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ABSTRACT

Potential gender-related differences in the process of mathematical word problem solving were investigated. Sixth and eighth graders (n=302) solved 2-step mathematical word problems using a 9-step problem solving plan. The nine steps were: (1) identify the facts; (2) identify the question; (3) draw a diagram; (4) choose the operations; (5) write an open sentence; (6) estimate the answer; (7) compute the answer; (8) state the answer; and (9) validate the answer. A 2 x 2 between-subjects multivariate analysis of variance was computed to determine the effects of gender and grade level on the subjects' scores on each of the nine steps of the problem solving plan. There was a significant gender-related difference in the overall process of problem solving in favor of females. Univariate "F"'s for each of the nine steps were not significant. Although there were no significant differences at any of the individual steps, the combined use of the same steps produced a gender-related difference. It is concluded that the use of a step-by-step problem solving plan might be gender biased. (Author/SLD)

Gender-Related Differences in Problem Solving at the 6th and the 8th Grade Levels

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Gender-Related Differences in Problem Solving at the 6th and the 8th Grade Levels

Gender-related differences in mathematical ability have been widely researched. Although no gender-related differences are manifest for overall mathematics ability, girls tend to outscore boys on tasks that are algorithmic in nature, including computation, and boys tend to outscore girls in problem solving and analysis. The research investigating gender-related differences in problem solving ability focuses exclusively on the product of mathematical word problem solving, the problem solution. This study investigated potential gender-related differences in the process of mathematical word problem solving. Sixth and eighth graders (n=302) solved two-step, mathematical word problems using a nine step problem solving plan. The plan was composed of nine steps, which appeared in textbooks and the literature of problem solving; 1) Identify the facts, 2) Identify the question, 3) Draw a diagram, 4) Choose the operations, 5) Write an open sentence, 6) Estimate the answer, 7) Compute the answer, 8) State the answer, and 9) Validate the answer.

A 2 X 2 between subjects MANOVA was computed to determine the effects of gender and grade level on the subjects' scores on each of the nine steps of the problem solving plan. There was a significant gender-related difference (p < .0038) in the overall process of problem solving in favor of females. Univariate Fs for each of the nine steps were not significant (p <.01). Although there were no significant differences at any of the individual steps, the combined use of those same steps produced a gender related difference. It was concluded that the use of a step by step problem solving plan might be gender biased.

There is considerable interest within the education community concerning gender-related differences in mathematical ability. Although the topic has been highly researched, attempts to determine the nature of gender-related differences in mathematical ability have obtained mixed results. However, several tendencies are apparent.

In a review Aiken (1971) found that females tended to be superior in computational, algorithmic activities while males were somewhat superior in arithmetic reasoning and application and that the gender-related difference in arithmetic reasoning tended to increase with age. Fennema (1974) concluded that gender-related differences tended to favor females on lower level mathematical skills and males on higher level mathematical skills including problem solving, and that the proportion of researchers reporting significant differences increased with the age and grade level of the subjects. Maccoby and Jacklin (1974) found that in studies involving grade school subjects males exhibited some superiority in arithmetic reasoning and that in studies with high school subjects males were more consistently superior to females in arithmetic reasoning.

Badger (1981) reviewed British research on gender-related differences and found that girls excelled at computation while boys excelled at application and the incorporation of computational and reasoning skills to solve word problems. These differences became manifest at age 11.

The National Assessment of Educational Progress (NAEP) (1986) reported that males outperformed females at moderately complex reasoning and multi-step problem solving at both ages thirteen and seventeen.

In a meta-analysis Linn and Hyde (1989) found that gender-related differences in mathematics ability were narrowing over time, a conclusion also reached by the NAEP (1986) and that no gender-related differences in overall mathematical ability existed when all levels of skills were considered simultaneously. Again, however, females were found to be superior at computational skills at all age levels and males were found to be superior in problem solving ability at the high school level.

Hyde, Fennema and Lamon (1990) and Hyde & Fennema (1990) reported that females were superior to males in computational skills in both elementary and middle schools. There were no gender differences in the understanding of concepts at any age level. Males surpassed females at the high school level in problem solving. No differences in problem solving were found at either the elementary school or the middle school levels.

In summary the literature reviews and meta-analyses indicate that females tend to excel at algorithmic tasks such as computation at all levels and that males tend to excel at application and problem solving. Male superiority in problem solving first appears in the upper elementary grades and increases with grade level.

