creativity. During the second year of the study, researchers found significant increases in creativity scores of children in classrooms of teachers at middle and high implementation levels (F[2, 993]= 14.43, 1-ß > .99, $?^2$= .028). Interaction effects also were found: while students' creativity in low implementers' classrooms decreased, students' creativity in high and middle implementers' classrooms increased as grade level increased. The authors recommended further research, however, because they did not find differences in students' creativity across implementation levels in the third year. In fact, all students' creativity scores decreased, regardless of the implementation level of the teachers, perhaps because the test was no longer novel, but other factors also could have been important. In a second study, Maker, et. al. (2008) investigated the effect of implementation of the DISCOVER curriculum on the development of children's creativity across grades K to 6. They found that the creativity of all children increased across the grades, but that children in classrooms of low implementers demonstrated a "slump" at grades 1 and 3 and peak in creativity at grade 2. In the classrooms of teachers at high and middle implementation levels, children's creativity development increased steadily.

In the first study of the implementation of the DISCOVER curriculum, Maker, Rogers, Nielson, and Bauerle (1996) investigated the effect of the DISCOVER curriculum on domain-specific creativity as measured by the DISCOVER assessment. Second grade students in the bilingual classroom of a high implementer showed greater gains in spatial artistic, oral linguistic and math problem solving abilities from pretest to posttest than did students in the middle implementer's bilingual classroom. These differences were statistically significant at .009 and .001 levels. A comparison of pre- and post-test math activities of the DISCOVER assessment showed that students' math scores in the high level implementer's classroom increased significantly (t=3.59, p=.001), while students' scores in the middle level implementer's class did not show a significant increase. More recently, Kuo, Maker, Su, and Hu (2010) found that gifted and twice exceptional (gifted students with disabilities) preschool children developed their domain-specific and general problem solving skills while participating in a special program in which the DISCOVER problem solving continuum was used to structure experiences within and across linguistic, logical-mathematical, naturalistic, musical, and spatial domains.

Sak and Maker's studies (2005, 2006) showed the effect of domain knowledge on fluency and a combined score for creativity in which concepts of Originality, Flexibility and Elaboration (OFE) were derived from the system used to score open-ended math problems on the DISCOVER assessment. Sak and Maker showed that mathematical knowledge made a considerable contribution to 3^{rd} to 5^{th} grade students' fluency: 7.2% in the third grade, 7.3% in the fourth grade, and 13.9% in the fifth grade. On the OFE score, math knowledge made a statistically significant contribution to 4^{th} and 5^{th} grade students' performance (R square = .068, $p < .05$; R square = .172, $p < .01$): 7% in the fourth grade and 17% in the fifth grade. This empirical study showed that mathematical knowledge strongly affected student's creativity (fluency and OFE) in classrooms in which the DISCOVER curriculum model and assessment were used.

Numerous researchers concluded that knowledge was important to creativity, especially domain-specific knowledge (c.f., Amabile, 1996; Fasco, 2001; Lubart, 1999; Weisberg, 1999). Knowledge has been considered to be a foundation for creative problem solving in real life, especially at the specific domain level (Kaufman & Baer, 2004b; Bharath, 2004; Plucker, 1998). Given these conclusions, the investigation of the effect of the DISCOVER curriculum model on math creativity should include mathematical knowledge. Therefore, we investigated the effect of DISCOVER on both mathematical knowledge and creativity. The purpose of this study was to explore how the DISCOVER curriculum model affected children's mathematical knowledge and creativity. The research questions were the following:

1. What were the differences in math knowledge and math creativity of students in the classrooms of high, middle, and low implementers of the DISCOVER Curriculum Model?

2. What were the differences in the math knowledge and math creativity of students at different grade levels in classrooms of teachers at varying levels of implementation of the DISCOVER curriculum model?

Method

Participants

Students: Participants were first- through fifth-grade students from four elementary schools located in the southwest and southeast regions of the United States (n=835). Table 1 shows the number of students by school and grade.

