Effects of Handheld Games on Students Learning in Mathematics

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The main purpose of this study was to investigate the effects of handheld gaming on student learning in mathematics. During the four-month instructional period, 50 2nd grade students from three classes used a handheld *Skills Arena* software program or paper-based flash cards under various conditions depending on their teacher's preference. Overall results proved that the handheld game activity in the classroom was beneficial to students in learning mathematics, especially for low-ability students, regardless of gender and ethnic background. In a non–experimental, correlational analysis, the results reveal that handheld game scores and attitude toward mathematics correlated significantly to students' scores on a mathematic test. In the results of a quasi-experimental control-group design with Repeated Measures, handheld gaming students outperformed students who did not use a handheld game on a mathematic test. Additionally, handheld low-level students outperformed those who did not use a handheld game on the same test.

Handheld devices in K-12 education have a great potential to improve teaching and learning. The essential value of a handheld learning environment is that every student has immediate access to a learning tool in a small and mobile package (Norris & Soloway, 2003). The high mobility of handheld devices enables students to be lifelong–learners with no limit of time and place (Crawford, Vahey, Lewis, & Toyama, 2002; Norris & Soloway, 2003). Educational programs have been developed to attain maximum benefits from handheld devices in learning activities such as game–based instructional programs. Games have been incorporated in the classroom for learning and understanding complex subjects. A game is a set of rule-guided, goal-directed activities that have no real-world consequences (Crookall, Oxford, & Saunders, 1987; Dempsey, Haynes, Lucassen, & Casey, 2002). Essential features in a game environment are authentic fantasy contexts, rules/goals, and challenges (Gredler, 1996; Thornton & Cleveland, 1990). Game research proved that the game features enhance dynamic cognitive processes for meaningful learning (Garris, Ahlers, & Driskell, 2002; Pillay, Brownlee, & Wilss, 1999; Rieber, Smith, & Noah, 1998; Rosas et al., 2002). The literature review of games and handheld devices has shown that there would be promising benefits to student learning in handheld gaming environments. The results of handheld game studies proved that games on handheld devices are easy to use and allow learners to focus on activities because of the small size of the handheld (Zurita, Nussbaum, & Sánchez, 1999). However, there are very few studies about the use of handheld games in classroom settings. Empirical evidence regarding educational handheld games in classrooms is insufficient to support favorable effects of handheld games on learning (Dempsey et al., 2002). Hence, comprehensive empirical studies are needed to support the idea that handheld gaming can potentially have a substantial impact on teaching and learning.

The primary purpose of this study is two fold. First is to explore what aspects of learners' characteristics influence student learning in a handheld gaming environment. Second is to investigate whether educational handheld games could promote student learning. The specific research questions of this study were:

- What aspects of learners' characteristics (attitude toward mathematics, attitude toward a handheld game, handheld gaming performance, gender and ethnicity) influence student learning in a handheld gaming environment?
- What is the impact of handheld games in the classroom on student learning, especially for female and low–ability students?

Methodology

Participants

The participants of this study were 50 2nd grade students attending an elementary school near a large city in the Midwest. The students were primarily upper middle class and Caucasian. The 50 participants were from three classes and included 28 male and 22 female students. The three classes had 21, 20 and 9 students, respectively. The ethnic composition of the participants was 31 Caucasians, eight Asians, six African Americans, four others and one Hispanic. We lost one female student because she transferred to another school.