Individual studies concerned specifically with word problem solving offer similar conclusions. Marshall (1984) compared the scores of 286,767 sixth graders on computational items and also on story problem items from the California Assessment Program's Survey of Basic Skills. The females tended to score higher than the males on computation items while the males tended to score higher than the females on word problem items. Armstrong (1981) reported results of the Women in Mathematics Project, a national survey conducted by the Education Commission of the States in 1978. Based on items from standardized tests, females age 13 (approximately eighth grade) scored significantly higher than males on both computational skills and also on spatial abilities. Males significantly outperformed females in solving one and two-step routine story problems. These results paralleled those of the NAEP (1986) in which female subjects, age 13, outperformed male subjects of the same age on computation skills while male subjects, ages both 13 and 17, outperformed female subjects of the same age in solving one and two-step word problems.

Moore and Smith (1987) analyzed data for gender-related differences collected in the National Longitudinal Study of Youth Labor Force Behavior. The data were obtained from both the Mathematics Knowledge and the Arithmetic Reasoning subtests of the Armed Services Vocational Aptitude Battery. No significant differences were found on scores on Mathematics Knowledge, but an ANOVA did indicate significant main effects for gender in ninth grade and beyond for scores on the Arithmetic Reasoning Subtest. The Arithmetic Reasoning Subtest was comprised of multiple choice arithmetic word problems. The authors concluded that ability to solve arithmetic word problems increased with age for both sexes, and also that the magnitude of the gender-related difference in word problem solving ability increased with educational level.

Doolittle and Cleary (1987) found that on selected classifications of items which appear in the Assessment Mathematics Usage Test word problems were relatively easier for males than for females and that the computation problems were relatively easier for females than for males.

Male superiority in word problem solving is not only apparent in general mathematics tasks, but also in algebraic tasks. Phillips, Uprichard and Blair (1983), measured the ability of 320 high school algebra students to solve algebraic word problems. On a measure of eight types of algebraic word problems commonly found in algebra textbooks the males overall averaged 5.16 points, of a possible 72, higher than the females.

Swafford (1980) also tested high school algebra students using consumer word problems. These consumer problems were described as word problems dealing with buying, selling, interest rates, and other topics concerning the uses of money. Boys did better than girls at the beginning of the course in algebra and boys improved even more than the girls by the end of the course in algebra. These results are consistent with the research which indicates that gender-related differences exist in word problem solving ability and that these differences increase in magnitude over time.

The aforementioned studies consistently indicated significant gender-related differences in mathematical word problem solving ability beginning at the upper elementary level and continuing into high school. This gender-related difference in verbal problem solving ability in favor of males first appears in the sixth grade (Marshall 1984). The superiority of males in word problem solving ability persists through the middle grades (Armstrong, 1981; NAEP, 1986) and into high school and college (Moore & Smith, 1987; Phillips, et. al., 1983).

Purpose

Virtually all of the research substantiating this gender-related difference in word problem solving ability has utilized dichotomously scored mathematical word problems. This approach, although logical, fails to address the possibility that gender-related differences may exist in the actual process of problem solving.

This study attempted to investigate potential gender-related differences in the process of solving routine word problems. A problem solving plan was synthesized from problem solving plans which are present in textbooks and in the literature on mathematical problem solving. Considering that females tend to excel at algorithmic mathematical tasks, a step by step problem solving plan that provides an algorithmic approach for solving word problems might exert a gender-differentiated influence on problem solving in favor of females.

Problem Solving as a Process

The necessary first step to investigate gender-related differences in the process of problem solving is to define the process. Although an unequivocal definition of the problem solving process is neither available now, nor likely to become so, solving a word problem is a multistep process (Kantowski, 1977). Many models of the processes used to solve word problems have been proposed. These models can be classified into two categories, prescriptive and descriptive (Uprichard, Phillips & Soriano, 1984). Prescriptive models recommend how a problem solver should proceed when solving a problem. Descriptive models describe problem solving as it is hypothesized to operate, or as it is observed in operation.

Prescriptive Plans

Prescriptive plans are not highly defined, research documented, psychological models, but they have been accepted by both textbook publishers and teachers as reasonable and useful approaches to problem solving. Schimizzi (1988) recommended that research should investigate the effectiveness of these step by step problem solving plans. The National Council of Teachers of Mathematics (NCTM)(1989) recommended in the Curriculum and Evaluation Standards for School Mathematics (1989) that instruction in problem solving should include classroom discussion about, and the use of, problem solving strategies. Florida's Model Curriculum (1991) recognizes the pervasive role of problem solving in school mathematics and lists eight problem solving strategies to be used at the elementary level; Acting it out, Making a physical model, Drawing a diagram, Making a table or a chart, Looking for a pattern, Guess-check-revise, Working backwards, Solving a simpler problem and Generalizing. Similarly, the Arizona Essential Skills (1991) encourages the development of problem solving skills in elementary school and recommends strategies such as; Role playing, Drawing pictures, Using models, and Writing mathematical sentences.

