The Use of Problem Solving Strategies in Teaching Mathematics

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A review of the research literature suggests that teachers need to provide students with engaging problems, facilitate their discovery of analysis methods, and encourage classroom discussion and presentation of their approaches to solving problems. Two separate studies compared differences in mathematics test scores involving students randomly assigned to experimental and control conditions using a causal-comparative design. The results from both studies indicated that mathematics test scores were significantly higher for the groups of students who learned problem solving strategies. Confidence intervals, effect sizes, and bootstrap estimates are reported.

Numerous studies in mathematics education have examined the factors that are essential for learning, especially in the area of problem solving (Hudgins, 1977). For example, according to several cognitive based studies, meaningful learning is reflective, constructive, and self-regulated (Bransford & Vye, 1989; Davis & Maher, 1990; Hiebert et al., 1996; Marzano, Brandt, & Hughes, 1988; Rickard, 1995; Wittrock, 1991). Other studies have indicated that specific transfer of knowledge paradigms exist for the assessment of learning (Levine, 1975; Stolurow, 1966) and that contemporary research designs can be useful to assess transfer of learning tasks (Cormier & Hagman, 1987; Gick & Holyoak, 1987). Brooks and Dansereau (1987) have further identified four general types of learning transfer: (a) content-to-content; (b) skills-to-skills; (c) content-to-skills; and (d) skills-to-content. Snow (1989) conceptualized the learning process to include concept formation, procedural skills, learning strategies, self-regulated functions, and motivational orientations. Rosenshine, Meister, and Chapman (1996) recently reviewed numerous intervention studies and found overall that teaching students cognitive strategies for generating questions about the material improved their learning comprehension and understanding.

Identifying the important information in a problem and using that information to attempt a solution is basic to successful problem solving. Subsequent use of that information in a new problem under different circumstances presents an even higher level of problem solving skill. Problem solving, in fact, has been shown to involve at least three stages: understanding the problem, solving the problem, and answering the question (Charles, Lester, & O'Daffer, 1987; Whitener, 1989).

Palumbo (1990) further reviewed the relevant issues in problem solving research, especially the distinction between specific and generalized problem solving which focuses on the strategy required to most effectively solve a particular type of problem. Early work by Bloom and Broder (1950) has also indicated the ways in which students provide solutions to their problems: (a) gaining an understanding of the nature of the problem; (b) obtaining an understanding of the ideas contained in the problem: (c) attempting a general approach to the problem (e.g., guessing, working backwards, logical reasoning, looking for patterns); (d) using an implementation approach (no work shown, possibilities overlooked, strategy not clear); and (e) having a positive attitude and motivation toward solving the problem. Consequently, effective assessment of problem solving ability appears to require more than simply an examination of right/wrong answers given by students (Szetela & Nicol, 1992).

A further review of the literature indicated that for problem solving strategies to be effective in mathematics they must be taught (Frederikson, 1984). Rickard's (1995) case study results revealed that a teacher generally structures teaching around *their own* problem solving goals and beliefs, and not necessarily those specified in the curriculum. These findings indicated that we can not assume that a teacher has taught the necessary strategies nor allowed students the opportunity to explore and discuss their methods and solutions to a problem.

Biehler and Snowman (1990) and Ormrod (1990) have provided specific mathematics problem solving strategies that teachers can use. Their research involving 9^{th} and 10^{th} grade public school children enrolled in Algebra I classes indicated that students who are aware of certain problem solving strategies are more effective in working algebra problems. Overall, their findings further suggest that teachers who want students to think critically must explicitly emphasize problem solving, use varied examples, and verbalize their methods and strategies, especially if they want students to generalize, i.e., transfer, what they have learned to new and different problems.

Effective teaching, therefore, should include both the teachers' involvement in providing engaging problems and strategies using various subject matter, as well as, the teachers' facilitation of students to become more aware of *their own* metacognitive strengths and weaknesses in problem solving. Basically, in the teaching of problem solving strategies, students should be provided an opportunity to express their own strategies. The problem solving skills most commonly cited as being needed by students include: identifying the problem; distinguishing relevant from irrelevant information; choosing main points; judging the credibility of sources; making inferences from information given; observing accurately; interpreting observations; and making value judgments (National Center for Research to Improve Postsecondary Teaching and Learning, 1989-1990).