Table 1
Distribution of Students across Grade Levels and Schools

School	Grade Levels					Total
	1st	2nd	3rd	4th	5th	
A	32		29	33	40	134
B	49	40	37	45	38	209
C	64	35	54	60	54	267
D	45	40	47	39	54	225
Total	190	115	167	177	186	835

The majority of the participants came from culturally and linguistically diverse groups, and all attended school in low-income areas. School A was composed of 50% Caucasian and 50% African American students, school B had 98% Hispanic students, school C had 99% Navajo students, and school D had mixed ethnicities, including Hispanic, Caucasian, African American, and Yaqui Indian students. Researchers and teachers assessed students with standardized tests and creativity tests at the end of each school year.

Teachers: Fifty one elementary school teachers participated in this study. Project staff, including site coordinators and researchers observed all teachers least one time each year in their classrooms and interviewed them about their perception of giftedness, causes and effects of students' actions, and their goals. Teachers were observed using a standard form to record specific descriptions of both teacher and student activities. Based on the information from observations, teacher interviews, level of participation in staff development, and length of participation in the project, two raters familiar with each teacher and who had observed in most classrooms in the school independently rated each teacher on a 5-point scale on implementation of each of the six DISCOVER curriculum implementation principles: (a) Integrated multiple intelligences through self-selected product formats, available/accessible tools, and choices based on interests and strengths; (b) Posed a variety of types of problems and, at times, encouraged students to design their own problems, to access information and demonstrate understanding; (c) Collaborated with students to establish a learner-centered environment that included student choice, flexible schedules and grouping, standards for behavior, sharing, openness, and acceptance; (d) Organized content around broad-based, interdisciplinary themes; (e) Modeled a variety of processes and gave students opportunities to use the processes to access and transform information; and (f) Encouraged students to develop varied products that reflected the diverse strengths, interests, and preferences of the students (Maker, 2005). Using the average of the two ratings, teachers were divided into high (average rating of 4-5), middle (average rating of 3) and low (average rating of 1-2) implementation levels (Table 2). In Table 2, we have included the numbers of teachers at each level, and in Table 3, we have listed the numbers of students in classrooms of teachers at each level of implementation.

Table 2
Distribution of Teachers across Schools and Implementation Levels

	Implementation			
School	High	Middle	Low	Total
A	2	14	2	18
B	4	4	3	11
C	3	3	2	8
D	2	5	7	14
Total	11	26	14	51

Table 3
Distribution of Students across Grades and Implementation Levels

	Grade Levels					
Implementation	1st	2nd	3rd	4th	5th	Total
High	46	27	45	38	22	178
Middle	106	66	53	78	112	415
Low	38	22	69	61	52	242
Total	190	115	167	177	186	835

Instrument

Independent variable: The independent variable was level of fidelity of implementation of the DISCOVER curriculum model. Differently from other researchers, we did not use an all-or-nothing process to assign teachers to groups. Because we found that the teachers varied widely in their ability and willingness to implement the model, we divided them into three levels to determine whether the degree of implementation was important. Teachers at the high and middle level used the model, and teachers at the low level basically taught in a traditional way, not using the model or using it infrequently. The DISCOVER curriculum model's high implementer classroom was student-centered: (a) students explored independently, (b) students solved problems individually and in groups, (c) students were engaged in learning, and (d) students participated in many hands-on activities. High and middle level implementers incorporated multiple intelligences in their teaching strategies in varying degrees, and encouraged students to engage actively in problem-solving. Middle implementers sometimes supported students in pursuing problem-solving and self-motivated learning. Low implementers offered direct instruction rather than dynamic learning opportunities. In the low implementers' classes, students had few chances to engage in solving open-ended problems (Maker, 2005).

Dependent variables: The dependent variables were mathematical knowledge and mathematical creativity: originality, flexibility, and elaboration (OFE) and fluency. Both mathematical knowledge and mathematical creativity were assessed using the math section of the DISCOVER assessment. Different forms were used for grades 1and 2 and 3 to 5.