In contrast to the general heuristics listed above, prescriptive models found in textbooks list steps for students to follow when solving word problems. These plans are designed for use with the routine word problems, problems which can be solved through the direct application of algorithms, found in the same textbooks. A review of the sixth and the eighth grade mathematics textbooks adopted for use in 1990 by the school district which cooperated in this study (Algebra, Addison Wesley; Invitation to Mathematics, Scott Foresman; Pre-Algebra, Heath; and Mathematics Today, Harcourt, Brace, Jovanovich) revealed that step by step plans varied from text to text, but there were several commonly recommended steps and strategies.

The similarity of plans is no doubt due to the influence of Polya's (1945) seminal work on problem solving. Textbook authors have used Polya's four phases of problem solving as a framework for building step by step plans workable for students. The four phases of problem solving proposed by Polya are; 1) Understand the problem, 2) Devise a plan, 3) Follow the plan, and 4) Look back.

Abbott and Wells (1985) (Harcourt, Brace, Jovanovich) used the following four steps (paraphrases of Polya's); 1) Read the problem, 2) Plan, 3) Find the answer, and 4) Check the answer. Abbott and Wells also provided suggestions for working through each step of their plan. Students were prompted to focus on identifying both the given facts and the question when reading the problem. Drawing a diagram or model was recommended as help in planning what to do. Additional recommendations included; Choosing an operation, Writing an equation, Solving the equation, Estimating, and Checking that the answer makes sense.

Bolster, Crown, Linquist, McNerney, Nibbelink, Prigge, Rahlfs, Robitaille, Schultz, Swafford, Vance, Wilson, & Wisner (1985) (Scott Foresman) prescribed a five step plan; 1) Read, 2) Plan, 3) Solve, 4) Answer, and 5) Look back. These steps subdivided Polya's step 3, Follow the plan, into Solving the problem and Answering the question. Recommended strategies included; Choosing an operation, Writing an equation, Estimating the answer, and Verifying that the answer is sensible.

Lowry, Ockenga and Rucker (1986) (Heath) offered no problem solving plan per se, but included instruction on problem solving strategies. These strategies included; Focusing on the facts, Drawing a picture, Choosing an operation, and Writing an equation.

Keedy, Bittinger, Smith and Orfan (1985) (Addison Wesley) provided a four step plan for solving word problems; 1) Choose a variable for the unknown, 2) Translate the problem into an equation, 3) Solve the equation, and 4) Check the answer with the original problem. They also recommended that students read the problem carefully to decide which information is to be used, and draw a diagram of the problem.

The Phillips and Uprichard Model for Problem Solving (Phillips, Uprichard & Johnson, 1974; Soriano & Phillips, 1982; Uprichard et al., 1984) included eleven steps intended to make Polya's plan workable for children. Steps for understanding the problem were; Read the problem, Paraphrase the problem, Circle the facts, List the known facts, and List the unknown facts. Steps for devising a plan were; Diagram the problem, Estimate an answer, Choose the operations, and Write an equation. Following the plan involved Solving the equation and Writing the answer. Looking Back was operationalized as Comparing the answer to the estimate and Checking the computations.

The problem solving plans discussed here are compared in Table 1.

Insert Table 1 about here.

Descriptive Plans

A second strand of the problem solving literature consists of theoretical models of the processes students use to solve problems and of empirical models from studies describing problem solving strategies used by students.

Theoretical Models

Kintsch and Greeno (1983) described the process of solving an arithmetic word problem with a three component processing model. The first component is the translation of the sentences comprising the problem into simpler propositions, or units of understanding. A proposition could be a statement of numerical value (e.g., the cardinality of set A is 3) or it could be a statement which relates one quantity to another (e.g., the value of A is less than B). The second component is the construction by the problem solver of a conceptual representation of the problem situation. A conceptual representation includes both the propositions and the relationships between them. This representation activates a schema identifying the problem as a specific type. The third component of the processing model is the activation of the appropriate schema necessary to solve the problem.

Gagne (1983) described three mental actions necessary for problem solving which are very similar to the three components proposed by Kintsch and Greeno (1983). Gagne suggested that a student must first translate a verbal problem statement into a mathematical expression. This translation of a verbal problem statement to a mathematical expression parallels Kintsch and Greeno (1983) except Gagne refers to a representation in the form of a mathematical expression, not a conceptual representation. Gagne's second action, Carry out operations on the mathematical expression, is similar to the third component in the Kintsch and Greeno (1983) model in which a schema is activated to perform the required operations. Gagne's third action is validation of the solution. Gagne stated that estimation of a solution is a way to check on the validity of the overall solution. Kintsch and Greeno omitted verification from their three component model.