Hiebert et al. (1996) argued that reform in curriculum and instruction in mathematics should be based on allowing the student to "*problematize*" the subject, rather than mastering skills and applying them. Their method involved allowing students to contemplate why things are, to inquire, to search for solutions, resolve incongruities, and to communicate their problem solving method(s) to others. They advocated an approach based upon Dewey's "*reflective inquiry*" which involves giving engaging problems, dilemnas, and questions for the students to solve. The features of this approach are: identifying problems; active studying of the problem; and reaching a conclusion. In this context, the teachers' role is to facilitate students' analysis of the adequacy of the methods to achieve a solution to a problem. That is, the teacher should help the students to develop their own problem solving strategies.

In a recent review across several decades of research literature, Alexander (1996) addressed the role knowledge plays in learning and instruction. Findings indicated that the knowledge a learner possesses affects what information they attend to in a problem, how that information is perceived, what is judged to be relevant or important, and what is understood and remembered. One further aspect of this review suggests that a student's knowledge of topics, procedures, or strategies can be influenced by instruction. Problem solving strategies are therefore important components in the student learning process and are important factors to consider when teaching mathematics.

One could easily assume that brighter students naturally excel at problem solving in the classroom because of their high level of achievement and exemplary metacognitive ability. Related research characterizing individuals with exemplary meta-cognitive ability indicate they are able to: perceive large meaningful patterns; reach solutions rapidly; represent problems at a deeper level; spend more time analyzing a problem; and possess stronger self-monitoring skills (Chi, Glaser, & Farr, 1988); display their ability to learn in specific domain areas (Minsky & Papert, 1974); are better at judging the difficulty of a problem (Chi, Glaser, & Rees, 1982; Glaser, 1987); and use memory more than a general reasoning process (Posner, 1988). As a result of these findings, it seems reasonable to assume that brighter students would not benefit from instruction in problem solving strategies, however, this has never been researched. In our investigation of the use of problem solving strategies in teaching mathematics, two separate studies were conducted. We examined the effect of direct instruction of problem solving strategies on mathematics test score performance among two different groups of students: high school students and accelerated early college entrance high school students, respectively. We specifically hypothesized that students given problem solving strategy instruction would have higher average test scores on a mathematics test than students who did not receive such instruction. This approach was employed because of the research focus of our study and the overemphasis on single studies in educational research (Rosnow & Rosenthal, 1989).

We further felt that our study has significant educational importance due to the findings from the Third International Mathematics and Science Study (Beaton, et al., 1996). In 1994-1995, achievement tests in mathematics and science were administered around the world to students in classrooms. Performance expectations centered around four areas: knowing, performing routine procedures, using complex procedures, and solving problems. The United States, in comparison to other world countries, ranked among the last in mathematics test scores. This may be due more to how we teach rather than to what we teach (i.e. content).

Study One

Subjects and Design

The subjects in the first study were seventy-eight (78) 10^{th} grade high school students who were selected for admission into an Academy of Mathematics and Science, an early college entrance program for gifted and talented students, during the spring semester. Students were accepted into the Academy based on SAT scores, personal interviews, letters of reference, and high school transcripts. The students left their respective high schools after completing 10^{th} grade to attend the Academy full time, which was housed, on a university campus. While in the Academy, students would take university undergraduate courses in mathematics, science, and the humanities. Students who graduated from the Academy after two years concurrently received their high school diplomas and two years college credit. The average SAT-Quantitative score was 640 and the average SAT-Verbal score was

550. Students ranged in age from 15 to 18 years with 37% females, 4% African-American, 9% Hispanic, and 12% Asian-American.

Students met in a large auditorium for orientation the first week of classes at the university. After a brief presentation, students were directed to one of two different classrooms based on randomly picked seats.

The students were randomly assigned to either a control group (n=43) which *only* received the mathematics test or an experimental group (n=35) which was instructed in problem solving strategies, followed by the mathematics test. The use of an experimental control group design to investigate the effectiveness of instructional interventions has been used before (Schumacker & Miller, 1992).

Materials

A mathematics test, which included 13 problems selected from an Algebra I textbook used by high school students (Coxford & Payne, 1990), was used as the dependent measure. The types of mathematics problems selected involved skills-to-skills (e.g., arithmetic to algebra) transfer in mathematics knowledge such as (a) determining profit and loss, (b) the volume of water in different sized containers, and (c) determining the area of different shapes. Students were required to indicate their problem solving strategies for each math problem in the test booklet, i.e., methods of analysis and steps taken to answer each problem, not just provide a right/wrong answer. Each math problem had five questions worth 1 point each if correctly answered (5 points per math problem), for a maximum possible score of 65.