Materials

An educational game program entitled *Skills Arena* was used in this study. The program was designed to teach students about basic arithmetic skills (such as addition and subtraction). The games were designed using a handheld GameBoy™. In *Skills Arena* students can create their own character with their name for playing the game. They are able to choose their game type and level based on their ability and learning goals. The game has several options for speed level, game type and arithmetic task. Six speed levels, from the easiest to the most difficult, are presented in the form of cartoon characters. The game types are mental, extension and place games. The mental game is the easiest, dealing only with single digit numbers such as "___ + 3 = 10". The extension game is the moderately difficult level game. For instance, "300 + 400 = _____, or 260 - 50 = ______". The place game is the highest level using multiple digit numbers such as "245 + 563 = ______, or 437 – 36 = ____." Each game has three options for arithmetic tasks which are addition, subtraction, and mixed addition and subtraction. The arithmetic problems in the *Skills Arena* are composed of one, two, three, and four digit numbers. Students have to solve the problems before the questions fade out on the GameBoy™ screen. As the students answer a question, they receive immediate feedback as to whether they have correctly or incorrectly answered the question. The game displays a performance summary immediately after each game finishes. The summary shows the total number of problems solved, and the number of correctly solved problems in each game. It also tells the total number of solved problems and correctly solved problems in the games they have played over time (see Figure 1).

Figure 1. Skills Arena game screen

Treatment

Handheld Game Group

The handheld game group (HG) was composed of the 20 participants in class two. Students used a GameBoy™ and the *Skills Arena* software program. For the first ten days of the *Skills Arena* handheld gaming, the students played the game for 15 minutes, five times per a week. After that, they worked on the *Skills Arena* activities for 15 minutes, three times per a week during the five-week instruction. After five-weeks of game activities, the students played the game for 15 minutes, twice per week for 13 weeks. They were kept from playing the game except for the period of handheld gaming activities.

Card Game Group

The card game group (CG) consisted of the 21 students in class one. Students used flash fact cards for practicing basic arithmetic skills during a five-week instructional period. The flash fact card is a triangle shape that has three numbers, one on each angle, and either an addition or subtraction sign in the middle of the card. Individual students have their own cards. A pair of students was teamed up. One student held a card by hiding one of the three numbers, and asked the other student what number was hidden on the card. The other student in the pair answered the question using the two remaining numbers and the arithmetic sign on the card. They repeated the procedure with all the cards that a questioner had and then they switched their roles once the questioner was finished with the cards.

They exercised addition and subtraction flash card activities for 15 minutes, three times per a week. After five weeks of flash card activities, the students used a GameBoy™ and the *Skills Arena* software program for the remaining 13 weeks of the semester. The first ten days with *Skills Arena,* the class two activities were the same as those of the HG. After that, they played the game for 15 minutes, three or four times per a week. Further, the students were also allowed to play the game anytime they finished their other class assignments.

Delayed Handheld Game Group

The delayed handheld game group (DG) consisted of the 9 students from class three. Class three joined this study ten weeks later after conducting a pre-test. Students used a GameBoy™ and the *Skills Arena* software program for eight weeks. The directions for the handheld game activity were the same as those of the CG.

Measures

Mathematic Scores and Handheld Game Scores

A 70 item instrument was developed to assess mathematics skills. The test items were directly aligned with the second grade mathematics curriculum standards of the participating school. The test had two sections. Part I consisted of 50 questions with 25 addition items and 25 subtraction items to measure basic arithmetic skills. Part II of the test had 20 questions including 10 addition and 10 subtraction items to assess advanced arithmetic skills. Face validity for this instrument was verified by the teachers at the participating school. The students took Part I of the test in 15 minutes and Part II in 5 minutes. We administered this test before starting any gaming, after 5-weeks and after 13-weeks of game activities.

The *Skills Arena* game maintains a record of the total number of solved problems and the total number of correctly solved problems in the games students have played over time. Hence, the students' game scores could be extracted from the summary page of the *Skills Arena* game when the mathematics test was administered. The students' game score is the number of correctly solved programs in the *Skills Arena* game.