Schoenfeld (1985) studied the manner in which problem solvers solve problems, using a problem solving protocol containing the following six components of the problem solving process; Read, Analyze, Explore, Plan, Implement, and Verify. These components parallel those previously discussed. (See Table 2 for a comparison of these theoretical descriptive models as well as the empirical descriptive models which follow.) To translate a word problem into mathematical propositions, the problem must be read and analyzed to determine the facts and the relationships between those facts. Exploration of the relationships inherent in the problem situation assists in the identification of the general problem type. Once the general problem type is recognized the problem solver is ready to plan a method of solution. The fifth component, Implementation, is the computation of the answer. Schoenfeld listed a final component, Verify.

Insert Table 2 about here.

Empirical Studies

Other researchers have observed students solving problems and identified the strategies used. The findings suggest that students use problem solving strategies found in textbooks.

Webb (1979), studying college algebra students, found that after reading the problem (a necessary first step in all plans) students used strategies such as; Drawing a diagram (the most commonly used strategy), Writing an equation, Using an algorithm, and Verifying the solution.

Sherrill (1983) conducted a similar study with seventh grade mathematics students. Sherrill found strategies used by the subjects included; Reading the problem, Drawing a diagram, Writing an equation, Using an algorithm to compute, Counting, and Checking the answer.

As early as the third grade level, the use of strategies becomes apparent in the solution to mathematics word problems. Romberg and Collis (1985) interviewed third graders about their problem solving techniques. Strategies which the students incorporated into their problem solving included; Producing a model of the problem (At this grade level the models were not diagrams but were produced with fingers or counting chips), Writing open sentences, and Using algorithms to compute.

Research on Individual Strategies

Other research has investigated the usefulness of individual strategies recommended by both prescriptive and descriptive plans. Van-Essen and Hamaker (1990) reported that fifth graders achieved higher on a test of mathematics word problems when they were instructed to make drawings of the word problems. Carpenter, Moser, and Bebout (1988) reported that second graders could represent problems directly with open number sentences and that the representation of problems through the use of open number sentences might help children solve word problems by providing them with a symbolic model of their counting and modeling strategies. Muth (1984) found that 54% of the observed variance in sixth graders' ability to solve one-step word problems was due to differences in reading skills (8% unique) and computational skills (14% unique). Quintero (1983) found that there was 66% agreement between finding the solution to a two-step word problem and the ability to restate the problem, and an 87% agreement between choosing the appropriate diagram and solving a two-step word problem.

Problem Solving Model for this Study

The review of the literature revealed that recommendations for word problem solving were similar across textbooks, and descriptive studies on word problem solving supported steps recommended in textbooks. The strategies which appeared in at least two of the prescriptive problem solving plans (Table 1) and which were supported by the descriptive literature (Table 2) were included in the problem solving model used for this study. The eight process steps, in addition to the solution (step 8, State the answer) comprising the problem solving plan for this study are; 1) List (find) the facts that are given, 2) List (decide) what must be found, 3) Draw a diagram (pictorial representation) of the problem, 4) Choose the operations you will use to solve the problem, 5) Write an open sentence, 6) Estimate the answer, 7) Compute the answer, 8) State the answer, and 9) Validate the answer by assessing its reasonableness and its proximity to the estimate.

These nine steps seem to form a logical approach to solving routine arithmetic word problems. The problem solver reads the word problem and identifies the given facts and the question. (For this study the subjects were asked to list both the facts that were given and what is to be found.) This identification is a necessary first step for understanding the problem. The problem solver then analyzes the relationships which exist between the givens and the unknown. Drawing a diagram (a model of the problem situation) is a way to clarify the relationships. The diagram of the problem situation, as well as the understanding which preceded the diagram, suggests to the problem solver which operation(s) are needed to arrive at a solution. The selection of the required operations and the relationships expressed in the diagram lead to the composition of an open sentence, a mathematical representation of the problem situation which symbolically represents the order in which the required operations must be completed. Guided by the open sentence the problem solver ascertains the appropriateness of the plan through estimation. If the estimate is deemed reasonable as a solution, the problem solver will then compute an answer. The result of the computations is then written in the form of an answer appropriate to the specific problem situation. Finally, the problem solver verifies the solution by comparing it to the estimate and evaluating its fit to the question.