A standardized set of overhead transparencies was prepared which presented different strategies for the various types of mathematics problems. The problem solving strategies were adopted from Biehler & Snowman (1990) and Ormrod (1990). The strategies involved information on how various mathematical problems could be reorganized, thus leading to clues on how to solve them. Each problem on the test was different and therefore had a different problem solving strategy associated with it, so as to minimize any "teaching to the test" effect. An example math problem and problem solving strategy is in the Appendix.

Procedures

Students were directed to one of two different classrooms based upon their randomly assigned auditorium seating. One classroom represented an experimental group while the other a control group. Two different teachers were also randomly assigned to one or the other classroom. The problem solving strategies for various types of mathematics problems were presented to students in the experimental group using standardized overhead transparencies. The random assignment of the two teachers and the standardization of the materials were done to reduce any bias or teacher effects in the study. The teacher in the experimental group indicated that students had no problems or concerns about the problem solving strategy instruction provided. The two teachers and the principal author scored the mathematics tests using a scoring rubric.

Study Two

Subjects and Design

The subjects in the second study consisted of fifty-two (52) 10th grade high school students completing an Algebra I class during the fall semester. The high school students were randomly assigned to either the control group (n=25) or the experimental group (n=27). The same exact design and procedures were followed as in the first study. These students were from a different academic setting, but were of similar age and demography as those in the first study. Although the high school grade point averages were similar for students in both studies, most of the high school students in the second study had not taken the SAT. These students mainly differed from students in the first study in that they were *not* selected to attend an early college entrance program targeted for gifted and talented students.

Materials and Procedures

The mathematics test used in the first study was used in the second study. The same procedures were followed with the exception that students did not attend a university orientation session. Two high school teachers were randomly assigned to one or the other classroom. The problem solving strategies for the various types of mathematics problems were again presented to students in the experimental group using the standardized overhead transparencies. The teacher in the experimental group indicated that students had no problems or concerns about the problem solving strategy instruction provided. The two teachers and the principal author scored the mathematics tests with the same scoring rubric used in the first study.

Results

The Cronbach (1951) Alpha internal consistency reliability coefficient for the academy student scores in the first study was .84. For the high school student scores in the second study, Alpha was .85. The mean test score difference between the groups in the first study for the Academy students was 13.86. The mean test score difference between the groups in the second study for the high school students was 12.18. The test score means and standard deviations for the experimental and control groups in both studies are also presented in Table 1.

Based on the sample characteristics from each condition in these studies, O'Brien's (1981) test for unequal variances was performed (Beasley, 1995;

Ramsey, 1994). These tests verified that the experimental groups had significantly less variability in their math scores for both the Academy [$F(1,76)=9.31$, $p=.0031$] and high school students [$F(1,50)=5.14$, $p=.0028$]. Thus, it is reasonable to assume that there were differences in the variability of performance between the groups in each study.

In order to test mean differences under these circumstances, independent *t*-tests for unequal variances were performed using Satterthwaite's (1946) correction for the degrees-of-freedom (*df*). A statistically significant mean difference was found between the experimental and control group in both the first ($t=4.74$, $df=64.07$, $p=.0001$) and second ($t=3.05$, $df=36.23$, $p=.004$) studies. Thus, students in the experimental groups of both studies who received instruction in problem solving strategies had significantly higher mean test scores than students in the control groups, after the correction for unequal variances. Students in both experimental groups also demonstrated less variability in their scores, hence a need to interpret results using unequal variances. The results from both studies taken together indicate that the use of problem solving strategies in teaching mathematics is effective in improving mathematics achievement.

Post hoc Analyses

Our findings are based upon significance testing, which has recently been scrutinized because the researcher controls the sample size, level of significance, and power of the tests (e.g., Huberty, 1987; Robinson & Levin, 1997; Thompson, 1988, 1989a, 1989b, 1993; 1997). It has been recommended instead that effect sizes, confidence intervals, and bootstrap estimates be provided to better indicate the practical and meaningful interpretation of results (Kirk, 1996). Therefore, the mean differences between the groups, their respective effect sizes, and bootstrap estimates were computed and presented in Table 2.