The six problem types in the Maker-Schiever problem continuum were used to create various tasks in the DISCOVER performance-based assessment. The six consecutive problem types ranged from problems with only one solution to problems with numerous solutions. The six problem types were determined by the definition of the problem, methods available to reach a solution, and the range of acceptable solutions (Maker & Schiever, 2004). Problem Type I consisted of well-structured problems with a method and solution known to the teacher or person who presented the problem. Problem Types II and III had a known problem. The presenter knew the method and solution or a variety of methods and solutions, but the problem solver did not know the method or solution. Problem Type II had only one method and problem Type III could be solved by a range methods known to the presenter. Problem Type IV was one in which the presenter and the solver knew the problem; however, a range of methods and solutions could be created by the problem solver. Problem Type V was one in which both the methods and solutions had to be created by the problem solver, but the problem had been defined by the one who presented the problem. In problem Type VI, the problem, method and solution were unknown. In other words, the problem solver defined the problem, developed a method for solving it, and created the solutions. In this study, we used the DISCOVER math assessment, which consisted of problem Types I, II, IV and V.

The DISCOVER math problem Types I and II were closed while math problem Types IV and V were open; thus, Types I and II were measures of mathematical knowledge while Types IV and V were measures of mathematical creativity (Table 4 for problem examples).

Table 4
Mathematical Knowledge and Creativity by Problem Types in the DISCOVER Math Assessment

	Problem Types			
	I	II	III	IV
Math problem for Grade 1-2	Solve one-answer problems using addition and subtraction (e.g., 3 +7= ?)	Solve three magic squares.	Use only three numbers to write correct addition and subtraction problems (e. g., 8, 3, 5)	Write as many problems as you can that have the answer of 7.
Math problem for Grade 3-5	Solve one-answer problems using addition, subtraction, and multiplication (e.g., 3 x 4=?)	Solve two magic squares and create one magic square.	Use only these numbers to write correct addition, subtraction, multiplication, or division problems (e.g., 4,3,12)	Write as many problems as you can that have the answer of 43.
Knowledge	Sum of correct answers			
Creativity			Sum of fluency scores	
			Sum of originality, flexibility, and elaboration (OFE) scores	

The correct answers to each problem in section 1, problem Types I and II, of the assessment showed the student's domain-specific mathematical knowledge. In section 2, problem Types IV and V, the originality, flexibility, and elaboration (OFE) and fluency scores for each problem showed domain-specific mathematical creativity (Sak & Maker, 2006).

The DISCOVER team members scored students' solutions to all the problems using standard criteria: correctness, variety, use of mathematical reasoning, use of mathematical processes, and originality of responses. To score magic squares, one point was given for correct squares except the final answer. Two points were given if an entire magic square was correct, and three points were given for the student-created correct magic square in the form used for grades 3 to 5. Scorers gave one point for each correct answer in all problem types. For the open-ended problems, this score was the fluency score for creativity, and for the closed problems, it was the score for mathematical knowledge. Scorers gave two points for the use of two operations, understanding of commutative and associative properties, related facts, inverse operations, and creative use of numbers anywhere within the problems. Four points were given for the use of three operations, and six points were given for using all four types of operations. Additional points were given for the use of more than one operation in the same problem. Five points were given for both clear use of a logical strategy for generating alternatives and writing unique problems such as story problems, charts, and graphs (Sak & Maker, 2006).

Procedure

For this study, we used data collected during the final year of the DISCOVER Project. The data were divided into two parts following the procedures developed by Sak and Maker (2006): (a) domain-specific mathematical knowledge as measured by the sum of correct answers to problem Types I and II (one-answer problems and magic squares), and (b) domain-specific mathematical creativity. Domain-specific mathematical creativity scores consisted of two types. The first was fluency, which was the number of correct answers written for the open-ended problems. The second was a combined score for originality, flexibility, and elaboration (OFE) in problem Types IV and V. Because the DISCOVER math assessment was not designed as a divergent thinking test, no separate scores were derived for the four usual components of divergent thinking. Thus, mathematical creativity in this study consisted of fluency, the number of correct problems students wrote in response to the open-ended questions and an OFE score, which was derived from scores for the use of a variety of mathematical operations in the same problem and across problems, the application of mathematical principles such as the associative and commutative properties in unique and varied ways, the use of clear logical strategies for generating alternatives, and the development of unique problems.

Data Analysis

We used multivariate analysis of variance (MANOVA) to analyze the differences in mathematical knowledge and creativity (fluency and OFE) in the classrooms of high, middle, and low implementers of the DISCOVER curriculum model. First of all, equality of error variance across implementation levels was checked and then MANOVA analysis was applied using the bonferroni adjustment to control for Type 1 errors. The original p value of .05 was divided by the number of dependent variables (knowledge, fluency, OFE). A new p value of .017 was applied in this study (Hair, Black, Babin, Anderson, & Tatham, 2006).

