The Effects of Using Personalized Computer-Based Instruction in Mathematics Learning

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Abstract

This study investigated the effects of personalized computer-based instruction on the achievement and attitudes regarding arithmetic problems and two-step mathematics word problems of 104 middle school American students from a predominately Hispanic population. Students were randomly blocked by ability level based on pretest scores to a personalized or non-personalized version of the computer-based instruction. Students made significant pretest-to-posttest gains across treatments and scored significantly higher on arithmetic than on two-step word problems on the posttest. However, the personalized treatment did not produce a significant achievement difference over the non-personalized one. A significant three-way interaction reflected that personalized lower-ability students improved more from pretest to posttest than personalized higher-ability students, non-personalized higher-ability students, and non-personalized lower-ability students. Personalized subjects had significantly more positive attitudes toward the computer-based instruction on mathematics learning than their non-personalized counterparts.

Problem solving is considered one of the most important components of mathematics, as well as in everyday and professional environments (Jonassen, 2000; Williams, 2003). Mathematical word problems are considered by students to be difficult at all age levels in elementary and secondary schools (National Assessment of Educational Progress, 2003). A major cause of the difficulty appears to be the students' inability to understand the problem structure that is embedded in the problem text (Bernardo, 1999; Mayer, 1982; Rosen, 1984). Besides language understanding, students need to possess the ability to find an equation for a given problem. However, converting the problems into the math operations is another major obstacle (Hart, 1996). Several studies (Clarkson, 1991; Dark & Benbow, 1990; Stern, 1993) have documented how the difficulties of comprehending the problem text are associated with corresponding difficulties in problem solution. An individual student's previous knowledge and information processing skills should also be counted as internal factors that affect his or her ability to understand word problems (Cummins, Kintsch, Reusser, & Weimer, 1988; Kinstch & Greeno, 1985).

Student performance can be improved by personalizing mathematics word problems, such as incorporating personal preferences and interests into the problem content (Anand & Ross, 1987; Davis-Dorsey, Ross, & Morrison, 1991; Ku & Sullivan, 2002; Lopez & Sullivan, 1991, 1992). In Anand and Ross's study (1987), fifth and sixth grade students scored significantly higher on mathematics word problems after receiving personalized computer-assisted lessons. They did better than peers without personalized instruction in solving standard problems and transfer problems, in recognizing rule procedures, and in task attitudes. Results of the study suggested that personalized contexts increase task motivation by describing applications of high interest to learners and increase comprehension by helping learners interpret and interrelate important information in the problem statements. Davis-Dorsey et al. (1991) found that both second-grade and fifth-grade students benefited significantly from personalization of the context in mathematics word problems. Ku and Sullivan (2002) researched the effects of personalization on fourth grade Taiwanese students. The results of their study revealed that participants in the personalized treatment made significantly greater pretest-to-posttest gains than those in the non-personalized treatment. In two separate studies, Lopez and Sullivan (1991, 1992) found that Hispanic American students at the junior high school level scored significantly higher on mathematics word problems when the problems were personalized by incorporating personal information and interests than when the problems were not personalized.

Student attitudes are more positive when student interests and preferences are incorporated into instruction in order to personalize it (Herndon, 1987; Ross, 1983; Ross, McCormick, & Krisak, 1986; Ross, McKormick, Krisak, & Anand, 1985; Ku & Sullivan 2002). Herndon (1987) found high school students who received instruction based on common group interests had significantly more favorable attitudes and higher return-to-task motivation than students whose instruction was not interests-based. Other studies, such as a series of adaptive personalized instructions employed by Ross and his colleagues (Ross, 1983; Ross, et al., 1986; Ross, et al., 1985), found students had more favorable attitudes toward personalized than toward non-personalized instruction. Ku and Sullivan (2002) have also found personalized subjects and higher-ability students both had significantly more positive attitudes toward the instructional program than their non-personalized and lower-ability counterparts.

Previous research has been shown to have implications for mathematics teaching and learning in that students responded positively toward the personalization of mathematics problems. In the Ku and Sullivan (2000, 2002) studies of student performance and attitudes using paper-based personalized mathematics instruction, group personalization was implemented because it was easier to construct and because there was limited access to computers in the school in Taiwan to facilitate individualized computer-based personalization. However, one limitation of paper-based personalization is that it is a time consuming effort for instructors to create individually personalized mathematics problems on paper. Incorporating computer-based personalized instruction would solve time and labor constraint of synthesizing group preferences and interests as well as facilitates individualized personalization.