Because mean differences were of primary interest, effect sizes were computed using a program by Mullen and Rosenthal (1985) in order to compare the results of both studies. The standard metric used for calculating the effect sizes was the standard deviation of the control group (Glass, McGaw, & Smith, 1981; Wolf, 1986). Interpretation of the effect size was based on the amount of standard deviation units the experimental group scored above the control group. It should be noted that in both studies, the control group standard deviation was previously determined to be significantly larger than the experimental group. Therefore, the mean differences reported provide conservative estimates of effect sizes.

Table 2 indicates that the Academy experimental group scored .83 standard deviation units above their respective control group, and the high school experimental group scored .69 standard deviation units above their respective control group. The gain associated with these effect sizes can be obtained by referring to a table of areas under the normal curve. Looking in a table of the areas under the normal curve, a .83 effect size corresponds to .30 of the area above the mean (above the 50th percentile). Thus, an effect size of .83 implies that if an average student in the control group were to receive instruction on problem solving strategies, they would now score at the 80th percentile of the control group. Similarly, the .69 effect size for the high school students corresponds to .25 of the area above the mean, and thus an effect size of .69 implies that if an average student in that control group were to receive instruction on problem solving strategies, they would now score at the 75th percentile of that group.

Table 1. Means and Standard Deviations of Experimental and Control Groups

Study	*n*	*Mean*	*SD*
1. *Academy*			
Control	43	43.14	16.76
Experimental	35	57.00	8.33
2. *High School*			
Control	25	45.60	17.69
Experimental	27	57.78	9.54

Bootstrap estimates and confidence intervals are also reported in Table 2 to further examine the stability of these findings. The bootstrap estimate (θ^*_B), the standard error of the bootstrap estimate, $SE(\theta^*_B)$, bias or the sampling error ($\theta^*_B - \theta$), where θ represents the contrast mean difference, and the 95% confidence interval [$\theta \pm 1.96SE(\theta^*_B)$] for each contrast were computed using programs by Lunneborg (1987). The bootstrap estimates were based upon 1,000 resampling trials.

Bias or sampling error is determined when bootstrap estimates are compared to the actual mean differences. The bias or difference between the bootstrap estimator and the sample mean differences were .20 = (14.06 - 13.86) and .10 = (12.28 - 12.18), respectively, which indicates that the magnitude of difference reflected in the means are reasonably stable estimates of the mean differences observed in the two studies (Mooney & Duval, 1993).

The 95% confidence intervals reflect the range of variation one could expect in the mean differences if conducting 1,000 replicated studies (the number of bootstrap resampling trials). The range of values for the lower and upper confidence interval estimates in both studies were similar. In the first study, the confidence intervals indicate that the mean difference between the two groups could vary between 8.12 and

Table 2. Contrasts, Effect Sizes, and Bootstrap Estimates for Experimental vs. Control Groups

Study Contrast	Effect Size[a]		Bootstrap Estimates[b]			
(1) Academy	Mean Difference	Δ	Estimator (θ^*_B)	$SE(\theta^*_B)$	Bias	95% CI
Experimental vs. Control	13.86	0.83	14.06	2.93	0.20	(8.12, 19.60)
(2) High School Experimental vs. Control	12.18	0.69	12.28	3.50	0.10	(5.32, 19.04)

Note. **a** The effect sizes (Δ) are based upon the mean difference divided by the standard deviation of the control group. (see Glass et al., 1981 for rationale on choice of metric).
b Based on 1,000 bootstrap resampling trials.

19.60. In the second study, the confidence intervals indicate that the mean difference could vary between 5.32 and 19.04.

Overall, the statistically significant mean differences, the small bootstrap estimator differences, and the 95% confidence interval values from both studies indicate strong evidence that the students in the experimental groups who were taught problem solving strategies performed better than those students in the control groups on the mathematics test.

Discussion

In two separate studies, students in the experimental group who were provided standardized instruction on problem solving strategies scored on average higher than students in a control group on a mathematics problem solving test. The first study involved 10th grade high school students who were considered above average or gifted and talented, and who had been selected to begin an early college entrance program rather than return to high school for their junior year. These students possessed high academic achievement levels and metacognitive skills, yet the experimental group of students still benefited from learning problem solving strategies. The second study involved 10th grade high school students who would be returning to complete high school. Although these students were in a different academic setting, those in the experimental group also benefited from learning problem solving strategies. The "lecture-type" presentation of problem solving strategies was practical and effective in getting the students to think about how to solve various mathematics problems and improved their mathematics test scores. The effect sizes, confidence intervals, and bootstrap estimates presented from both studies strengthen the ability to generalize the findings from these two studies to other 10th grade high school age students taking Algebra I classes.

