A Comparison of Constructivist and Traditional Instruction in Mathematics

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Introduction

Picture an elementary classroom in which children are vigorously engaged in debating their solutions to a math problem. The whole class is involved, as the teacher listens and moderates the discussion, occasionally providing some insight or direction to the discussion. Envision further that these children are grabbing for pattern blocks, rulers, calculators, perhaps even a computer, to support their argument and must explain and justify their solution to the entire class. Children are actively involved constructing their own mathematical knowledge, not memorizing the steps of a teacher-directed algorithm or endlessly practicing a litany of procedures. Such a classroom is the goal of constructivist elementary programs such as Cognitively Guided Inquiry (Carpenter, Fennema, and Franke, 1996; Carpenter, Fennema, Franke, Levi, and Empson, 1999), the Purdue Problem-Centered Mathematics Project (Cobb et al., 1991), and the work of Constance Kamii (Kamii, 1985a, 1990b; Kamii and Dominick, 1998; Kamii and Warrington, 1999). These progressive educators espouse a constructivist view of mathematics learning, that the teacher cannot transmit mathematical knowledge directly to students, but students construct it by resolving situations they find problematic. Driscoll (2000), Davis, Mayer, and Noddings (1990), and Fosnot (1996) provide a more detailed explication of constructivism and its implications for classroom practice. All three of the above projects stress student thinking and active learning, are problem-centered and intensely interactive, and highlight communication, reasoning, and conceptual understanding; all are consistent with the vision presented in the National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (NCTM, 2000).

Can preservice elementary teachers be expected to teach comfortably and capably in such a classroom when mathematics instruction the majority of preservice elementary teachers have received is preoccupied with procedures and based upon lectures (Battista, 1999; Manouchehri, 1997; O'Brien, 1999)? This study used constructivist instruction modeled after that developed in the progressive elementary math programs above in university mathematics courses for preservice elementary teachers; it examined the effectiveness such constructivist instruction would have on their math anxiety, mathematics teaching efficacy beliefs, and perceptions of autonomy or empowerment.

Math anxiety was investigated because it can have such a crippling effect upon students learning mathematics (Stuart, 2000; Fiore, 1999) and because research has shown that preservice elementary teachers have by far the highest level of math anxiety of any college major (Hembree, 1990). Self-efficacy was chosen because there is a direct relationship between the perceived levels of teacher efficacy and attitudes about innovative reform practices (De Mesquita & Drake, 1994). According to Bandura's (1997) theory of social learning applied to the mathematics classroom, learning will occur when teachers not only expect good teaching to result in learning (outcome expectancy), but also believe in their own ability to teach math (self-efficacy). The researcher chose autonomy because preservice elementary teachers are often teacher-dependent, passive learners who rely on memorization, facts, and procedures instead of their own independent thought (Ball, 1990, 1996).

Methods

Participants

The participants in this study were students during the Fall Semester of 2001 in Math Concepts I and Math Concepts II, required mathematics courses for preservice elementary teachers at a small (about 4,000 students) rural liberal arts university in the Midwest. Two sections of Math Concepts I and one section of Math concepts II, all taught by the same instructor, were included in the study. One of the sections of Math Concepts I and the section of Math Concepts II were experimental courses and the other section of Math Concepts I a control group. At the conclusion of the study there were 27 students in the Experimental Math Concepts I, 17 students in Math Concepts II, and 17 students Control Math Concepts I.

Instrumentation

An Abbreviated Version of the Mathematics Anxiety Rating Scale (AMARS) developed by Alexander and Martray (1989) was used in this study. The instrument was used with permission of the authors. The AMARS is a 25-item version of the full scale Mathematics Anxiety Rating Scale, which is a 98-item Likert scale survey; each item on the scale represents a situation that may arouse anxiety within a respondent. The respondent chooses the level of anxiety associated with the item and checks one of five responses: not at all, a little, a fair amount, much, or very much. The responses are converted to a numerical form by assigning the weights, 1, 2, 3, 4, or 5, to each of the possible responses. The sum of the item scores yields the total score. A higher score on the AMARS, as on each of the subscales, indicates a higher level of math anxiety. Using factor analysis Alexander and Martray identified three independent dimensions of math anxiety in their original sample of 517 college students: Math Test Anxiety (apprehension about taking a test in mathematics or receiving the results of a mathematics test), Numerical Task Anxiety (anxiety about executing numerical operations), and Math Course Anxiety (anxiety about taking a mathematics course). The first 15 items on the AMARS represent Math Test Anxiety, the next five Numerical Task Anxiety, and the concluding five Math Course Anxiety.