The purpose of the study was to determine whether individually personalized computer-based instruction on mathematics word problems improves student achievement and attitudes. The following research questions were addressed:

1. Does personalization of computer-based instruction increase student achievement on mathematics word problems?
2. Does personalization of computer-based instruction have a differential effect on the performance of higher-ability and lower-ability students on mathematics word problems?
3. Do students perform differently on the arithmetic problems than on word problems on the posttest when both types of problems are at the same difficulty level?
4. Does personalization of mathematics word problems influence student attitudes toward the computer-based instructional on these problems?

Method

Participants

The participants consisted of 104 sixth to eighth grade American students from six computer classes taught by the same computer lab teacher at a public middle school. Two classes from each grade were selected to participate in the study and the final numbers of participants by grade levels were 39 sixth graders, 41 seventh graders, and 24 eighth graders. The ethnicity of the group studied was 55 percent Hispanic, which correlates to the middle school's 57 percent Hispanic population, but is higher than the community's 35 percent Hispanic population.

Materials

Favorites Survey. A total of 22-items student favorites surveys (10-itesm on first set of instruction and 12-item on second set of instruction) were used to determine the personal backgrounds and interests of the participants. Topics included the name of student's favorite places, friends, activities, sports, foods, and so forth. Students typed in one favorite response for each survey item.

Pretest. A total of 16 arithmetic problems and eight two-step word problems in non-personalized form were developed for the pretest. These 16 arithmetic problems had the same number values and operations as the eight word problems. The 16 arithmetic problems consisted of 8 problems involving multiplication operations and 8 problems involving division operations. The 8 two-step word problems, two from each of the four combinations of multiplication and division mathematical operations, were assigned to the pretest. To determine the pretest score, each answer on the pretest was scored as correct or incorrect only based on the final answer. One point was giving to correct answers for each of the 16 arithmetic problems (total of 16 points) and one point was giving to correct answers for each step of the eight two-step word problems (total of 16 points), for a possible score range of 0 to 32 points. The pretest had a Cronbach's alpha reliability coefficient of .85.

Posttest. Similar to the pretest, posttest problems were administered in two forms that consisted of 16 arithmetic problems and 8 two-step word problems in non-personalized form. These 16 arithmetic problems had the same number values and operations as participants had practiced on the eight two-step word problems (practices 1-8) during the instructional program. Like the answers on the pretest, each answer on the posttest was scored as correct or incorrect only based on the final answer, for a possible score range of 0 to 32 points. The Cronbach's alpha reliability coefficient was .90 for the posttest.

Attitude Survey. An eleven-item attitude survey served as the criterion measure for assessing the students' attitudes and motivation. Nine of the 11 items are four-choice Likert-type questions that assessed student attitudes and continuing motivation toward the computer-based instructional program. Responses to these nine items were assigned a score of 4 for the most positive response and a score of 1 for the least positive response. The two remaining items are open-ended questions dealing with student likes and dislikes about the computer-based instructional program. The Cronbach's alpha for reliability of the nine Likert-type items of the Attitude Survey was .80.

Instructional Program. The computer-based instructional program for this study was designed and developed by authors using Macromedia Authorware. Two parallel versions of a computer-based instructional program were designed and developed for solving arithmetic problems involving multiplication and division operations and using procedures for solving two-step word problems involving four different combinations of multiplication and division operations with whole numbers. The non-personalized version of the instructional program included standard problem types from the students' mathematics textbooks. A four-step strategy on solving word problems based on the work of Enright and Choate (1993) was incorporated into the instructional program for both version of the computer-based instructional program.

The student favorite survey was administered to participants at the beginning of the computer-based instructional program. The 22-item student favorite survey was used to determine the personal backgrounds and interests of the participants. For the personalized group, student responses were subsequently used by the software to convert the non-personalized word problems into the personalized content for the instructional program. For non-personalized group, although students were required to type in their responses, the content of the instructional program still remained in the non-personalized context.