Our findings suggest that teachers should be trained to explicitly emphasize problem solving strategies in teaching mathematics. Previous research by Biehler & Snowman (1990) and Ormrod (1990) was supported. Hiebert et al. (1996) supports the idea of a teacher using engaging problems and facilitating a students "*reflective inquiry*" so that they can discover methods to solve a problem (also see, Hiebert et al. 1997, Prawat, 1997, and Smith, 1997 for further discussion). Other research has suggested that a teacher should use a variety of examples and verbalize their methods to increase students' ability to learn and to solve problems. Hattie, Biggs, and Purdie (1996) also provide additional research support in their review of the effects of interventions on student learning. They broadly classified instructional interventions as *cognitive*, *metacognitive*, and *affective* in nature. The approach taken in this study could be characterized as a cognitive intervention because specific *tactics* were taught, which were grouped and purposefully used as *strategies* (Derry & Murphy, 1986; Snowman, 1984). Our findings should encourage teachers to address the need for using problem solving strategies during instruction (i.e., model and verbalize strategies for problem solving to their students). Given the previous research literature cited and our findings, we recommend that teachers practice giving engaging problems to students to solve, facilitate discovery of problem solving strategies and methods, use varied problem examples, and verbalize their methods and strategies, as well as, those of other students. We highly recommend that university teacher preparation programs instruct student mathematics educators in these approaches in their curriculum and instruction course work.

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APPENDIX

Math Problem and Problem Solving Strategy

Mathematics Problem One

Assume that you have just purchased a lot on which you plan to build a home. You must tell the lender the area of your lot. Unfortunately, your lot is in the shape of a parallelogram. How do you determine the area of your parallelogram shaped lot?

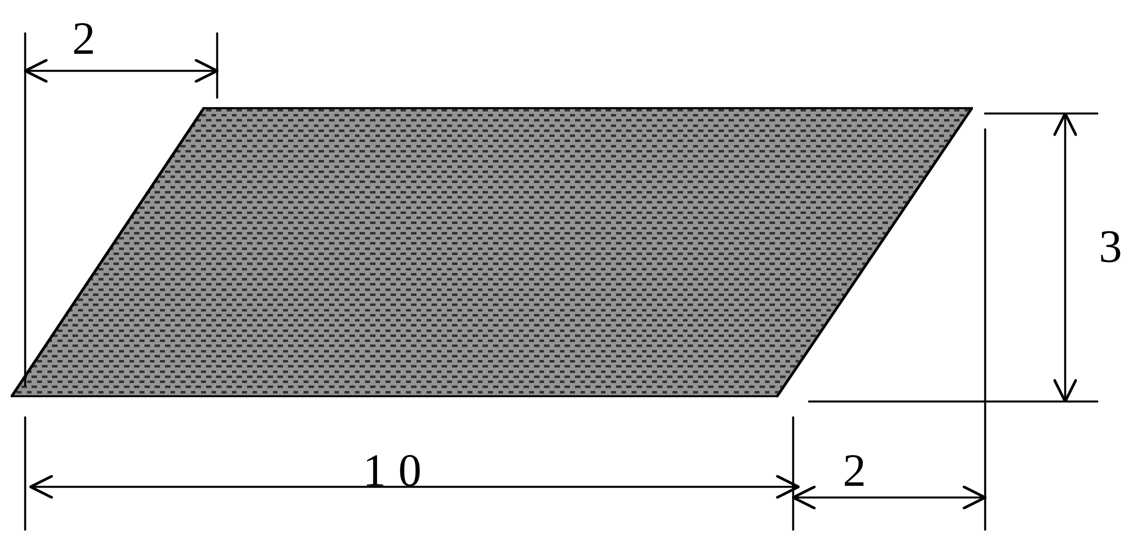
1. What is the problem?
2. What do I need to know?
3. What steps can I take to solve it?
4. What other methods could be used?
5. What is the area of your lot?

Problem Solving Strategy:

1. Convert the parallelogram into a rectangle.
2. Use the formula for determining the area of a rectangle:
   (Area = Length x Width).

Method and Solution:

1. Drop a line perpendicular to side(length).
2. Move newly formed right triangle area to opposite side
   to form a rectangle.
3. Use formula for determining area of a rectangle:
   (Area = Length x Width)



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