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Learning Mathematics with Interactive Whiteboards and Computer-Based Graphing Utility

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ABSTRACT

The purpose of this study was to explore the effect of a technology-supported learning environment utilizing an interactive whiteboard (IWB) and NuCalc graphing software compared to a traditional direct instruction-based environment on student achievement in graphs of quadratic functions and attitudes towards mathematics and technology. Sixty-five high school graduates attending cram schools (called *dershane* in Turkish) to study for the university entrance examination participated in the study. The significant interaction effect between time of testing and groups indicated that student performance across time of testing was dependent upon the presence or absence of the treatment. Comparisons suggest that although both experimental and control group students' performances increased from pre-test to post-test and then decreased from post-test to retention test, the rate of decrease was about the same and the rate of increase was different, with students showing a greater rate of increase in the experimental group. The results also revealed that the treatment had positively affected students' attitudes towards technology and mathematics. Moreover, students' reasoning and interpretation skills regarding graphs of quadratic functions were better in the experimental group as compared to those in the control group.

Keywords

Interactive whiteboard, Computer-assisted learning, Graphing, Quadratic functions, Mathematics education

Introduction

IWBs may turn a computer into a powerful teaching and learning device with the use of vivid colors, different fonts, integrated web pages and applets, presentation software, and scanned images (Fernandez & Luftglass, 2003). In recent years, large-scale investments in IWB technology throughout the world have been quite striking (see Digregorio & Sobel-Lojeski, 2010; Hennessy & London, 2013; Kitchen, Finch, & Sinclair, 2007; Slay, Siebörger, & Hodgkinson-Williams, 2008; Somyurek, Atasoy, & Ozdemir, 2009). For example, a recent effort called "Movement of Enhancing Opportunities and Improving Technology," abbreviated as the "FATİH Project" (Turkish Ministry of National Education [MoNE], 2011), proposes that a "Smart Class" project be put into practice in all schools around Turkey. With this project, 42,000 schools and 570,000 classes will be equipped with the latest information technologies and turned into computerized education classes (Smart Classes) by providing tablets and LCD touch screen interactive boards. As part of the project, each of the around 630,000 teachers will receive laptops. But is it worth it?

Several studies suggest that use of IWBs can have positive effects on teaching and learning (British Educational Communications and Technology Agency [BECTA], 2003) as they promote students' interest and motivation, provides longer sustained concentration and more effective learning (Glover & Miller, 2001; Somekh et al., 2007; Wood & Ashfield, 2008) and foster responses to a range of learning processes (Glover, Miller, Averis, & Door, 2007). However, much of the literature supporting the use of the IWBs provides insubstantial evidence (Clarkson, 2011; Smith, Higgins, Wall, & Miller, 2005). The literature regarding IWBs in mathematics education, on the other hand, is limited in terms of how they affect students' attitudes toward technology in mathematics and how their achievement is affected by this new technology (Heemskerk, Kuiper, & Meijer, 2014). The current research emphasizes mostly how to use these new devices (e.g., Miller, Glover, & Averis, 2005; Shae & Tseng, 2001), teacher use of IWBs (e.g., Beauchamp, 2004; Kennewell & Beauchamp, 2007), the pedagogy of using IWBs, student attitudes, and interaction among students, teacher, and technology (Armstrong, Barnes, Sutherland, Curran, Mills, & Thompson, 2005; Wall, Higgins, & Smith, 2005). For example, after investigating if the concepts of rotation, translation, and reflection can be taught by IWB more effectively in seventh grades, Robinson (2004) concluded that the IWB has no significant effect on achievement but improves the attitudes towards the lesson. Similarly, Heemskerk, Kuiper, and Meijer (2014) found no evidence that the use of an IWB in mathematics lessons is associated with better learning results, while students with higher exposure to IWB lessons are more motivated for mathematics and perform better than students with lower exposure to IWB lessons. So why and how to use IWBs in mathematics education is still a question open to empirical test.