The teachers (n=14) of the all the participating classes and a random sample of subjects (n=30) completed questionnaires about their perception of the plan. Prior to data collection, the teachers were given a list of the process steps of the problem solving plan and were asked to respond to three questions; 1) Which of these steps do you consider useful for word problem solving? 2) Which of these steps are covered in the textbook you are currently using? and 3) Which of these steps do you include in your classroom instruction? All of the teachers but one indicated that all of the steps listed were important, in the textbook, and covered in class. The one exception indicated that estimation and verification of the answer were not considered important.

Randomly selected students also completed a questionnaire after using the problem solving plan. Twenty-five of the thirty responded that the order of steps in the problem solving plan made sense and that the plan was useful for solving problems. Two of the five who responded negatively altered the plan by interchanging Choosing and operation and Writing an equation. It was concluded that the teachers and students both perceived the plan as useful in the solution of word problems.

The Word Problems

This study used routine two-step word problems (see Table 3). A routine word problem is one that can be solved through the direct application of algorithms. A two-step word problem is one which requires the use of two operations to arrive at the answer, for example to solve problem 3 (Table 3) you add then divide. The problems for this study were written so that for each possible combination of two operations is represented. The combination of addition-addition was not used because double addition (adding three numbers) was considered one step.

Insert Table 3 about here.

Although routine word problems are only one component of mathematical problem solving as envisioned by the NCTM (1989), the choice of two-step routine problems (Table 3) for this study is supported by several factors. 1) One and two-step routine word problems comprise the majority of word problems presented in textbooks (Stigler, Fuson, Ham & Kim, 1986). 2) The majority of research on gender-related differences in word problem solving ability has also focused on solutions to routine word problems. This study did not attempt to look for differences in solving other types of problems, but to investigate gender-related differences in one approach to problem solving. 3) The modifier "routine" should not be confused with "easy". Many students experience frustration and failure even when attempting to solve "routine" word problems. Some students have no strategies for approaching word problems and as a result make no efforts to solve them. Quintero (1983), using 9-14 year old subjects, found that about 80% solved routine one-step word problems correctly whereas only about 20% solved two-step word problems correctly. This low level of achievement related to two-step routine word problems indicates that a useful approach to their solution is needed.

Method

Sample

Research indicated that the gender-related difference in problem solving ability became apparent as early as the sixth grade. The present study used sixth and eighth grade subjects in an attempt to detect gender-related differences at the critical age level when gender-differences first become manifest.

In the spring of 1990 two entire sixth grades from two different elementary schools and nine eighth grade classes from three different middle schools in a west central Florida school district were administered a data collection instrument composed of the 10 two-step arithmetic word problems listed in Table 3. The sample included 153 sixth grade subjects, 75 males and 78 females, and 149 eight grade subjects, 78 males and 71 females, a grand total of 302. The samples were heterogeneous at each grade level with stanines ranging from two to nine on the Total Mathematics Subtest of the Stanford Achievement Test. The male and female subjects were deemed to be equivalent in terms of overall mathematics achievement based upon both stanine scores and raw scores from the Total Mathematics Subtest of the Stanford Achievement Test. Mean stanines were 5.81 for all males and 5.83 for all females. Mean raw scores were 71.84 for all males and 72.45 for all females.

Procedure

The subjects at both grade levels were given two 50 minute periods on two consecutive days to solve 10 routine, two-step word problems, each presented on a problem solving worksheet. The worksheet was a page containing each step of the nine step problem solving plan followed by space for the required work and response. Approximately the first 10 minutes of the first session were spent working through a sample problem as a demonstration on the use of the problem solving worksheet. This 10 minute introduction was not meant to teach the subjects the steps of the problem solving plan but only to demonstrate the use of the problem solving worksheet. The students were instructed to utilize the plan in their attempts to solve each of the word problems.

Scoring

Each subject's work was scored on each of the nine steps of the problem solving plan on the basis of predetermined scoring criteria. The scorer did not know the gender or grade level of the subjects while scoring. The responses to each of the process steps were scored two, one , or zero. A totally correct response was assigned a "two", a totally incorrect response was assigned a "zero", and a partially correct response was assigned a "one". For example, when writing a number sentence for problem 6 (Table 3), a two point response had to contain the expression $(122-7)\div5$. The expression alone or the expression included in a number sentence, $(122-7)\div5 = n$, was scored "2". A number sentence or expression that only partially expressed the relationships inherent in the problem, for example, the correct response sans parentheses, was scored "1". A missing response or a response that did not contain any of the relationships inherent in the problem was scored "0". The solution step, step eight, was scored as one (correct) or zero (incorrect).