Attitude Toward Mathematics and Attitude Toward Handheld Games

The subjects' attitude toward mathematics was measured using the Attitude Toward Math Survey. This survey, developed by Pearce, Lungren, & Wince, was designed focusing on closely balanced representations of positive and negative statements with respect to young students' attitudes toward mathematics (Pearce, Lungren, & Wince, 1998). The teachers presented 23 statements orally to students. The students responded by marking yes or no to the statements on their answer sheet. Finally, an 8-item debriefing questionnaire was developed to capture qualitative data regarding participants' attitude toward elements of the game such as the interface of the program, the usefulness of the feedback for learning math, the sounds and colors of the game, the likeability of the game, their attitude toward handheld games and additional comments. The items were a combination of "Yes or No" and open-ended questions. The participant teachers checked the readability of the items for second grade students. A researcher conducted an individual interview with all the students in order to get participant responses on each item.

Procedures

The study was conducted for a four–month period during the spring semester of 2005. The pretest was done under the supervision of teachers and two investigators before the handheld gaming instruction was given. Two investigators conducted a one-hour training session for teachers and students before the handheld game use began. Most students had previous experience playing games on the GameBoy™. Students were able to play the game with the basic guidelines we provided.

During the five weeks of mathematics classes, all the students in the Handheld Game group (HG) used a GameBoy™ and the *Skills Arena* software program. In the Card Game group (CG), the students worked on addition and subtraction activities using the flash cards for the same number of hours as the HG students. After five–weeks of instruction, the teachers and the investigators administered the posttest. After the posttest, all students in these two groups used a GameBoy™ and the Skills *Arena* software program for 13 weeks following their teachers' directions. After 10 weeks and conducting a pre-test, the delayed handheld group (DG) used a GameBoy™ and the *Skills Arena* software program for eight weeks. The teachers and the investigators administered the final test in the three classes after the four-month handheld game instruction intervention. Finally, the teachers administered the survey of students' attitudes toward mathematics.

During the implementation stage of the handheld game, a researcher and an assistant researcher conducted a classroom observation for the HG and CG classes twice a week. During the five-week instruction, the main purpose of the classroom observation was to ensure that the *Skills Arena* game was implemented in the handheld game group as intended. For the flash card game group, the observation was to guarantee that students' arithmetic skill practice hours would be the same as the handheld game group. During the 13-week instruction, the classroom observation was conducted to confirm that the handheld game students played the game constantly in an appropriate way, and the *Skills Arena* game was precisely implemented in the flash card group.

Research Design and Data Analysis

This paper includes two research designs and data analyses to investigate the impact of handheld games on learning. The results of two data analyses can support each other to validate the analysis and provide concrete evidence to conclude the effects of handheld games on student learning. In Research Design One, 50 students from three groups (HG, CG and DG) were used for data analysis. This was a non-experimental, correlational analysis of the predictors of students' performance in mathematics. Multiple regression was used to test the relationship between mathematics scores and the predictor variables including attitude toward the handheld game, attitude toward mathematics, ethnicity, gender and performance with a handheld game (number of correctly solved problems).

In Research Design Two, 37 students from the two groups (HG and CG) were used for conducting data analysis. Three male students were excluded from the analysis because they did not take the pre–test. During the five-week instruction, the study provided information regarding the performance differences between the Handheld and Non-Handheld game groups. In the 13–week handheld gaming instruction, the results showed differences on student learning based on the playing time of the handheld game. This was a quasi-experimental control-group design with Repeated Measures. The data analysis for student performance was carried out as a Repeated Measures with two groups (Card game and Handheld game) as a between factor, and Time of Measurements (pretest, posttest and final test) as a within factor. Dependent variables were scores of the mathematics tests.

The Repeated Measures was employed to analyze gender differences as well. The analysis for low–level student performance was conducted using a Repeated Measures with only low–level students from both of the groups. The students were divided into low- and high-level groups based on their pretest scores. The low-level group consists of the students who had scores lower than 42 on the pretest. The sample size of each low–level group ($n = 10$ from HG and $n = 11$ from CG) was relatively small. Assumptions for the statistical measures were checked by the significant Levene's test for equality of variances among the groups. The data of the low–level samples met the assumptions. The statistical analysis was interpreted to examine the effects of the handheld game on the low–level students. Additional information is provided by the effect sizes obtained from the differences of two groups. Significance values given are *** ($p < .001$), ** ($p < .01$), and * ($p < .05$).