Purpose of the study

As in the case of the FATİH Project in Turkey, widespread technology initiatives and investments worldwide require empirical evidence about if and how the intended technologies would be beneficial to the students and teachers. Without such evidence, while there are less expensive projection technology, justification of IWB use for enhancing students learning beyond being a presentation tool is problematic (Wall, Higgins, & Smith (2005). According to Moss and Carey (2010, pp. 20-23), the effect of IWBs depends crucially on how it is used, not on the mere absence or presence in the classroom. Considering that IWBs are growing popular even without such strong evidence, then, as Ringstaff and Kelly (2002) once asked about education technology in general, the important question should be "Under what conditions do IWBs have the most benefit for students?" rather than "Are IWBs worth the cost?" Moreover, as Digregorio and Sobel-Lojeski (2010) concluded in their extensive review of the research on the effects of IWBs on student performance and learning, the evidence of the effect of IWB use on students' learning and motivation is inconclusive and research regarding IWBs should focus beyond generic learning gains and on subject-specific learning, along with taking the contextual factors and mediating variables into account. Geiger, Forgasz, Tan, Calder, and Hill (2012) conclude that while IWBs are becoming increasingly available, there is little research identifying "how best to use it to promote deep mathematical knowledge and understanding, or to enhance genuinely collaborative approaches to learning" (p. 132). Regarding the role of IWBs for enhancing the quality of interaction and improving conceptual mathematical understanding, De Vita, Verschaffel, and Elen (2014) concludes that "there is need for greater attention to the pedagogy associated with IWB use and, more specifically, to stimulate the design of new kinds of learning environments." Thus, the purpose of the present study was to investigate the effects of a technology-supported learning environment utilizing IWBs in conjunction with NuCalc graphing software (Avitzur, Gooding, Wales, & Zadrozny, 1998) on students' achievement in quadratic equations and functions compared to traditional direct instruction. Furthermore, students' attitudes towards technology and mathematics and their views about using IWBs and computers in learning mathematics were also studied.

Technology and mathematics education: Case of graphs and graphing

Graphs and graphing are particularly considered by many teachers and researchers to be the most important and fundamental concepts in all of mathematics (Doerr & Zangor, 2000; Leinhardt, Zaslavsky, & Stein, 1990; Mevarech & Kramarsky, 1997), since graphs are essential for school algebra and can be used as a bridge between concrete thinking and abstract thinking (Piaget, Grize, Szeminska, & Bang, 1977). As technological environments support visualization and experimentation (Arcavi & Hadas, 2000), technology has allowed much more emphasis to be placed on graphs and their interpretation. They offer many advantages over manual graph plotting, such as multiple representations, and they also allow students to examine many more graphs more quickly with a high degree of accuracy and with minimal input effort (Forster, 2006; Fung, Hennessy, & Scanlon, 2001; Pierce, Stacey, & Barkatsas, 2007). With technology, students can plot the graphs and then observe their patterns and make connections among algebraic, tabular, and graphical representations with high accuracy in shorter periods of time compared to manual plotting of graphs (Heid, 1995; Interactive Educational Systems Design, 2003). This is particularly important as students find it very hard to understand relationships and translate among representations, because each representation and translation among them requires a different psychological process (Leinhardt, Zaslavsky, & Stein, 1990). For example, in most problems involving graphing, translations from equation to graphs and from graphs to equation are required. Concerning these two translations, movement from graphs to their equation would be a more difficult task because it involves pattern detection. If the latter is in the form of a matching-type item, students check for the equations and do not attempt to move graphs to equations. On the other hand, the graphs in textbooks usually have equal scales, and critical points (e.g., *x*-*y* intercepts, axis of symmetry) are usually integers. However, in realistic or real-life problems, students are faced with unequal scales and rational or decimal critical points, and they find it difficult to interpret results on the graphs. Partial views, axes without labels, and individual points on the graphs are other difficulties for students to interpret. However, with utilization of graphing technologies, students are forced to think about such issues, since the equation may be given with or without the scale, or even with a partial view (Cavanagh & Mitchelmore, 2003; Leinhardt, Zaslavsky, & Stein, 1990).

Methodology

Participants

Like other national standardized exams in Turkey, students are prepared for university entrance exams mostly in *dershanes*, which is the Turkish counterpart of the cram schools found all over the world. While the high school graduates preparing for the university entrance exam typically attend *dershanes* on weekdays, those attending regular schools attend *dershanes* on weekends and in some instances after school hours. In *dershanes*, students are mostly taught towards standardized tests for solving multiple-choice items. Based on their intended field of study at university, they are required to solve tests including mathematics (mostly arithmetic, algebra, and geometry), Turkish language, history, geography, and philosophy.