The Mathematics Teaching Efficacy Beliefs Instrument (MTEBI) was developed for preservice elementary teachers (Enochs, Huinker, & Smith, 2000). The MTEBI is used with permission of the authors. It has 21 items, 13 on the Personal Mathematics Teaching Efficacy (PMTE) subscale, measuring confidence in ability to teach mathematics, and eight on the Mathematics Teaching Outcome Expectancy (MTOE) subscale, measuring strength of the belief that effective teaching influences student learning. Each item has five response categories: strongly agree, agree, uncertain, disagree, strongly disagree. A response of strongly agree is weighted 5, agree 4, etc.; the sum of the item scores yields the total score. A higher total score on the MTEBI, as on each of the subscales, indicates a higher level of perceived teaching efficacy. The pilot study to examine the validity of the MTEBI utilized a sample of 324 elementary preservice mathematics teachers taking methods courses in universities throughout the country.

A simple rating scale was used to measure students' sense of autonomy (empowerment) over instruction, curriculum, and evaluation in the course and previous math courses. The survey also explained the concept of autonomy. Possible scores on the scale ranged from 1 to 10, with the higher score indicating more perceived autonomy.

Description of courses

Math Concepts I and Math Concepts II usually are taken during the students' junior year and have a pre-requisite of College Algebra, the mandatory general education mathematics course. All three were face-to-face, on-campus courses taught by the same instructor during the regular school day. The curriculum for Math Concepts I includes the following topics: problem solving, sets, algorithms for basic operations, number theory, integers, fractions, decimals and percents. Math Concepts II covers elementary statistics, probability, and geometry. Both courses last an entire semester and are content, not methods courses. Most students enrolled in Math Concepts II continue the next semester to take a required course in elementary math methods.

Procedure

The study examined the hypothesis that preservice elementary teachers, who had experienced a mathematics course designed to emphasize active learning and student involvement and modeled after pedagogy employed by progressive, constructivist educators in elementary classrooms, would demonstrate an increase in their perceived ability to teach mathematics to elementary-aged children, an increased feeling of empowerment or autonomy, and a decrease in their mathematics anxiety, when compared with preservice elementary teachers, who had experienced a more traditional lecture-recitation format of instruction.

Two courses, one section of Math Concepts I and the section of Math Concepts II, were chosen at random to receive the experimental pedagogy. The instructor often began the class period in the experimental sections with a short lecture (10 – 20 minutes) about the key concepts and calculations of the day's content. Sometimes students taught the class in groups; sometimes, when the instructor deemed it appropriate, there was no introduction. Following this students worked in groups of three or four to solve problems they, themselves, had chosen or created the previous class period, and to prepare presentations of their solutions to the whole class for discussion. As students worked in groups, they determined the problems they could not solve to their satisfaction of all group members and requested these unsolvable problems be included in a "work list". When the "work list" was completed, the instructor asked groups to volunteer to present their solutions to any problem on the "work list". For a problem to be solved the group presenting had to not only give their answer to the problem but also to explain the method they used to obtain the solution and convince the rest of the class of its reasonableness. A "solution" was not just an answer; a "solution" involved an explanation and justification of the mathematics used to reach the answer. If another group disagreed with a "solution", it could challenge the first group by requesting further elaboration or offering to present its own "solution."

The instructor was a facilitator of this whole-class discussion time; he did not offer solutions to the problems. Occasionally the instructor would clarify a point of mathematics, suggest an idea to investigate, focus the discussion on the key aspects of the problem, or summarize his interpretation of a group's solution. The students had to solve the problems and come to a consensus (general agreement) about the solution. If no consensus could be reached, the problem was considered an “open problem”, which, as in the community of mathematicians, had no generally agreed upon solution.

Once during the semester each group of four students was responsible for teaching one section of the textbook, which included presenting the essential concepts and procedures, providing homework either by determining it themselves or allowing class members to do so, and reviewing the assigned homework. The group could teach in whatever manner they desired; they used games, hands-on activities, manipulatives, lecture, and class discussion.