Results

Reliability

Criterion scoring reliability was determined from a sample of 20 student packets randomly selected from the total of 302 scored packets. The 20 randomly selected packets were independently rescored by a mathematics educator from a local state university. Any disagreements between the numerical score assigned to a response by the original scorer and the numerical score assigned to that same response by the criterion scorer were tallied. Of a total 1800 responses (nine responses on each of 10 problems by 20 subjects) there were three disagreements, one on computing the answer, one on writing an equation, and one on estimating. The three disagreements accounted for .16% of the total number of rescored responses. The percent of agreement was computed by subtracting the percent of disagreement from 100%. The resulting percent of agreement was 99.84%.

Internal consistency reliability estimates were computed for nine distinct subsets of responses on the data collection instrument (See Table 4). The reliability of the subset comprised of the solution step was computed with a Kuder Richardson-20 for both the sixth grade subjects (.80), and the eighth grade subjects (.78). Cronbach's Coefficient Alpha was computed for each of the eight subsets of process step responses for both the sixth grade subjects and the eighth grade subjects. The resulting correlation coefficients ranged from .66 to .94 with a median of .86 for the sixth grade and .69 to .96 with a median of .80 for the eighth grade. In addition, an overall measure of internal consistency for the combination of all the steps on all of the problems was computed for the sixth grade subjects (.80), and the eighth grade subjects (.80).

Insert Table 4 about here.

Mean scores

For each of the 302 subjects in the analysis, a step score was computed for each of the nine steps of the problem solving plan. This step score was the mean of the scores assigned to a particular step across the entire 10 problems for that student. A mean step score was then computed for the entire sample by averaging the step scores of all of the subjects on each of the nine steps. These mean scores are listed in Table 5 by gender and grade level.

An overall mean score, the mean of all the steps across all 10 problems, was also computed for both males and females. The overall mean score was 1.43 for females and 1.38 for males.

Insert Table 5 about here

Regression Analysis

To determine the influence of the process steps on successful problem solving, two step-wise regression analyses were computed, one on the data from females only and the other on the data from males only. The eight process steps (Steps 1, 2, 3,4, 5, 6, 7 and 9) were entered as independent variables and the solution step (step 8) was entered as the dependent variable. The resulting Rs-squared indicated that the combined process steps accounted for 70% of the observed variance in the solutions to the problems for females and 66% of the observed variance for males.

Multivariate Analysis

A 2 X 2 between subjects MANOVA (N=298) was performed on nine dependent variables, that is the step scores of each subject on the nine steps of the problems solving plan. The independent variables were gender (male-female) and grade level (6-8).

The Wilks' criterion indicated that the combined dependent variables were significantly affected by gender, $F(9, 286) = 2.78, p < .0038$ and by grade level, $F(9, 286) = 14.58, p < .0001$. These results indicated a moderate association between gender and the set of nine dependent variables ($\eta^2 = .08$) and a moderate association between grade level and the combined dependent variables ($\eta^2 = .31$). The interaction effect was not significant, $F(9, 286) = 0.38, p < .9450$.

Univariate Analysis

Univariate Fs were computed for each of the nine separate dependent variables, that is the step scores of each subject on the nine steps of the problem solving plan. The independent variables in all cases were gender (male-female) and grade level (6-8). The results appear in Table 6.

Insert Table 6 about here

Although the MANOVA detected a significant gender-related main effect at the multivariate level, no significant gender-related differences existed at any of the individual steps ($p< .01$)

The MANOVA indicated a significant grade level main effect on the overall process of problem solving. The univariate Fs computed with grade level entered as the independent variable indicated significant differences in favor of the eighth grade subjects at every step of the problem solving model except step three, Diagramming the problem. The MANOVA indicated no significant interaction effect of gender and grade level on the overall process of problem solving. The univariate Fs also indicated no significant interaction effects at any of the nine steps of the problem solving model.

Discussion

A limitation of this study is that it did not investigate problem solving in a typical, naturalistic situation. The subjects were directed solve the problems utilizing a nine step problem solving plan. The use of this plan discouraged subjects from using steps not included in the plan and it also encouraged them to use all the steps. Left to their own devices subjects attempting to solve the problems could very likely have used combinations of steps different from the plan. This limitation is moderated in that this research attempted to determine the potential gender-differentiated usefulness of a plan representative of plans present in textbooks and the intent of those plans is that students follow the steps as they attack word problems (Zambo, in press).

