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Impact of Hand-Held Technology for Understanding Linear Equations and Graphs[1]

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This article describes a research project that examined the impact of hand-held technology on students' understanding linear equations and graphs in multiple representations. The results indicated that students in the graphing-approach classes were significantly better at the components of interpreting. No significant differences between the graphing-approach and traditional classes were found for translation, modeling, and algebraic skills. Further, students in the graphing-approach classes showed significant improvements in their attitudes toward mathematics and technology, were less anxious about mathematics, and rated their class as more interesting and valuable.

I. INTRODUCTION

Recently there have been many calls for the reform of mathematics education in Korea due to technological advances. Among the most consistent recommendations are incorporating mathematics programs that take advantage of the power of calculators and computers (MOE 1997; NCTM 1989). Specifically, function graphing tools on calculators and computers are suggested as means producing both a richer mathematics curriculum and a deeper understanding of (Demana & Waits 1990; Fey 1989; Kaput 1989; Demana & Waits 1989).

In response to calls for reform in the teaching and learning mathematics this paper reports results of a study where graphing calculators were used with 14 year–old Korean students, none of whom had used calculators in mathematics lessons before this exper-

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iment. This research investigated the value of making explicit links between three different representations of linear algebraic equations: the symbolic, graphical, and tabular forms. While these representations have often been used before, here the concept of equation and function, and in particular the underlying idea of conservation of a solution to an equation under cross-representation transformations, was emphasized for this study.

II. REVIEW OF RELATED LITERATURE

2.1. Systems of linear equations and functions

Setting up and solving systems of linear equations are critical skills in middle school mathematics; however, teachers often focus on teaching algorithms through equations. Consequently, students are acquainted with only particular algorithms rather than understanding their implications. Therefore, alternative approach is needed, such as graphical or tabular methods to aid in comprehending the underlying concepts in realistic situations.

Students should be able to describe various representations in order to understand the concept of functions. Algebraic representations, tabular representations, and graphic representations are considered as three core representations in mathematics (Fey 1984). Tabular representations are used for expressing data with varying parameters. Algebraic representations specify the exactly relationship between variables, but give neither simple examples nor visual shapes (Goldenberg 1987). Graphic representations, however, are important tools in enabling students to predict relationships between variables and to display the nature of these relationships concrete because they provide visual gestalts (McKenzie & Padilla 1984). Translation and interpretation among different representations are important because students can select the most suitable representation out of these representations to solve the problem at hand.

When students study abstract equations, tables and graphs devoid of practical relevance, the nature of understanding of linear functions is veiled. An essential understanding of functions should include an awareness of, and the ability to, make use of concepts linked with functions in the real world as well as flexibility in transforming among representations of equivalent ideas (Wilson & Krapfl 1994). Graphing technology can assist in developing skills for the translation, interpretation among representations, and the recognition of connections between abstract mathematics and the real world.

O'Callaghan (1998) inducted Kieran's frameworks — a process-object duality to learning with technology. He developed four aspects on the conceptual knowledge of function in a study of the effects of the Computer-Intensive Algebra (CIA):

(1) Modeling a real context using a function,
(2) Interpreting a function by a real-world situation,
(3) Translating among different representations of functions, and
(4) Reifying functions.

Hollar and Norwood (1999) extended O'Callaghan's framework to investigate the effects of a graphing-approach curriculum employing the TI-82 graphing calculators. The main purpose in this study was to apply O'Callaghan's study by using his framework to investigate a different curriculum, namely a graphing-approach curriculum employing the TI-92 graphing calculator in linear equations and graphs.

(a) *Algebraic skills:* skills are abilities that contain algebraic operations and symbolic manipulations
(b) *Interpreting*: Interpreting means that students are able to acquire meaning in a concrete context, as well as convert multiple representations to verbal expressions (O'Callaghan 1998). In this study, interpreting is defined as an ability to change graphs into verbal expression. Students can extract information from graphs that they need to solve problems and make different types of interpretations or focus on different aspects of a graph.
(c) *Translating*: Students can use flexible representations to incorporate mathematical information in functions because multiple representations are not independent (Goldenberg 1987). The ability to move from one representation another is defined as translating among mathematical representation. Moreover, students need to translate among representations, select appropriate representations among them, and transfer proper representations.
(d) *Modeling*: Mathematical modeling is a procedure of recovering a mathematics process from the experience of describing and interpreting physical and social phenomena (O'Callaghan 1998). In this study, it is defined as an ability to convert real-world situations into graphs. Modeling can clarify understanding of the complex phenomenon in real-world situations and select appropriate graphs corresponding to the real context. It entails the use of a graph to form an abstract representation of the quantitative relationships in that situation (Fey 1984). Through this process, students come to appreciate the value of mathematics and experience the delight of discovery.