The participants in this study were 65 high school graduates preparing for the university entrance examination. The experimental group (EG) consisted of 31 students while the control group (CG) consisted of 34 students. Although there were 35 students in each group at the beginning of the study, the number of participants for each group is defined as the number of students who completed the treatments and all the tests administered. The students' ages in both groups ranged from 18 to 20. Students in both groups were attending two separate *dershanes*. Thus, students in the experimental and control groups did not know or have a chance to interact with each other. Moreover, in both groups, students' social and economic statuses were nearly the same. Except for two students in the control group, students in both groups had only one parent working and family incomes were nearly the same. Also, none of the students had a computer at home. The students in both groups were chosen based on the scores that they received from the university entrance examination the previous year and their high school grades. In terms of these, the students that participated in the study were average students.

Instruments

Graphing Achievement Test

The Graphing Achievement Test (GAT) was developed by the researchers to measure student achievement in graphing quadratic functions. It consisted of 15 items, some of which included sub-tasks: 10 multiple-choice, 3 matching-type, and 2 essay-type. Explanations are required for answers in all items, including the multiple-choice ones. The items in the GAT consist of three task types to assess how students interpret and construct graphs of quadratic functions: translation (translating among algebraic, tabular, and graphical representations of quadratic functions; translating a graph of a quadratic function, parabola), classification (classifying given parabolas using properties and coefficients), and drawing (drawing the graph of a quadratic function, a parabola, provided in algebraic form) (see Leinhardt, Zaslavsky, & Stein, 1990). Furthermore, all items involved the concept of scaling.

The test was checked by three mathematics teachers for level of difficulty, accuracy of wording, and suitability to measure the related objectives in the curriculum. The pre-test consists of the same number of questions with the same context as the other two tests. The only difference between the pre-test and the others is that different numbers are given in every question assessing the same objective. The post-test was piloted with 75 students chosen from three different *dershanes* in Ankara. The students were given 60 minutes to complete the test. Students were interviewed to reveal if the tasks were easily understandable and if there were any incorrect or incomplete questions, and also to assess the reliability and consistency. After this pilot, the test remained unchanged. Cronbach's alpha was .82.

The GAT was administered as a pre-test, post-test, and delayed post-test (two months after the treatment was over) to both groups. Fifty minutes were given to complete the test. All tasks in the test were scored as 0, 1, or 2 for each incorrect answer, correct answer, and correct answer with complete explanation, respectively. The maximum possible score in all three tests was 58.

Attitudes towards Mathematics Inventory

The Attitudes towards Mathematics Scale (ATMI) (Tapia, 1996; Tapia & Marsh, 2002, 2004) was administered to the experimental group before and after the treatment to assess the students' attitudes and attitude changes toward mathematics. The ATMI consisted of 40 five-point Likert type items with 28 positive and 12 negative statements: from "strongly disagree" (0) to "strongly agree" (4). Higher scores indicate more positive attitude towards mathematics. Students were given 20 minutes to complete the ATMI. Cronbach's alpha reliability coefficient of internal consistency was .75.

Attitudes towards Technology Scale

The Attitudes towards Technology Scale (ATTS) was administered to the experimental group before and after the treatment to assess students' attitudes toward technology use in mathematics lessons. The ATTS consisted of 20 items scored on a Likert-type five-point scale ranging "never" (0) to "always" (4). Higher scores indicate a positive attitude towards technology. The students were given 10 minutes to complete it.

The first 10 items that were taken from *the Mathematics and Technology Attitudes Scale* (MTAS) (Pierce, Stacey, & Barkatsas, 2007) were about attitude towards computer technology. Cronbach's alphas for the *confidence in using technology* and *attitude to the use of computers to learn mathematics* sub-scales were .79 and .89 respectively. The remaining ten items were taken from *the Computer Attitude Questionnaire* developed by Knezek and Christensen (1996) for middle and high school students. The scale measures IWB enjoyment and motivation, importance of IWB, and use of IWB to learn mathematics. The corresponding Cronbach's alpha values for these sub-scales were .80, .84, and .81, respectively.

Procedures

The study was designed as a pre-test, post-test, delayed post-test quasi-experimental control group study in which two different teaching and learning environments were utilized: one with traditional instruction and the other with the incorporation of an IWB and computer sessions. Students in the experimental group were taught in a classroom with an IWB and in a computer laboratory with 16 computers. Connected to a large screen, one of the computers was for teacher use. On the other hand, students in the control group were taught in a classroom with a blackboard and did not have computer access. Other than the IWB and computers, class size and classroom items (seats, desks, etc.) in both cases were similar.