With the experimental sections the instructor made every effort to create a student-centered course that emphasized active learning, communication, reasoning, and the development of deep conceptual understanding of mathematics through a problem-solving curriculum. With the control group the instructor strove to teach in a more traditional, lecture-recitation format, beginning most class periods with a brief time (about 10 minutes) for students to work together in examining their solutions to the homework, then solving the problems students requested and addressing their questions about the content. In contrast to the experimental courses, which stressed student ideas, algorithms, solutions, and reasoning, with the control group the instructor used his own methods of solving the problems and did not explore the validity of students’ own creative solutions. After the homework review the instructor generally lectured on the new content and assigned homework for the next class period. Manipulatives such as pattern blocks, decimal squares, and fraction bars were used in all classes, but, whenever the instructor used manipulatives or utilized hands-on activities with the control group, he prescribed exactly how the manipulatives should be used or in detail how the hands-on activities should be completed.

There was an emphasis on problem solving and conceptual understanding in all three courses in addition to the expected requirement of procedural competence. The emphasis of conceptual understanding was a critical component of instruction for all courses and was not just a perfunctory obligation. To ensure students would not just stop at algorithmic proficiency, the instructor on all exams asked students to write short essays regarding their solutions to some problems.

The experimental classes and the comparison class were similar in the emphasis placed on problem solving and conceptual understanding and in the use of manipulatives and hands-on activities; the difference was the method of instruction. In the experimental classes the instruction was designed to be thoroughly constructivist, focusing on students’ own mathematical ideas with discussion and debate to test and clarify these ideas; public scrutiny was the anvil on which student ideas could be forged or broken. Students had as much power as could be reasonably permitted; they taught about one third of the classes, chose or created homework problems, led discussions, decided upon the acceptability of proposed solutions, developed rubrics to evaluate group teaching and did the actual evaluation, themselves, and proposed possible exam questions. The control class was intended to be teacher-centered; students did not teach, there was no discussion or debate of student ideas, the instructor chose the homework and all exam questions, and students did not go to the board to present their solutions to problems.

The first day of class students were administered the AMARS, the MTEBI, and the Autonomy Survey; the next-to-last day of class students were given the same three instruments. Only those students completing all three instruments both times were included in the study; students were eliminated from the study that dropped the course or were enrolled simultaneously in Math Concepts I and II.

All students, given the choice to participate in the study, agreed to participate. As part of the study, students had to compose a mathematics autobiography, to keep a daily journal about their experiences in the class, especially the classroom instruction, and to conduct a half-hour, audio taped, personal interview with the instructor at the end of the semester evaluating course instruction.

Description of instructor

The instructor in all three courses in this study was a veteran teacher with 20 years experience teaching mathematics at the public school and university level and 27 years teaching experience overall. Prior to this study he had taught mathematics courses for preservice elementary teachers about 40 times and had used constructivist instructional techniques for many years in these classes. He holds a Ph. D. in Mathematics Education and a Masters Degree in Mathematics.

Results

Analysis of covariance (ANCOVA) with pretest scores on each scale as the covariate for the posttest scores was used to compare students in the experimental courses with those in the comparison course. Using an ANCOVA reduces the effects of initial group difference so that group differences on the posttest are due to the treatment effect rather than preexisting group differences. See Table 1 for the results of the AMARS, MTEBI, and the Autonomy Survey.

TABLE 1: Comparison of Experimental Course Students and Control Group Students on Affective Scales

Measure	Experimental	Control	F
Math Anxiety			
Observed Mean	56.4	51.4	3.0
Adjusted Mean	56.5	50.9	
Teaching Efficacy			
Observed Mean	78.0	78.7	0.8
Adjusted Mean	77.7	79.3	
Autonomy			
Observed Mean	7.9	6.6	4.8 *
Adjusted Mean	7.8	6.6	

*p < 0.05

TABLE 2: Comparison of Students in All Three Courses on Affective Variables

Measure	Experimental Math Concepts I	Experimental Math Concepts II	Comparison Math Concepts I	F
Math Anxiety				
Observed Mean	55.1	58.4	51.4	1.8
Adjusted Mean	55.4	58.2	50.9	
Teaching Efficacy				
Observed Mean	79.4	75.7	78.7	1.6
Adjusted Mean	78.9	75.9	79.3	
Autonomy				
Observed Mean	8.5	6.8	6.6	6.5*
Adjusted Mean	8.5	6.9	6.6	

* p < 0.05

Students in the control group appeared to have a slightly lower level of math anxiety than those in the experimental group, although the result was not statistically significant. Students in both groups seemed to have a similar level of perceived teaching efficacy at the conclusion of the study, while students in the experimental group demonstrated a significantly higher sense of autonomy than those in the control group.

ANCOVA was again used to compare students in all three classes (Table 2).