2.2. Technology in functions and systems of linear equations

Technology allows students to examine the nature of functions by exploring the links between graphical and algebraic representations (Goldenberg 1987). Kieran (1992) reported that although students rarely acquire any real sense of the structural aspects of algebra, graphing software might help to develop structural conceptions. O'Callaghan (1998) studied the effects of Computer-Intensive Algebra (CIA) within a function-oriented curriculum to evaluate students' perceptions of functions.

Magidson (1992) explored the effects of learning linear functions in terms of GRAPHER, a computer program that allows students to manipulate the parameters in equations and look for the graphical implications of these manipulations. The Technical Education Research Centers (TERC) developed the Microcomputer-Based Labs (MBL) facility that uses the computer in the laboratory for real-time data gathering and analysis to advance students' graphing skills (Mokros & Tinker 1987). Technology helps students to collect data directly and to develop more precise definitions of concepts in functions.

Although the computer is a powerful tool for learning mathematics, the graphic calculator has many advantages. Calculators are more affordable and user-friendly than computers. In many studies, students who receive graphic calculator-based instruction achieve higher scores compared to traditional methods (Harvey 1993; Mustafa 1997), especially in understanding relations among different representations (Chandler 1992; Browning 1989; Rich 1991; Ruthven 1990; Beckmann 1989). In addition, students understand functions better through graphing (Bryon 1994). Because they spend more time solving problems than calculating numbers, they can concentrate on the mathematics problem, not on algebraic manipulation (Farrell 1990; Rich 1991; Rizzuti 1992). Students can better understand concepts, translate between different representations, and interpret their contexts (Kieran 1992; Boers-van Oosterum 1990; Shoaf-Grubbs 1992).

III. RESEARCH QUESTIONS

The purpose of this study was to examine the impact of graphic calculators in Korea on learning function and the connections among different representations. More specifically, the four research questions of the study are listed below.

1. Do graphic calculators help students multiple representations within a mathematical context?
2. Do graphic calculators help students in linking multiple-representations between the mathematical and real contexts?
3. Are there any differences in performance between calculator and non-calculator users?
4. Do graphic calculators in any alter students' attitudes toward mathematics?

IV. METHODOLOGY

4.1. Participants

The participants for this study were 197 seventh grade students enrolled in three public middle schools located in Seoul, Korea. Most of the students were from lower-middle to middle socio-economic class and would be considered to be of average scholastic ability. They had not used any technology such as graphic calculators or calculator-based rangers in mathematics learning. Two classes from each school participated in this study. One class participated as the comparison group and the other class acted as the experimental group (Table 1).

Table 1. Participants in this study

	Comparison groups (boys/girls)	Experimental groups (boys/girls)
A school	30(21/9)	31(22/9)
B school	36(19/17)	34(17/17)
C school	32(20/12)	34(21/13)
Total	98(60/38)	99(60/39)

4.2. Treatment

The unit of the study is the systems of linear equations. This study took place from April to June 1999. For each group, the experiment took 17 total class periods for pretest, treatment, and posttest. One class period lasted for 45 minutes. Also, for each school, one teacher taught both the experimental group and the comparison group.

In the comparison groups, students learned to solve the systems of linear equations in the traditional method, that is, by only paper and pencil. Learning in the comparison group emphasized memorizing isolated facts and training algorithms such as the elimination method by adding and subtracting, substitution, and equivalence.

In the experimental group, students learned to solve the systems of linear equations by using graphic calculators. Learning in the experimental group emphasized using and linking multiple representations to solve the systems of linear equations. Use of the graphic calculator enabled students to explore, estimate, and discover graphically and numerically as well as algebraically in order to solve the systems of linear equations.

During the first four hours, activities allowed students in the experimental group to connect the systems of linear equations with the graph of linear function. First, They drew the graph of time-distance by moving themselves using technology such as Calculator-Based-Ranger (CBR) and graphic calculator. The CBR was used for learning the concept of functions. This device allows students to make measurements of real data related to time and motion collected from activities involving themselves. Then they represented algebraically these graphs and connected linear functions with linear equations.

During next eight hours, activities were involved them solve the systems of linear equations linking three representations of function, using graphic calculator. Lastly, students solve using three representations. They selected and modeled proper representation according to problem.

4.3. Instruments

The multiple representation pre- and post-test investigated four components such as algebraic skill, interpretation, translation, and modeling. The pre- and post-test were designed to be administered without access to graphic calculators for both the experimental and comparison groups. Each component assessed the following abilities.