Multiple Regression Results

To understand how students in the three groups performed on the mathematic test, descriptive analysis of each group were conducted (see Table 1). In order to detect multicollinearity among the independent variables, we computed Pearson correlation coefficients for the entire sample. There was no potential of multicollinearity among variables. In the first step of the analysis, all the predictor variables, including attitude toward mathematics, attitude toward handheld games, scores of handheld gaming, gender and ethnicity were entered into the model simultaneously. Only two variables, handheld game scores, ß = .42, $t = 3.61$, $p = .001$, and attitude toward mathematics, ß = .39, $t = 3.30$, $p = .002$, emerged as significant predictors of mathematics test scores. In the second step of the analysis, to reduce the error term associated with the inclusion of nonsignificant predictors in regression models, we included only the significant predictors from the first regression analysis. In this step, attitude toward mathematics, along with handheld game scores, was a significant predictor of mathematics test scores. Handheld game scores ß = .48, $t = 4.32$, $p < .000$, and attitude toward mathematics, ß = .40, $t = 3.52$, $p < .001$, accounted for 45% ($p < .000$) of the variance in mathematics test scores. Overall, students who had higher attitudes toward mathematics and handheld game scores were more likely to achieve high scores on the mathematics test. Attitude toward the handheld game, gender and ethnicity were not significant predictors of mathematics test scores. The regression results from the first and second step analyses are summarized in Table 2.

Table 1. Mean scores among three tests by treatment.

Group		Pre test		Post test		Final test	
		M [%]	(*SD*)	*M* [%]	(*SD*)	*M* [%]	(*SD*)
Card (*n* = 20)							
Math total (70)		37.05 [53]	(15.58)	39.95 [57]	(17.00)	47.60 [68]	(16.92)
	Basic (50)	34.80 [70]	(13.40)	34.85 [70]	(14.31)	39.30 [79]	(11.48)
	Advanced (20)	2.25 [11]	(2.65)	5.05 [25]	(3.86)	8.30 [42]	(6.05)
Game score	Total[1]	--	--	--	--	3560.00	(2850.39)
	Correct[2]	--	--	--	--	2371.03	(1677.05)
Ability	Low (n=11)	25.36 [36]	(10.85)	28.81 [41]	(15.23)	37.00 [53]	(15.92)
	High (n=9)	51.33 [73]	(3.50)	53.44 [77]	(4.61)	60.56 [87]	(4.42)
Gender	Male (n=12)	44.67 [64]	(12.38)	45.67 [65]	(13.49)	54.25 [78]	(11.46)
	Female (n=8)	25.63 [38]	(13.02)	31.38 [45]	(19.01)	37.63 [54]	(19.52)
Handheld (*n* = 17)							
Math total (70)		37.06 [53]	(14.31)	44.71 [64]	(12.62)	45.53 [65]	(15.22)
	Basic (50)	35.12 [70]	(12.32)	40.18 [80]	(9.75)	40.06 [80]	(11.57)
	Advanced (20)	1.94 [10]	(2.59)	4.53 [23]	(3.59)	5.47 [27]	(5.21)
Game score	Total	--	--	917	(414.82)	3369.59	(1403.14)
	Correct	--	--	770	(423.83)	2790.82	(1408.22)
Ability	Low (n=10)	27.00 [38]	(9.32)	38.50 [55]	(12.76)	38.80 [55]	(16.22)
	High (n=7)	51.43 [74]	(2.51)	53.57 [77]	(4.93)	55.14 [79]	(6.31)
Gender	Male (n=9)	39.22 [56]	(14.88)	43.33 [63]	(13.73)	44.67 [64]	(17.05)
	Female (n=8)	34.63 [48]	(14.22)	46.25 [65]	(11.97)	46.50 [66]	(13.97)
Delayed (*n* = 9)							
Math total (70)						46.78 [67]	(15.86)
	Basic (50)					41.33 [83]	(12.10)
	Advanced (20)					5.44 [27]	(5.05)
Game score	Total	--	--			4910.89	(2263.57)
	Correct	--	--			3286.33	(1806.89)
Gender	Male (n=4)					55 [79]	(6.06)
	Female (n=5)					40.20 [57]	(18.81)

Note. 1. The total solved problems of the game. 2. The correct answers in the solved problem of the game.