The only significant difference was found in the Autonomy Scale. Subsequent t-tests revealed that there was a significant difference between the levels of autonomy experienced by the students of

Experimental Math Concepts I and the Control Group. There was also a significant difference in the levels of autonomy experienced by students of Experimental Math Concepts I and Math Concepts II; there was no significant difference between students in the Control Group and the Math Concepts II. It is striking that students in Math Concepts II had the highest level of math anxiety and the lowest level of teaching efficacy of all three classes at the conclusion of the study.

ANCOVA was utilized to compare the response levels of students in the experimental courses and in the control group on each of the subscales of the AMARS and the MTEBI; no significant differences were detected. In addition, ANCOVA was again employed to compare the response levels of students in all three classes on each of the subscales of the AMARS and the MTEBI. Again, there were no significant differences.

Paired two-sample t-tests were used to detect any changes over the semester in the level of math anxiety, teaching efficacy, and autonomy for students in each of the courses and for all students participating in the study. The results are summarized in Tables 3, 4, and 5.

The most salient observations from these results are that, in general, math anxiety declined dramatically for all participants in the study, when they are viewed collectively, and that students in Math Concepts II experienced only slight decreases in their level of math anxiety and actually showed an increase in their level of math course anxiety. When a t-test was used, combining students in both Math Concepts I courses, there was a significant ($p < 0.05$) decrease in the level of math course anxiety.

The results of analysis of the MTEBI are provided in Table 4.

It is noteworthy that the Total Score on the MTEBI and the level of self-efficacy increased dramatically during the study. However, the level of perceived mathematics-teaching efficacy did not increase significantly for Math Concepts II on the Total Score or either or the subscales. It is also worthy of mention that there was no significant increase in the level of Outcome Expectancy for all participants or any of the classes individually.

The results of the analysis of the Autonomy Survey are collected in Table 5.

Participants in this study experienced an impressive increase in their sense of autonomy. Those in the control group exhibited smaller, although significant, increases than evidenced in the experimental courses.

Table 3: Math Anxiety

Measure	Pretest Mean	Posttest Mean	t Value	p Value
Total Score All Participants	61.0	55.0	-3.8	**
Test Anxiety All Participants	44.6	40.0	-3.6	**
Numerical Anxiety All Participants	7.8	6.8	-3.1	0
Math Course Anxiety All Participants	8.2	8.1	-0.1	0.89
Total Score Experimental Math Concepts I	60.5	55.1	-3.1	*
Test Anxiety Experimental Math Concepts I	44.0	40.1	-2.5	0.02
Numerical Anxiety Experimental Math Concepts I	7.8	7.0	-1.8	0.07
Math Course Anxiety Experimental Math Concepts I	8.7	8.0	-1.5	0.15
Total Score Experimental Math Concepts II	61.3	58.4	-0.8	0.46
Test Anxiety Experimental Math Concepts II	44.5	41.9	-0.9	0.38
Numerical Anxiety Experimental Math Concepts II	7.9	7.3	-1.1	0.29
Math Course Anxiety Experimental Math Concepts II	8.8	9.1	0.3	0.75
Total Score Control Group	61.6	51.4	-3.3	*
Math Test Anxiety Control Group	45.8	37.8	-3.1	*
Numerical Anxiety Control Group	7.6	6.2	-2.5	0.02
Math Course Anxiety Control Group	8.3	7.4	-1.4	0.18

* $p < 0.01$
** $p < 0.001$

Table 4: Mathematics Teaching Efficacy

Measure	Pretest Mean	Posttest Mean	t Value	p Value
Total Score All Participants	75.1	78.2	3.4	0.001
Self Efficacy All Participants	46.4	49.0	3.8	**
Outcome Expectancy All Participants	28.7	29.2	1.0	0.33
Total Score Experimental Math Concepts I	76.0	79.4	3.17	*
Self Efficacy Experimental Math Concepts I	47.2	49.7	2.8	*
Outcome Expectancy Experimental Math Concepts I	28.8	29.7	1.7	0.11
Total Score Experimental Math Concepts II	74.9	75.6	0.4	0.71
Self Efficacy Experimental Math Concepts II	45.5	46.8	0.9	0.40
Outcome Expectancy Experimental Math Concepts II	29.4	28.8	-0.5	0.65
Total Score Control Group	74.0	78.7	2.8	0.01
Self Efficacy Control Group	46.0	50.0	3.0	*
Outcome Expectancy Control Group	28.0	28.7	0.8	0.42

* $p < 0.01$
** $p < 0.001$

Table 5: Autonomy

Group	Pretest Mean	Posttest Mean	t Value	p Value
All Participants	5.0	7.5	8.2	**
Experimental Math Concepts I	5.3	8.5	8.6	**
Experimental Math Concepts II	4.5	6.8	3.5	*
Control	4.8	6.6	2.8	0.01

* $p < 0.01$
** $p < 0.001$

Discussion

The researcher in this study theorized that preservice elementary teachers who had taken a semester-long mathematics course emphasizing a constructivist approach to instruction would realize a decreased level of math anxiety and gains in perceived teaching efficacy and autonomy over those who had taken a teacher-centered course based on a more traditional lecture-recitation model of instruction. Although the results of this study did not unequivocally support that conjecture, they are encouraging, curious, and thought provoking.