We estimated the effect size to determine to what extent the results showed practicality, and used a power analysis to control for type II error that constitutes a false positive (Cohen, 1992). To investigate the effect of the DISCOVER curriculum model by grade, we separated the data by grade level and analyzed with MANOVA. If a result was significant, we used a post-hoc Fisher LSD procedure to find out which implementation levels differed from each other (Kirk, 1995). SPSS 16.0 software was used.

Results

Research Question One: The Overall Effect of the DISCOVER Curriculum Model

Means and standard deviations of students' math knowledge and creativity across grade and implementation levels were calculated (Table 5). Students' math knowledge and math creativity increased gradually from first grade to fifth grade. With grade controlled as a covariate, MANOVA was conducted to investigate performance differences in mathematical knowledge and creativity (fluency and OFE) of students by DISCOVER teacher implementation levels. Equality of error variance was found in knowledge, fluency, and OFE. Analysis of the three factors (knowledge, fluency, and OFE) showed no significant differences between students in classrooms of teachers at different implementation levels (Table 6). Because we found no significant differences among three implementation levels, no further analysis was performed.

Table 5

Means and Standard Deviations of Students' Math Knowledge and Creativity across Grade and Implementation Levels

		Grade Levels				
	Implementation	1st (Mean/SD)	2nd (Mean/SD)	3rd (Mean/SD)	4th (/Mean/SD)	5th (Mean/SD)
Knowledge	High	6.93 (4.07)	8.50 (4.14)	8.34 (3.71)	10.29 (3.62)	11.50 (3.23)
	Middle	7.26 (3.71)	8.78 (3.59)	5.63 (3.52)	8.62 (3.77)	11.26 (3.26)
	Low	6.21 (3.45)	10.00 (2.60)	6.80 (3.29)	9.99 (3.73)	11.86 (3.35)
	Total	6.97 (3.75)	8.95 (3.57)	6.84 (3.61)	9.45 (3.78)	11.45 (3.28)
Fluency	High	7.35 (5.54)	12.81 (6.91)	15.16 (9.71)	9.74 (7.15)	17.14 (14.04)
	Middle	7.58 (7.23)	9.29 (10.74)	11.09 (7.69)	15.59 (13.97)	17.41 (16.93)
	Low	2.53 (2.93)	14.41 (8.49)	7.90 (7.22)	16.12 (10.93)	25.06 (26.23)
	Total	6.52 (6.48)	11.10 (9.73)	10.87 (8.57)	14.08 (11.94)	19.52 (19.90)
OFE	High	4.48 (4.89)	7.52 (5.83)	9.20 (6.15)	8.53 (5.91)	8.73 (4.91)
	Middle	3.42 (4.47)	4.10 (4.82)	6.37 (5.20)	7.76 (5.10)	10.53 (6.13)
	Low	1.70 (2.04)	6.39 (4.11)	5.11 (4.87)	10.29 (6.18)	12.55 (7.58)
	Total	3.33 (4.30)	5.34 (5.13)	6.61 (5.57)	8.80 (5.74)	10.88 (6.52)

Table 6

Multivariate Analysis of Mathematical Knowledge and Creativity for Students in Classrooms of Teachers at Three Implementation Levels (Low, Middle, High) across Grades 1 to 5

Source	Dependent	*df*	*SS*	*MS*	*F*	?^{2}	1-ß[a]
Grade	Knowledge	1	1787.307	1787.307	127.686	.133	1.0
	Fluency	1	15562.120	15562.120	99.119	.107	1.0
	OFE	1	6286.802	6286.802	208.070	.200	1.0
Implementation	Knowledge	2	26.244	13.122	.937	.002	.21
	Fluency	2	41.996	20.998	.134	.000	.07
	OFE	2	240.768	120.384	3.984	.009	.71
Error	Knowledge	831	11632.040	13.998			
	Fluency	831	130470.298	157.004			
	OFE	831	25108.549	30.215			
Total	Knowledge	835	77251.000				
	Fluency	835	277117.250				
	OFE	835	73709.250				

* $p < .05$

Research Question Two: The Effect of the DISCOVER Curriculum Model by Grade Level

For each grade, we used MANOVA to examine performance differences in mathematical knowledge and creativity (Figures 1-3). In the analysis of first-graders' scores, equality of error variance was found in knowledge (Table 7). The first grade students' performance on mathematical knowledge was not significantly different across the levels of implementation.