Instructions for solving each of the four types of word problems contain the four-part strategy with two worked examples for each of the four problem types. After each example, the instructional program presents two practice problems for the students to work, resulting in eight practice problems in total. For each step of the two-step word practice problems, students needed to type the first whole number, choose the correct operation (either multiplication or division), type the second whole number, and type their final answer. For these eight practice items, the computer also provided instant feedback to students' answers at each step, informing them whether their answers were correct or incorrect. Students would be given one more chance to try if their first attempt failed. If they failed to solve the problem again, the computer would provide the correct final answers on the screen and direct them to go on to the second step or the next question.

The computer-based instructional program was also designed to capture all of the responses that students typed in and the time they spent on the program into one summary sheet.

All instructional materials including the pretest, instructional program, student attitude survey, and posttest were saved on a CD-ROM.

Procedures

All participants took the pretest three days prior to the experiment. After the pretests had been scored, the participants were blocked within each class by their pretest scores into higher-ability and lower-ability groups, and were randomly assigned within blocks to either the personalized or the non-personalized versions of the computer-based instructional program.

The experimental part of the study took place over three 42-minute class periods on three different days after the pretest. On the first day, all participants filled out the first set of Favorites Survey (for practices 1-4) in the beginning of the instructional program. For the personalized group, the software converted the non-personalized problems into the personalized content for the instructional program using each response that students typed into the Favorites Survey. For the non-personalized group, even though participants also filled out the Favorites Survey to indicate their favorite things and/or places, the content of the instructional program still remained in the non-personalized context. All participants completed the first instructional part of the program (examples 1-4 and practices 1-4) that consisted of two examples and two practices involving a multiplication operation followed by a second multiplication operation (multiply-multiply) and two problems involving multiplication followed by division (multiply-divide).

On day two, all participants filled out the second set of Favorites Survey (for practices 1-4), which asked different questions than on the previous day because of different word problems being asked. The students then completed the second instructional part of the program (examples 5-8 and practices 5-8) that consisted of two examples and two practices involving a division operation followed by a second multiplication operation (divide-multiply) and two problems involving division followed by a second division (divide-divide). Students then answered the student attitude survey to indicate their reactions toward the two parts of the instructional program. On the final day, participants took the posttest. All summary sheets were printed and collected at the end of each class period by the computer lab teacher.

Data Analysis

The data analysis for student achievement on solving word problems as the dependent variable was a 2 (Treatment: personalization versus non-personalization) x 2 (Ability Level: higher ability versus lower ability) x 2 (Test Occasion: pretest versus posttest) Repeated-Measures univariate analysis of variance (ANOVA). A 2 (Ability Level: higher ability versus lower ability) x 2 (Problem Type: arithmetic versus word) ANOVA was also conducted to compare higher- and lower-ability student posttest performance on the arithmetic problems and two-step word problems. Attitude data were analyzed using multivariate analysis of variance (MANOVA) for the overall questionnaire means by treatment, followed by univariate analyses of variance (ANOVA) of the treatment means for each item. The frequency of constructed responses on the attitude survey to the two open-ended questions regarding what students liked most and what they liked least were also tabulated using content analysis.

Results

Achievement on Word Problems

A 2 (Treatment) x 2 (Ability Level) x 2 (Test Occasion) analysis of variance yielded significant differences for test occasion and for ability level, but not for personalization tretament. For test occasion, subjects' mean score was significantly higher for the posttest (M = 6.64, or 42% correct) than for the pretest (M = 4.53, or 28% correct), F (1, 100) = 40.39, MSE = 230.88, $p < .001$. For ability level, higher-ability students significantly outscored lower-ability students across both tests: 8.36 items or 52% correct for higher-ability subjects and 2.80 items or 18% correct for lower-ability subjects, F (1, 100) = 86.14, MSE = 1607.29, $p < .001$. For personalization level, the mean scores correct were 5.85 (38%) for the personalized subjects and 5.31 (33%) for the non-personalized subjects, F (1, 100) = .83, MSE = 15.49, $p = .364$. None of the two-way interactions were significant.