Foremost of all, although only in autonomy did students in the experimental courses significantly outperform their counterparts in the control group, participants, analyzed collectively, experienced a significant decrease in math anxiety, together with a significant increase in mathematics teaching efficacy and autonomy. Examining the subscales of the AMARS and MTEBI it was found that participants, when viewed collectively, revealed a significantly lower level of Math Test Anxiety and Numerical Anxiety and a significantly higher level of Self Efficacy. They did not, however, realize a decrease in Math Course Anxiety, probably because students in the Experimental Math Concepts II actually exhibited greater Math Course Anxiety at the conclusion of the study. Students, in general, did not show a gain either in Outcome Expectancy.

A rather surprising outcome of this study was the profound effect the instructor apparently had in decreasing students' math anxiety and strengthening their belief in their ability to teach children mathematics. Control-group students actually realized the steepest decline in math anxiety of all three classes, so the overall decrease in math anxiety was not due to the majority of participants being included in the experimental courses but was probably due to the instructor's personality and teaching style. It is likely that the increase in mathematics teaching efficacy and decrease in math anxiety among all students was due in great part to the instructor's ability to communicate and clarify mathematical ideas, his emphasis on deep conceptual understanding and the interconnectedness of mathematical concepts, and his various representations and approaches to problems; in sum, his experience teaching mathematics (and other content areas), combined with a calm and reassuring disposition, may have had the most pronounced effect on students' mathematics anxiety and teaching efficacy. It is fascinating that students in Experimental Math Concepts II did not realize a gain in mathematics teaching efficacy, even though throughout the semester they were actively involved teaching classes, presenting problems on the board, and collaborating on problems in small groups. Conversely, control-group students experienced a significant increase in mathematics teaching efficacy; this was startling because, except for about ten minutes of a 75-minute class period, these students most often listened passively to the instructor present new content or solve problems on the board.

Another result evident from this study was the strong interaction between content and instruction. In the experimental section of Math Concepts I the constructivist instructional strategies were resoundingly successful; students became less anxious about math, more confident in their ability to teach it, and more empowered with regard to their own learning. From the instructor's perspective students seemed to enjoy working with one another and being more actively involved during the class period. In personal interviews conducted at semester's end almost all students remarked that they preferred the constructivist instructional approach to a more traditional one because they had learned more mathematics, were more involved, and had a more pleasant experience. Math Concepts I was mostly a review course, except for sets, logic, and nondecimal bases. For this reason students appeared to be more comfortable teaching the content and participating in small group and whole-class discussions.

The constructivist instructional approach did not have the impressive results in Experimental Math Concepts II that it did in Experimental Math Concepts I. In Experimental Math Concepts II, however, the content was less familiar; students had little exposure to probability and statistics and many expressed an intense loathing for the two-column proof geometry forced upon them in high school and did not welcome a second venture into geometry. They appeared to struggle with key concepts, be less secure about teaching the class, and were sometimes reticent about engaging in whole-class discussion or putting problems on the board. Although many students voiced their approval of the instructional approach, some disliked being "guinea pigs" and complained that it would have been easier to understand the content if the instructor had taught the class and solved the problems on the board, instead of allowing students to do so. The contrast with Experimental Math Concepts I was even more pronounced because Experimental Math Concepts I was a much larger class (32 students) than Experimental Math Concepts II (20 students) and students in Experimental Math Concepts II were also taking the course with many of the same students and the same instructor as in the preceding semester, so it might be expected that the Experimental Math Concepts II classroom would have been more relaxed and secure than that of Experimental Math Concepts I.

In the broader scheme of things this study may cause those of us in the math education community to pause and reflect about the rewards and challenges of constructivist instruction at the university level. Constructivist instruction may falter, as it did in Experimental Math Concepts II because there was not the right interaction of students, teacher, curriculum, and instruction, but when it works, as it did in Experimental Math Concepts I, it is exciting, energizing, and productive.

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