The problem solving plan used for this study was highly predictive for both females (.70) and males (.66). Students who successfully completed the steps of the plan tended to correctly solve the word problems. The plan was designed to be representative of the step by step plans presented in many textbooks, so it appears that success with those problem solving plans might also be predictive of word problem solving ability. The individual steps of the plan represent specific skills predictive of problem solving ability and could be used as the basis for writing specific objectives for problem solving instruction.

Past research has found males superior in word problem solving in product oriented investigations. This research indicated a a small but statistically significant gender-related difference in the process of problem solving in favor of females, based on the overall means of 1.43 for females and 1.38 for males. Little evidence has been collected on gender-related differences in the process of problem solving and the inspection of the results at the univariate level shed little light on this gender-related difference. Even though none of the individual steps had a significant gender-related effect, the use of the overall step by step plan did. It is possible that the algorithmic nature of the plan was more useful to females than males and acted to eliminate a gender-related difference in finding the solutions to the problems. A study is being designed that incorporates control groups. That study could supply a more definitive indication of the usefulness of the problem solving plan in general and its potential gender-differential effects.

The lack of a significant interaction effect of gender with grade level indicated that the gender-related differences at the sixth grade level were similar to the gender-related differences at the eighth grade level. This is consistent with past research concluding that gender-related differences become manifest as early as the sixth grade.

A grade-related difference ($p < .01$) was found, as expected, in favor of the eighth grade on all steps of the problem solving plan except step 3, Diagramming the problem. This result was unexpected since the eighth graders were expected to outperform the sixth graders on all nine steps of the problem solving model. It is noted that the means for step 3 were the lowest of any of the process steps. Further investigation into the role of diagramming in the process of problem solving is necessary.

This study found evidence that suggests step by step problem solving plans provide a useful approach for solving routine mathematical word problems. Although research has found that males tend to outscore females on word problem solving tasks, this study found a gender-related difference in favor of females when the steps of a problem solving plan were included in the analysis. This finding suggests that a step by step approach to solving word problems might assist in reducing the gender gap in problem solving ability.

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Table 1
Step by Step Comparison of Prescriptive Problem Solving Plans

Polya	Abbott and Wells	Bolster, et al.	Lowry, et al.	Keedy, et al.	Phillips, et al.
Understand the problem.	Read the problem. Focus on the facts. What's the question?	Read.	Focus on the facts.	Read the problem carefully. List the information. Choose the needed information.	Read the problem. Write the problem. Circle the facts. List the known and unknown facts.
Devise a plan.	Make a drawing. Choose the operation. Write an equation. Estimate to choose a sensible answer.	Choose an operation. Write an equation. Estimate.	Draw a picture. Decide which operations to use. Write an equation.	Often a drawing helps. Choose a variable. Translate to an equation.	Diagram the problem. Choose the operations to use. Write and equation. Estimate the answer.
Follow the plan.	Solve the equation.	Answer.		Solve the equation.	Solve the equation. Answer the problem.
Check the results.	Check the answer. Does the answer make sense?	Look back. Give a sensible answer.		Check your results with the words in the problem.	Look back to see if the answer makes sense.

Table 2
Step by Step Comparison of Descriptive Problem Solving Plans

Webb	Romberg & Collis	Sherrill	Kintsch & Greeno	Gagne	Schoenfeld
Reading the problem.			Translate English sentences into propositions.	Translate the verbal problem into a mathematical expression.	Read. Analyze.
Diagram the problem.	Direct modeling.	Draw a diagram.	Produce a problem representation that shows the relationships between the sets.		Explore.
Writing an equation.	Written open sentences.	Write an equation.			Plan.
Using an algorithm. Counting.	Use an algorithm.	Use an algorithm.	Activation of the correct schema for carrying out the calculations.	Carry out the indicated operations.	Implement.
Verifying the solution.				Validate the solution.	Verify.

Table 3
Ten word problems.

1. Tommy collected 59 coins in his coin collection. He gave his mom 13 coins as a gift. Then Tommy bought 23 coins at the coin shop. How many coins does Tommy have in his collection now?

2. There were 9 boxes and each of the boxes contained 10 marbles. Terry added 4 marbles to each of the boxes. How many marbles are there all together in the 9 boxes?

3. John and Judy decided to put all of their candy into 3 equal piles. John had 25 pieces of candy and Judy had 38 pieces of candy. How many pieces of candy were put into each of the piles?

4. Don's teacher graded 23 homework papers at school. That night he graded 16 of the papers before he ate dinner. He started with a total of 95 homework papers to grade. How many papers did Don's teacher have left to grade?

5. Juan had 18 packs of chewing gum with 7 sticks in each pack. If Juan gave away 2 sticks from each of the packs, how many sticks would he have left all together?