The 2 x 2 x 2 Repeated Measures ANOVA also yielded a significant three-way interaction for treatment by ability level by test occasion, F (1, 100) = 4.15, MSE = 23.72, $p < .05$. This three-way interaction reflected the fact that personalized higher-ability students, non-personalized higher-ability students, and non-personalized lower-ability students improved less from pretest to posttest than personalized lower-ability students. Personalized higher-ability participants had mean scores of 7.56 (47%) on the pretest and 9.04 (57%) on the posttest, an improvement of 1.48 items correct. Non-personalized higher-ability participants had mean scores of 7.27 (45%) on the pretest and 9.58 (60%) on the posttest, an improvement of 2.31 items correct. Non-personalized lower-ability participants had mean scores of 1.50 (10%) on the pretest and 2.88 (18%) on the posttest, an improvement of 1.38 items correct, whereas personalized lower-ability participants had mean scores of 1.78 (11%) on the pretest and 5.04 (32%) on the posttest, an improvement of 3.26 items correct. As the follow up to the three-way interaction, a test of simple effects was conducted and it revealed that the pretest-to-posttest improvement for higher-ability students between personalized and non-personalized treatment was not statistically significant ($p = .40$), whereas the pretest-to-posttest improvement for lower-ability students between personalized and non-personalized treatment was highly significant ($p < .05$).

Posttest Performance by Problem Type

Posttest performance was also analyzed by problem type to determine whether there was a difference in subjects' achievement on the posttest arithmetic problems and word problems when both problems types had the same number values and operations.

This analysis yielded significant differences for ability level and for problem type. For ability level, higher-ability students had a mean posttest score of 23.62 (74%) and lower-ability students had a mean of 16.34 (51%), F (1, 102) = 45.54, MSE = 690.21, $p < .001$, $\eta^2 = .31$. For problem type, subjects had a mean score of 13.32 (83%) on the posttest arithmetic problems and a mean of 6.60 (41%) on the word problems, F (1, 102) = 285.37, MSE = 2325.54, $p < .001$, $\eta^2 = .74$.

The ANOVA for posttest scores also revealed a significant interaction for ability level by problem type, F (1, 102) = 18.19, MSE = 148.23, $p < .001$, $\eta^2 = .15$. This interaction reflected the fact that higher-ability students had similar scores of 14.31 (89%) compared to lower-ability students on the arithmetic posttest problems 12.36 (77%), but higher-ability students had significantly higher scores on the word problems (9.31, or 58%) than lower-ability students (3.98, or 25%).

Student Attitudes

A significant overall effect on the attitude measure was obtained for treatment (M = 3.23 for personalization and M = 2.96 for non-personalization), F (1, 100) = 7.32, MSE = .25, $p < .01$, $\eta^2 = .07$. Univariate analyses on the nine survey items by personalization level revealed significantly more positive attitudes on four of the items for subjects in the personalized treatment than for those in the non-personalized treatment. Students in the personalized treatment had significantly more favorable scores at the $p < .01$ level on one statement: "This program had many familiar persons, places, and things" (*M* = 3.31 for personalization and *M* = 2.71 for non-personalization), and at the .05 level on three statements: "This program was easy" (*M* = 3.18 for personalization and *M* = 2.83 for non-personalization), " I liked the program" (*M* = 3.27 for personalization and *M* = 2.87 for non-personalization), and "I would like to do more math word problems like the ones in the program" (*M* = 3.16 for personalization and *M* = 2.75 for non-personalization.)

The frequency of constructed responses on the attitude survey to the two open-ended questions regarding what students liked most and what they liked least about the computer-based instructional program was tabulated. Student responses indicated what they liked most were "It was a good learning process. I have learned something about two-step word problems" (36%) and "The problems were easy" (34%). When asked what they liked least about the program, their responses were "I don't like math" (24%) and "I didn't like it when I can't go back to fix my mistakes" (17%).

Discussion

Although students made significant pretest-to-posttest gains across treatments, the personalized treatment did not produce a significant achievement difference over the non-personalized one. This finding is inconsistent with the results in several personalization studies (Anand & Ross, 1987; Davis-Dorsey et al., 1991; Ku & Sullivan, 2002; Lopez & Sullivan, 1991, 1992). One possible reason why personalization of instruction did not produce a significant achievement effect in this study might be due to students' lack of reading competency in English. Since the majority of subjects (55%) were from a predominately Hispanic population, during the experimental period, several students asked other classmates and/or computer lab instructor to translate word problems into Spanish so they could understand what have been asked in order to solve these problems.