First, items in the algebraic skill component assessed the ability to solve the systems of linear equations algebraically and to compute y values of a given equation when the x value is given in the problem. Second, interpreting is the procedure that changes tabular, graphic, algebraic representations into verbal representations of realistic contexts. Third, a mathematical model may be represented in various ways: algebraically, graphically, or numerically.

Translating is the ability to move from one representation of a function to another. Lastly, the process of mathematical problem solving involves a transition from a problem situation to a mathematical representation of that situation. This process entails the use of equations to form an abstract representation of the quantitative relationships in that situation. Modeling is the ability to implement this process.

Table 2. Components of multiple representations in the pre- and post-test

Components	The number of items	Score
Algebraic skills	5	15
Interpreting	4	12
Translating	2	6
Modeling	5	15

Total score:48

The test consisted of 9 items. The components of each item are shown in Table 2. The postest was conceptually the same and essentially an alternative version of the pretest The reliability of this instrument yields a Cronbach value of $\alpha = 0.8954$. Each correct multiple-choice item was worth 3 points, each incorrect one was 0 points, and each free-response item was scored as 3, 2, 1, 0 according to the quality of the answer. Total points are 48 points (Table 2).

The following are examples of questions from each category.

Algebraic skill: Solve the following systems of linear equations.

$$(1)\ \begin{cases} 6x - 5y = 3 \\ x - y = 5 \end{cases}$$

$$(2)\ \begin{cases} 2x + y = 3 \\ 5x + 3y = 5 \end{cases}$$

Interpreting: Solve the linear equation $x + 2 = -2x + 8$ using the given representations

(1) Solve the equation using the given graph and explain how you solve it.

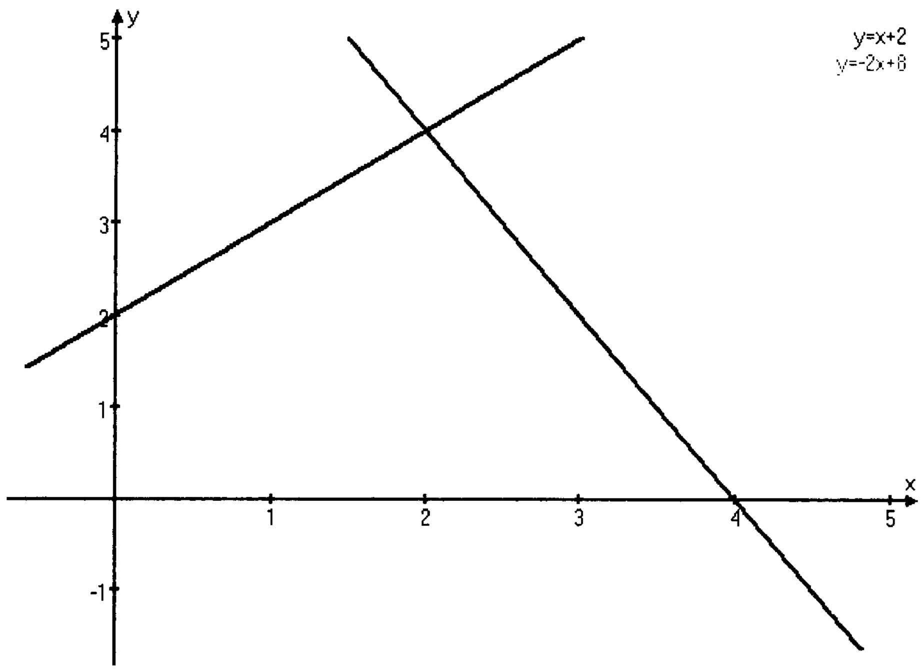

Figure 1. Solving a system of equations

(2) Explain the equation using the given two tables and explain how you solve it.

X	Y
–2	0
–1	1
0	2
1	3
2	4
3	5
4	6
5	7

X	Y
–2	12
–1	10
0	8
1	6
2	4
3	2
4	0
5	–2

Translating: The following tables record the number of push-ups completed by 3 students. Connect each student's table with the corresponding type of graph.

Seung-hee	
1st day	28
2nd day	31
3rd day	34
4th day	37
5th day	40

Gil-dong	
1st day	22
2nd day	23
3rd day	25
4th day	28
5th day	32

Se-hee	
1st day	30
2nd day	35
3rd day	38
4th day	40
5th day	41

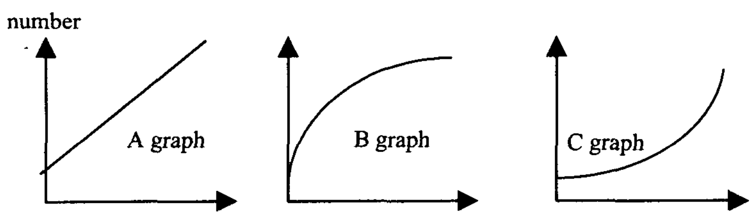

Figure 2. Corresponding graphs

Modeling: Read the paragraph below and draw the graph. Label each axis to distinguish between the motorboat's graph and Titanic's graph.