Table 7
Multivariate Analysis of Mathematical Creativity (Fluency) for Students in the Three Implementation Levels (Low, Middle, High) at Grade 1

Source	Dependent	*df*	*SS*	*MS*	*F*	?[2]	1-ß[a]
Implementation	Knowledge	2	31.145	15.572	1.109	.012	.24
Error	Knowledge	187	2626.724	14.047			
Total	Knowledge	190	11898.000				

* $p < .05$

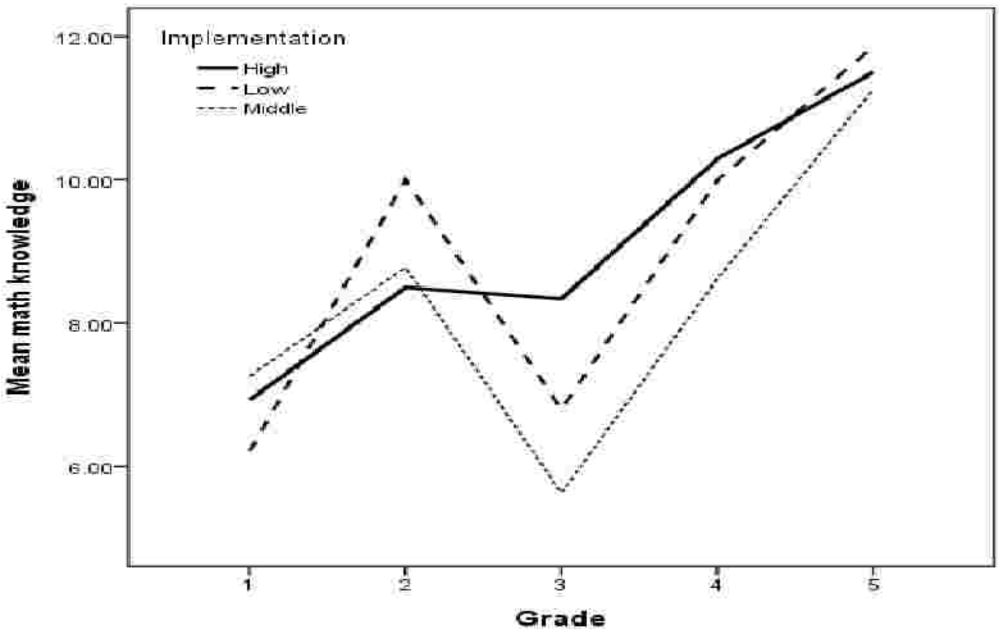

Figure 1 The mathematical knowledge of students in classrooms of high, middle and low implementers of the DISCOVER Curriculum Model from grade 1 to 5.