Another possible reason might be due to the students' motivation toward the subject matter to be learned. The lack of both internal and return-to-task motivation for students to perform well was reflected on their responses to the student attitude survey. From students' written responses, nearly a quarter of students (24%) expressed their dislikes about the program simply because it was about math. On the student attitude survey, even though students indicated the importance of knowing how to solve two-step mathematics problems as the highest rated statement, they also pointed out that they would not like to do more math word problems like the ones in the program as the lowest rated statement.

Aside from the language barrier and motivation issues, another possible reason is the inflexibility of the navigation feature in the computer-based instructional program. The program was designed as self-paced so students could control the presentation rate to avoid overloading their working memory, however, the program was also designed in a linear fashion so students could only go forward to learn new information but could not to go back to review previous pages. This might create potential problems because some students might have skipped frames unintentionally while others might have concentrated on particular frames and thereby created cognitive overload.

The significant differences for test occasion supported the assertion that computer-based instruction can improve lower-ability students' mathematics achievement (Baum, 2001; Glickman & Dixon, 2002; Macnab & Fitzsimmons, 1999; Van Eck & Dempsey, 2002). The significant treatment by ability level by test occasion three-way interaction also corresponded to previous studies indicating that while computer-based instruction assists individualized, self-paced learning and increases student motivation, it can be used primarily or complementarily to enhance the performance of disadvantaged and lower-ability students within regular classrooms (Hannifan & Peck, 1988; Kulik, 1983).

A potential concern about relying more heavily on familiar problem settings in mathematics instruction and assessment is that it may reduce transfer of learning to less familiar problem settings. Similar to the Ku and Sullivan (2002) study, the present results for all non-personalized posttest items do not support this concern, especially for lower-ability students. Prior to instruction, lower-ability students who ultimately were in the personalized treatment and those who ultimately were in the non-personalized treatment had similar scores (11% and 10% respectively) on the non-personalized two-step word problems on the pretest. Following instruction, lower-ability students who had received personalized instruction scored significantly higher (32% to 18%) on non-personalized two-step word problems than those who had received non-personalized instruction on the posttest. The higher posttest score for lower-ability students in the personalized treatment on non-personalized posttest items is extremely encouraging. It may indicate greater transfer of learning for personalized treatment who practiced personalized items than for their-non-personalized counterparts who practiced non-personalized items during computer-based instruction.

In terms of problem types with the same difficulty level, a significant difference was found between the overall posttest mean scores for the arithmetic problems (83%) and the two-step word problems (41%). It showed that two-step mathematics word problems were still difficult for students even after they completed the instructional program, especially when it came to lower-ability students (77% on arithmetic items and 25% on two-step problem items). Marshall (1995) stated that the word problems are strongly disliked by both children and adults because they find the problems are difficult to solve even when they have adequate computational skills. This result implies that educators need to take into consideration reinforcing the instructions of mathematics word problems in mathematics curricula.

The attitude data clearly indicated student preference for personalized instruction, a result consistent with the findings in previous studies (Ku & Sullivan, 2000, 2002; Lopez & Sullivan, 1992; Ross & Anand, 1987). The strongest difference between students receiving personalized and non-personalized instruction are on the items stating this program had many familiar themes, the program was easy, I liked this program, and I would like to do more math word problems like the ones in the program. These statements reflect the intended nature of the personalized program that makes learning easy and improves learners' return-to-task motivation.

The present results have implications concerning mathematics educational practices in general. Personalized computer-based instruction is effective in improving lower-ability students performance to solve mathematics problems. The results of this study can benefit K-12 teachers, administrators, parents, textbook writers, and instructional designers to incorporate best practices in mathematics. Computer software companies that develop educational programs can determine how to best serve the students' interests and needs and incorporate effective strategies and scaffoldings (e.g., Enright and Choate's four-part strategy, worked examples, practice items, and immediate feedback) to enhance student learning. It is also suggested that instructors could incorporate computer-based instruction to support students' cognitive and megacognitive skills and further improve student performance.

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