> Leonardo Decaprio arrived at the harbor just after the Titanic set sail. The ship sailed away at a steady speed. Leonardo jumped into a motor boat and chased the Titanic. After about 10 minutes, he reached the Titanic.

The school tests consisted of regular tests such as a midterm and final test. In this study, the pre-test was the midterm test during the first school term and the post-test was the final test of the semester. There were 100 total points on each test which consisted primarily of algebraic skill items, conceptual understanding items, and calculator-neutral problems such as those indicated by Harvey (1993).

An instrument based on the mathematical attitude scale designed by Aiken(1979) was used to measure attitude before and after the treatment. The 19 items each include five choices on a Likert-scale. The questions deal with the students' attitude toward mathe-atical anxiety, the value of mathematics, the value of graphs in mathematics, and mathe-atical confidence (Table 3). The reliability of this instrument was Cronbach α=0.8850. Pre- and post-test are the same test.

Table 3. Components of attitude survey

Components	Number of items
Anxiety on mathematics	6
Usefulness of mathematics	5
Value of graphs in mathematics	4
Confidence in mathematics	4

V. Data Analysis

5.1. Linking multiple representations

This multiple representation test was aimed at examining the impact of graphic calculators when students link multiple representations within a mathematical context or between mathematics and real contexts.

The items in the multiple representation test were classified into four components: algebraic skills, interpreting, translating, and modeling. Table 4 shows the means and standard deviations of the post-test of the multiple representation test.

Table 4. Mean scores and Standard Deviations for the multiple representation test on the post-test

Component	Comparison (n = 98)		Experimental (n = 99)		F	Sig
	M	SD	M	SD		
Algebraic Skills	2.38	1.64	2.44	1.86	0.718	0.398
Interpreting	5.21	3.27	6.51	4.08	5.961	0.016*
Translating	8.34	4.25	8.92	3.82	0.069	0.794
Modeling	8.15	4.23	9.29	4.35	3.604	0.059
Total	28.86	14.36	32.47	15.36	3.154	0.077

Total Score = 48

As Table 4 shows, the experimental group performed on average 3.6 marks higher on the total scores than the comparison group, but statistical analysis reveals a weak significant difference between the two groups (ANCOVA, $F = 3.154$, $p = 0.077 > 0.05$). The means for all components on the post-test in the experimental group were higher than that in the comparison group.

The statistical difference between the two groups was not significant on algebraic skills ($F = 0.718$, $p = 0.398 > 0.05$), on translating ($F = 0.069$, $p = 0.794 > 0.05$) or on modeling ($F = 3.604$, $p = 0.059 > 0.05$). However, there was a significant difference for the interpreting component between the comparison group and the experimental group ($F = 5.961, p = 0.016 < 0.05$).

Although the experimental group had a slightly higher mean score on algebraic skills, no significant difference was found between the scores of treatment and comparison classes. This data indicated that the students who used the graphic calculators were not hindered in their computational ability. Moreover, the significant difference for the interpreting component may indicate that the students who used the graphic calculators felt more comfortable than the students who did not use the graphic calculators in working with realistic situations. The graphing-approach students in the present study had access to the graphing calculator during every class meeting as well as homework and so had more opportunities to explore linear equations and to examine their applications.

Table 5 shows the means and standard deviations for the post-test by the three schools.

Table 5. Mean scores and Standard Deviations of by the three schools

	A		B		C		*F*	Sig
	M	SD	M	SD	M	SD		
Comparison group	28.00	2.65	29.00	2.42	29.49	2.57	0.623	0.432
Experimental group	31.08	2.89	34.32	2.66	31.89	2.75	0.379	0.685

Total Score = 48

As shown in Table 5, statistical analysis reveals no significant difference between the three schools in the comparison group (ANCOVA, $F = 0.623$, $p = 0.432 > 0.05$) and the experimental group ($F = 0.379$, $p = 0.685 > 0.05$). This data demonstrates that teacher had little impact on students' connections of multiple representations and modeling of real situations.