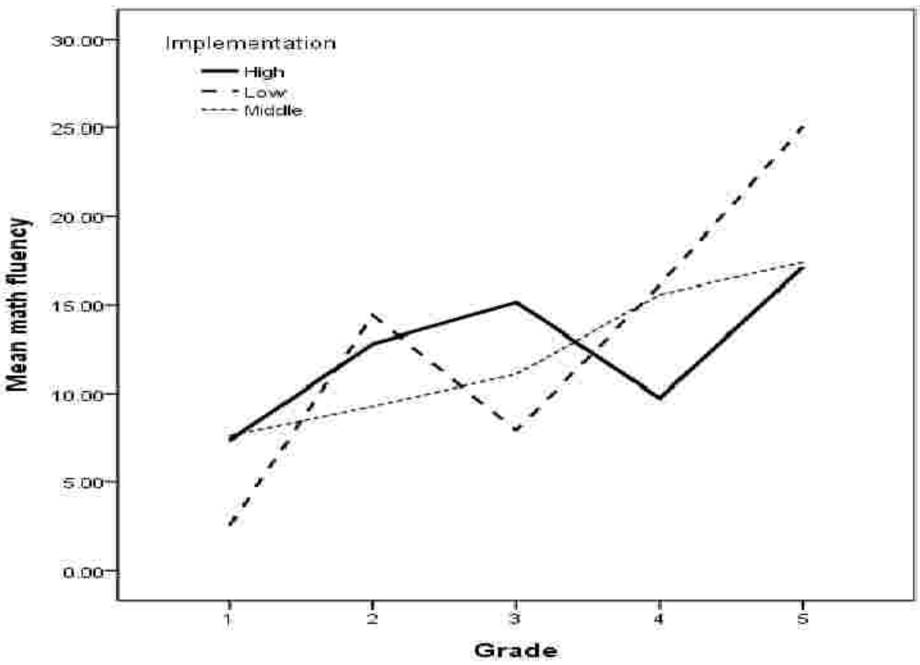

Figure 2 The mathematical creativity (fluency) of students in classrooms of high, middle and low implementers of the DISCOVER Curriculum Model from grade 1 to 5.

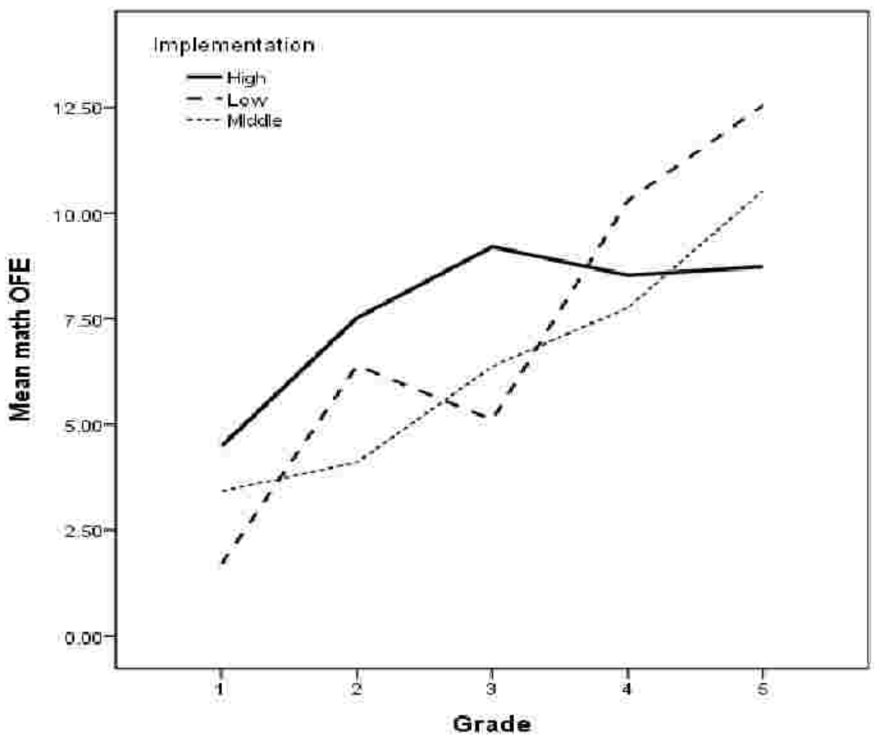

Figure 3 The mathematical creativity (OFE) of students in classrooms of high, middle and low implementers of the DISCOVER Curriculum Model from grade 1 to 5.

In the analysis of second-graders' scores, equality of error variance was found in fluency and OFE. The second grade students' performance on mathematical fluency was not significantly different across the levels of implementation, but OFE scores were different across the levels. The effect size of OFE was large (Table 8). The second grade students' performance on mathematical creativity (OFE score) was higher in classrooms of high implementers than in classrooms of middle implementers (high>middle). The scores of students in high and low implementers' classrooms were not significantly different, nor were the scores of students in classrooms of middle and low implementers.

In the analysis of third graders' scores, equality of error variance was found in knowledge, fluency, and OFE. The third grade students' performance on mathematical knowledge and creativity (fluency and OFE score) had significant differences across the three implementation levels. The effect size was large in mathematical knowledge, fluency, and OFE (Table 9).

With respect to mathematical knowledge, students' scores in the classrooms of high level implementers were higher than students' scores in the classrooms of middle and low implementers (high>middle=low). Using the Fisher LSD, differences between middle and low implementers were not found. Students' fluency scores increased through implementation levels (high>middle>low).