Table 2. First and second steps of simultaneous regression analysis for variables predicting mathematics scores.

Variable ($N = 50$)	B	SEB	ß	*t*	*p*
Game scores	3.88	0.00	0.42	3.61	.001
Math attitude	1.11	0.34	0.39	3.30	.002
Gender	-5.87	3.55	-0.19	-1.65	.106
Game attitude	2.24	4.16	0.06	0.54	.592
Ethnicity	-2.54	1.42	0.00	-0.02	.986
Constant	13.17	24.47		0.54	.593
First step regression analysis. $R^2 = .48$ ($p < .000$)					
Game scores	4.52	0.00	0.48	4.32	.000
Math attitude	1.12	0.32	0.40	3.52	.001
Constant	15.04	6.04		2.49	.016
Second step regression analysis. $R^2 = .45$ ($p < .000$)					

Violations of any assumptions of multiple regression analysis were checked in the overall plot and normal probability plot of residuals. Overall results of the residual graphs indicated that the samples of this study met the assumptions of multiple regression analysis and the multiple regression technique can be used to analyze the data of the mathematics test. Finally, we used the technique of cross-validation to determine whether the prediction equation has a chance of being successful when it is used with a new group of individuals. The results confirmed that the prediction equation of the mathematics scores works for students other than those who were used to develop the equation.

Repeated Measures Results

The results of the Repeated Measures show a significant Time of Measurement X Group effect F (2, 34) = 5.61, p = .008 in the total math scores. It indicated that a statistically significant difference in the mathematics scores' changes over time in the two groups (HG and CG). In the five-week instruction with the handheld game only for the handheld game group, the handheld game group (HG) outperformed the card game group (CG) from the aspect of improving scores. The HG and CG groups had similar scores on the pretest at the beginning of the instruction. The HG group scored higher than those of the CG group on the posttest. The HG students gained 11% (M = 7.65, SD = 7.84) from the pretest to the posttest. In the case of the CG group, students increased only 5% (M = 2.90, SD = 6.46) on the tests. The effect size of the total gain difference between the two groups was .61. In the next 13-week instruction period with the handheld game for the both groups, the CG group outperformed the HG group on gain scores. The CG students increased 11% (M = 7.65, SD = 6.15) from the posttest to the final test. The HG students increased only 1% (M = 0.82, SD = 6.54) on the tests. The effect size of gain difference between the two groups was 1.04 (see Figure 2).

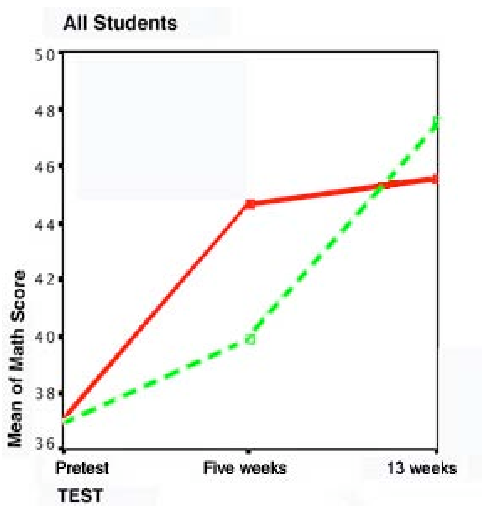

Figure 2. Overall students on math score.