Table 6 shows means and standard deviations for the midterm school test and the final school test (used to measure the students' traditional algebraic skills). For the comparison group, the mean in the post-test was higher by 2 points than that in the pre-test. For the experimental group, the mean in the post-test was lower by 3 than that in the pre-test. No significant difference, however, was found between the scores of the experimental and comparison groups on the post-test scores (ANCOVA, $F = 0.785$, $p = 0.441 > 0.05$). Similarly, no significant differences were found for main effects of instructor or for any interactions among the two variables.

Table 6. Mean and Standard Deviation for midterm test and final test

	Comparison (n = 98)		Experimental (n = 99)		*F*	Sig
	M	SD	M	SD		
Midterm test (pre-test)	58.270	7.930	60.150	7.614	.785	.441
Final test (post-test)	59.113	1.185	57.621	1.185		

Total Score = 100

5.2. Attitude toward mathematics

This test was aimed at examining any change in students' attitudes toward mathematics. Table 7 shows that the means for four components and the total scores of the pre-test and the post-test. For the comparison group, the mean in the post-test was 4 points lower than that in the pre-test, while for the experimental group, the mean in the post-test was similar with that of the pre-test. These statistical analyses indicated that the use of graphic calculators enables the students to ameliorate their negative attitudes toward difficult mathematics content.

The means for all components and total scores on the post-test in the experimental group was higher than that in the comparison group. Moreover, statistical analysis of this data reveals a significant difference between the two groups for the total scores (ANCOVA, $F = 17.761, p = 0.000 < 0.05$), for the anxiety in mathematics ($F = 9.820$, $p = 0.002 < 0.05$), for the usefulness of mathematics ($F = 9.162, p = 0.003 < 0.05$), for the value of graphs in mathematics ($F = 21.464$, $p = 0.000 < 0.05$) and for confidence in mathematics ($F = 10.285, p = 0.002 < 0.05$).

Table 7. Mean scores for post-test on attitudes toward mathematics

Component	Comparison ($n = 98$)		Experimental ($n = 99$)		F	Sig
	M	SD	M	SD		
Anxiety in mathematics	17.00	5.277	19.14	5.144	9.82	0.002
Value of mathematics	16.13	3.495	17.63	3.572	9.16	0.003
Value of graphs in mathematics	10.78	2.851	12.61	2.902	21.46	0.000
Confidence in mathematics	10.96	3.07	12.39	2.89	10.28	0.002
Total	54.88	10.98	61.78	11.47	17.76	0.000

Students' levels of mathematics anxiety were significantly reduced as a result of their experience using graphic calculators. Because graphic calculators have many functions to automate traditional tasks of arithmetic manipulation, the use of graphic calculators can reduce anxiety regarding mathematics.

The significant difference between two groups for the value of graphs in mathematics could spring from the fact that graphs can help students to investigate mathematical problems: the graphic calculators can generate many graphs quickly and dynamically translate graphs into other representations.

VI. CONCLUSION

There was no significant difference in linking multiple representations among mathematical realistic contexts between the two groups but the experimental group performed better than the comparison group. This result shows that when solving systems of linear equations, students who used graphic calculators had a tendency to derive the answer from a multiplicity of methods, while the other students tended to answer the item using only algebraic representations.

However, on linking multiple representations within mathematical context (interpreting component), no significant difference was found between the experimental group and the comparison group. Although this research shows no significant difference between the two groups, many previous studies revealed the effects of graphic calculators on translation. O'Callaghan (1998) reported that the algebra curriculum using graphic calculators was very thorough in its treatment of the numeric as well as the graphic and symbolic properties of functions, and led to proficiency in translating between multiple representations.

In the school mathematics tests, no significant difference between the two groups was obtained in the final test. Also, no significant difference between the two groups resulted in algebraic skills for the multiple representation test. It can therefore be inferred that the experimental students who used graphing calculators were not hindered in their computational ability. The graphing calculator treatment was not expected to give the students any advantage over the traditional students because the school mathematics tests focused mainly on paper-and-pencil calculation and manipulations such as simplifying and transforming symbolic expressions and solving equations.

Further, students using graphic calculators showed significant improvement in their attitudes toward mathematics. Using the graphic calculator provided students with an opportunity to solve an interesting practical problem that promoted the development of concepts through exploration. Moreover, the graphic calculator enabled students to increase their self-confidence and it engenders more positive attitudes toward learning as a pleasurable activity.

There results are somewhat congruent with findings in the study of O'Callaghan (1998). However, students in the graphing-approach curriculum as a group did not differ from traditional students in their attitudes toward mathematics for Hollar & Norwood's study. As yet, there is no consensus on the effect of technology use on attitude. Studies are needed to advance the knowledge of structural and procedural conceptions interact with when students are doing algebra such as solving linear equations within a technological environment.

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