Table 8
Multivariate Analysis of Mathematical Creativity (OFE) for Students in the Three Implementation Levels (Low, Middle, High) at Grade 2

Source	Dependent	*df*	*SS*	*MS*	*F*	$?^2$	1-ß^a
Implementation	Fluency	2	537.025	268.513	2.934	.050	.56
Error	Fluency	112	10248.923	91.508			
Total	Fluency	115	24944.000				
Implementation	OFE	2	253.957	126.979	5.174*	.085	.82
Error	OFE	112	2748.816	24.543			
Total	OFE	115	6281.000				

* $p < .05$

Students' OFE scores in classrooms of high level implementers were higher than students' scores in middle and low level implementers' classrooms (high>middle=low). Using the Fisher LSD, we found no differences between the scores of students in the classrooms of middle and low implementers.

Finally, we found no significant differences in the fourth and fifth grade students' performance on mathematical knowledge or creativity (fluency and OFE scores) in classes of low, middle, and high implementer teachers (Tables 10 and 11). No further analyses were performed on the data for fourth and fifth graders.

Discussion

The first purpose of this study was to investigate whether the domain-specific mathematical knowledge and creativity scores of children in classrooms of teachers

Table 9
Multivariate Analysis of Mathematical Knowledge and Creativity for Students in the Three Implementation Levels (Low, Middle, High) at Grade 3

Source	Dependent	*df*	*SS*	*MS*	*F*	?^{2}	1-ß[a]
Implementation	Knowledge	2	179.306	89.653	7.410*	.083	.94
Error	Knowledge	164	1984.146	12.098			
Total	Knowledge	167	9986.500				
Implementation	Fluency	2	1438.373	719.186	10.955*	.118	.99
Error	Fluency	164	10766.729	65.651			
Total	Fluency	167	31931.000				
Implementation	OFE	2	460.490	230.245	8.059*	.089	.96
Error	OFE	164	4685.210	28.568			
Total	OFE	167	12444.000				

* $p < .05$

Table 10
Multivariate Analysis of Mathematical Knowledge and Creativity for Students in the Three Implementation Levels (Low, Middle, High) at Grade 4

Source	Dependent	*df*	*SS*	*MS*	*F*	?^{2}	1-ß[a]
Implementation	Knowledge	2	99.019	49.510	3.570	.039	.66
Error	Knowledge	174	2413.023	13.868		3	
Total	Knowledge	177	18315.750				
Implementation	OFE	2	221.613	110.806	3.451	.038	.64
Error	OFE	174	5586.065	32.104			
Total	OFE	177	19504.000				

* $p < .05$

Table 11
Multivariate Analysis of Mathematical Knowledge and Creativity for Students in the Three Implementation Levels (Low, Middle, High) at Grade 5

Source	Dependent	*df*	*SS*	*MS*	*F*	?^{2}	1-ß[a]
Implementation	Knowledge	2	12.702	6.351	0.589	.006	.15
Error	Knowledge	183	1971.659	10.774			
Total	Knowledge	186					

* $p < .05$

who used the DISCOVER curriculum model at a moderate or high level were significantly higher than the mathematical knowledge and creativity scores of children in classrooms of teachers using a traditional approach. Basically, we found no significant differences across grade levels. Because the implementation of the curriculum had an impact on domain-general creativity in other studies (Maker, et al, 2004, 2008), these results were surprising. In an attempt to understand the results of this analysis, we examined the protocols from classroom observations and interviews. Without performing a detailed analysis, we did find that very few observers recorded examples of the teaching of mathematics in classes of teachers across all levels of implementation.

If this pattern is indeed characteristic of all schools, grade levels, and observers in the study, two hypotheses can be posed to explain the lack of overall differences across teacher implementation levels. The first is that teachers' methods for teaching mathematics were not considered in the raters' classifications of teachers as high, medium, or low implementers of the DISCOVER curriculum. If, for example, a teacher implemented the DISCOVER curriculum principles at a high level in social studies and language arts, but at a low level in math, and no information was available about math instruction, the teacher's level of implementation was not accurate for the current study. Perhaps, in the study of domain-specific creativity, teachers' levels of implementation should be rated based on their implementation of the model in the domain being investigated rather than based on their overall implementation of these principles.