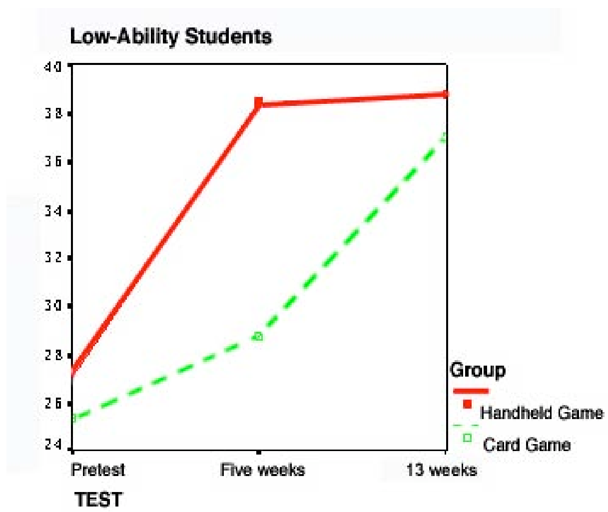

Figure 3. Low-ability students on math score.

The results of repeated measures with only low-level students revealed that there was a significant Time of Measurement X Group effect, F (2, 18) = 4.04, p = .036, indicating a statistically significant difference in the mathematics scores' changes over time in the two groups as well. The HG low-level students using the handheld game gained 16% (M = 11.50, SD = 7.12) from the pretest to the posttest. In case of CG group, students increased only 5% (M = 3.45, SD = 8.34) on the tests. The effect size of total gain difference between the two groups was .97. In the next 13-week instruction period with the handheld game for the both groups, the CG low-level students outperformed those of the HG group on gain scores. The CG low-level students increased 12% (M = 8.18, SD = 7.64) from the posttest to the final test. The HG low-level students increased almost 0% (M = 0.30, SD = 7.32) on the tests. The effect size of gain difference between the two groups was 1.03 (see Figure 3). However, there was no significant result with respect to gender difference on the test.

Discussion and Implications

The main purpose of this study was to investigate the effects of handheld gaming on student learning in mathematics. Based on the results of this study, it can be concluded that the handheld game activity in the classroom is beneficial to the students, especially low-ability students, in learning mathematics regardless of gender and ethnicity. It is consistent with previous research on handheld technology and games that indicates they could be an effective tool for facilitating student learning (Cordova & Leper, 1996; Knezek, 1997; McFarlane, Sparowhawk, & Heald, 2002; Rosas et al., 2002). Additionally, the results of analyses reveal that the students' scores on the mathematics test were not different based on ethnicity and gender. The gender difference was expected with the hypothesis that the handheld game would be more favorable to female students because the game's nature was not aggressive. However, the t-test results of the attitude scores revealed that there was no significant attitude difference toward the handheld game between 21 male and 16 female students. Therefore, a general conclusion that the handheld game would equally influence student learning without bias of gender and ethnic differences could be drawn.

There are several key findings from this study. First, on gain scores on the mathematic test, the students who used the handheld-based arithmetic game outperformed those who did not use it. Second, students who played the handheld game more than four times per a week outperformed those who used the game only twice a week. Also, on gain scores on the same mathematics test, low-ability students who had used the handheld game outperformed those low-ability students who had not used it. Lastly, the cumulative number of problems solved correctly as indicated by the handheld game scores and the students' attitude toward mathematics significantly correlated to the students' scores on the mathematics final test. Overall results prove that the handheld gaming environment impacts positively on students' learning in mathematics, especially for low-ability groups. Nonetheless, this study sample size was relatively small for conducting statistical analyses, especially gender and ability-level analyses. The small sample size might skew the result. Hence, more extensive study with a larger sample size would be required to generalize the results of this study about the effects of a handheld gaming environment on student learning in mathematics.

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Acknowledgments

The authors thank to the two teachers, Anne Proctor and Donna Ramsey who gave us valuable feedback and continuous support to collect high quality data from their classes.