6. Debby ate 7 cookies while she was putting them into piles of 5 cookies each. Debby had 122 cookies to start. How many piles of cookies were there?

7. A small ribbon is 4 inches long. A large ribbon is 6 times as long as a small ribbon. The longest ribbon is as long as 9 large ribbons. How long is the longest ribbon?

8. Kim has 9 packages of crackers. Each package has 25 crackers in it. Kim divided the crackers evenly into 15 stacks. How many crackers are there in each stack?

9. Cathy had 4 boxes of toy cars with 15 cars in each of the boxes. She took all of the toy cars and put the same number into each of 3 new boxes. How many cars were in each of the new boxes?

10. Linda had 105 pieces of ribbon. She divided the pieces of ribbon equally into 5 piles. Bobby took one of the piles of ribbon and divided it into 3 equal piles. How many pieces of ribbon were in each of the piles which Bobby made?

Table 4
Internal Consistency Reliability Estimates

Subset	Grade 6 n=153	Grade 8 n=148	Item n
Step 1	0.82	0.76	10
Step 2	0.93	0.96	10
Step 3	0.86	0.87	10
Step 4	0.81	0.69	10
Step 5	0.91	0.92	10
Step 6	0.94	0.93	10
Step 7	0.66	0.70	10
Step 8	0.80	0.78	10
Step 9	0.87	0.80	10
Overall	0.80	0.80	90

STEPS: 1) Stating the given facts, 2) Stating the unknown facts, 3) Drawing a diagram, 4) Choosing the operations, 5) Writing an equation, 6) Estimating the answer, 7) Computing the answer, 8) Stating the answer, and 9) Verifying the answer.

Table 5
Mean Step Scores by Gender and Grade Level

	Gender	6th Grade Mean	8th Grade Mean
STEP 1			
	F	1.70	1.85
	M	1.66	1.85
STEP 2			
	F	1.80	1.95
	M	1.66	1.82
STEP 3			
	F	0.97	0.85
	M	0.85	0.76
STEP 4			
	F	1.55	1.78
	M	1.54	1.78
STEP 5			
	F	1.16	1.47
	M	1.03	1.45
STEP 6			
	F	1.11	1.53
	M	0.90	1.52
STEP 7			
	F	1.72	1.88
	M	1.64	1.85
STEP 8			
	F	0.53	0.76
	M	0.55	0.80
STEP 9			
	F	1.51	1.78
	M	1.53	1.80

STEPS: 1) Stating the given facts, 2) Stating the unknown facts, 3) Drawing a diagram, 4) Choosing the operations, 5) Writing an equation, 6) Estimating the an ver, 7) Computing the answer, 8) Stating the answer, and 9) Verifying the answer.

Table 6
Univariate Tests of Gender, Grade Level, and Interaction on the Nine Steps of the Problem Solving Plan

	DV	Univariate F	df	Significance of F
Gender	STEP 1	0.42	3, 294	0.5191
	STEP 2	6.38	3, 294	0.0120
	STEP 3	3.85	3, 294	0.0507
	STEP 4	0.01	3, 294	0.9421
	STEP 5	0.95	3, 294	0.3311
	STEP 6	1.19	3, 294	0.2764
	STEP 7	2.52	3, 294	0.1137
	STEP 8	1.76	3, 294	0.1852
	STEP 9	0.66	3, 294	0.4178
Grade Level	STEP 1	31.66	3, 294	0.0001
	STEP 2	9.72	3, 294	0.0020
	STEP 3	4.20	3, 294	0.0414
	STEP 4	41.19	3, 294	0.0001
	STEP 5	33.28	3, 294	0.0001
	STEP 6	44.51	3, 294	0.0001
	STEP 7	37.26	3, 294	0.0001
	STEP 8	59.94	3, 294	0.0001
	STEP 9	46.27	3, 294	0.0001
Interaction	STEP 1	0.35	3, 294	0.5569
	STEP 2	0.02	3, 294	0.8808
	STEP 3	0.08	3, 294	0.7822
	STEP 4	0.03	3, 294	0.8661
	STEP 5	0.92	3, 294	0.3393
	STEP 6	1.63	3, 294	0.2032
	STEP 7	1.02	3, 294	0.3141
	STEP 8	0.10	3, 294	0.7499
	STEP 9	0.00	3, 294	0.9933

STEPS: 1) Stating the given facts, 2) Stating the unknown facts, 3) Drawing a diagram, 4) Choosing the operations, 5) Writing an equation, 6) Estimating the answer, 7) Computing the answer, 8) Stating the answer, and 9) Verifying the answer.