The second hypothesis is that the fact that very few examples of mathematics instruction were recorded by observers could indicate that very little instructional time was being spent on mathematics. In at least one of the schools, over half the school day was spent in a required program for structured teaching of reading, leaving little time for other academic subjects. Additionally, perhaps many teachers did not use the DISCOVER model during mathematics instruction. Indeed, many teachers have difficulty believing that creativity in math is desirable or even possible during the elementary school years. This attitude could contribute to both reluctance and inability to implement a model like DISCOVER in math.

The second purpose of the study was to investigate whether the differences in creativity of children varied across grade levels in addition to variations across implementation levels. Based on the results of Sak and Maker's (2006) study of the relationship between mathematical knowledge and mathematical creativity, one would expect that the implementation of the DISCOVER curriculum would have a significant impact on mathematical creativity in grades 1, 2, and 3, but not in grades 4 and 5. Sak and Maker found, for instance, that the unique contribution of knowledge to OFE increased from 19% at grade 1 to 41.5% at grade 5, and that the unique contribution of knowledge to fluency was significant at grades 3, 4, and 5, but not at grades 1 and 2. In other words, the knowledge of mathematical principles may be more important to children's creativity in math at the higher grades than the use of teaching strategies to encourage problem solving and creativity.

Part of this hypothesis was supported in that in grade 3, children's mathematical knowledge and both aspects of creativity were higher, at statistically significant levels, in classrooms of middle and high implementers than in classrooms of low implementers. These results can be used to support the hypothesis that, for these children from varied ethnic, cultural, and racial groups from low-income backgrounds, grade 3 is a critical time for development of creativity in mathematics, and perhaps for domain general creativity as well. Maker and colleagues (2006) found that, in this same population of students, the only "slumps" in domain-general creativity, as measured by the Test of Creative Thinking-Drawing Production (TCT-DP), were in grades 1 and 3 in classrooms of teachers who used a traditional approach (low implementers).

Why, then, did we not find a difference in creativity scores of first grade children in classrooms of teachers at different implementation levels? A possible reason for this result is that, regardless of the methods a teacher uses, very few, if any, children in first grade possess a high enough level of mathematics knowledge to demonstrate a high degree of creativity. Sak and Maker (2004) found, for example, that almost no linear relationship exists between average knowledge and creativity, but a linear relationship does exist between above average knowledge and creativity. They concluded that 2 standard deviations (SD) above the mean of domain specific knowledge in math is a threshold for a 1 SD above the mean performance in creativity. If very few or no children at these schools possessed a high level of mathematical knowledge, not enough variability in creativity was possible, and effects of strategies to develop domain-specific creativity could not be measured. Some support for this interpretation can be found in the results of Bahar and Maker's (2011, this issue) study of the relationship between creativity and achievement in math. Both creativity and achievement scores were low, with a SD of only 3.63 in fluency scores and 2.69 in OFE scores, while at grade 2 and up, SDs ranged from 5.23 to 23.96. To extend the idea further, perhaps high scores in domain-specific creativity in math are rare in children in first grade.

Certain limitations of the study must be considered in the interpretation of these results. One is that the population consisted of children mostly from culturally diverse groups, and all were attending schools in low-income areas. Readers should exercise caution when generalizing the results to high-income groups. Although one of the strengths of the study for educators in the US is the fact that many diverse cultural groups were included, educators from other countries who have populations that do not resemble these groups must use caution when interpreting the results. Another limitation is that the DISCOVER math assessment has two forms, one for grades 1 and 2 and a different one for grades 3, 4, and 5. At grades 1 and 2, the knowledge section contains only addition and subtraction problems and at grades 3, 4, and 5, the knowledge section contains multiplication and division problems along with addition and subtraction problems. Although the problems used to assess creativity (fluency and OFE) are similar in nature and structure in both forms, the differences between the forms may have contributed to performance differences.

Clearly, more research is needed to test the hypotheses presented in this discussion, both in the mathematical domain and in other domains. Perhaps the most important implication of this research is that the third year of school may be a critical period for the development of creativity in the mathematical domain. A second, and more general implication is that more attention may need to be placed on mathematics instruction in the elementary grades in the United States.

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