Both experimental and control group students were taught by the second author, who followed the same sequence and content of lessons and solved the very same questions in both classes. The lessons and assignments were in line with the standards and objectives dictated by the MoNE. The content was also aligned with the official textbook of the MoNE for the tenth grade, where the topics are first introduced. The lessons included tabular, graphical, and algebraic representation of quadratic equations/functions, their translations, and their properties depending on the coefficients and discriminants of the equations and the symmetry axis.

After preparing assignments and lessons, two other mathematics teachers' opinions were sought: One was 35 years old with 10 years of teaching experience and the other was 37 year-old with 12 years of teaching experience. The assignments' levels are determined by the students' success from their high school mathematics scores and scores from their exams in the *dershane*.

To assess the appropriateness of the lesson plans, activities, use of IWB, and computers, the study was piloted with 7 students. All students were asked to write an essay about their feelings and thoughts regarding the learning environment and the lessons. We also carried out an hour-long interview with 2 of the students. While no problems were encountered in terms of IWB and computer usage, some changes (e.g., removing or clarifying the content, increasing the number of solved questions regarding translating among different representation types) were made in the lesson contents.

Data were collected over a period of two weeks. Participants met twice a week and took four hours of lessons, each of which lasted 60 minutes for both groups. In the experimental group, class sessions were followed by computer laboratory sessions, each lasting about 60 minutes. Furthermore, interviews were carried with 6 students chosen based on their scores in pre- and post-tests to learn more about (*i*) whether the IWB created a difference in their learning, (*ii*) if and how the IWB changed the students' opinions about mathematics and technology, and (*iii*) what would be the advantages and disadvantages of using the IWB. Three of these students (i.e., Students A, B, and C) got zero points from the pre-test of the GAT. Their scores for attitude towards mathematics and technology were also lower prior to the study. They expressed that they did not know or have any idea about quadratic equations and functions. The other three (i.e., Students D, E, and F) were average students according to their pre-test scores. They had an average or above average attitudes prior to the study. Despite their differences, all of these 6 students increased their performance in the GAT and attitudes significantly after the treatment. The interviews were video-recorded.

Treatments for the experimental and control groups

For the experimental group, lecture notes were given to the students in the lessons and also reflected on the screen of IWB. However, the control group students needed to take notes in the lessons and so sometimes the lectures took longer as compared to the experimental group. Students worked with NuCalc graphing software (Avitzur et al., 1998) in the computer lab. In order to draw a graph with NuCalc, the user only needs to enter the equation and press the enter button without the need for any command syntax. The post-lesson computer laboratory sessions for the experimental group helped students to explore and interpret relationships between the knowledge that they learned in the classroom and gave them the opportunity to draw multiple graphs in order to observe and interpret relationships as coefficients in the functions changes. In the NuCalc environment, it is possible to draw multiple graphs with different colors on the same screen so that users can compare graphs by their coefficients. Moreover, zoom in and zoom out options are available in the program and the most powerful feature of the software is its capability to turn a graph of any function into an animation. The software recognizes the letter "*n*" in an equation as a parameter and graphs can be animated on any variable and on any defined domain. The experimental group was taught about NuCalc before the treatment by the second researcher and it took 60 minutes. During this time students learned coordinate systems, points on the coordinate systems, to plot graphs of linear functions, to draw more than one graph in one coordinate system, to draw graphs of quadratic functions, to draw multiple graphs on the same screen, to graph polynomial functions with any degree, and other functions like sine, cosine, and absolute value.

In the experimental group, the first part of the treatment took place in the classroom where the IWB was present. Before the lessons, the lecture notes were prepared by the teacher (i.e., the second researcher) and were distributed to the students. The lecture notes consisted of the definitions, main titles and subtitles, and examples to be solved together in the classroom. The notes were reflected on the IWB screen. As they did not need to write down the information and definitions, students had more time to listen, discuss, and solve more examples. The graphs and tables were ready to draw and to fill in on the IWB. Such graphs and tables were also present in the students' notes. Thus, the teacher and the students together constructed the table with values and drew the graphs on the coordinate system. After drawing a couple of graphs, multiple graphs with different colors were drawn on the same coordinate system. The students had a chance to compare and contrast the graphs and interpret their properties, which are connected to the solution sets. They also learned to draw graphs of the following types of functions:

$y = x^2 + a$, $y = (x+a)^2$, $y = (x+a)^2 + b$, and $y = ax^2 + bx + c$ $(a, b, c \in \mathbb{R})$ starting with $y = x^2$.

After the lessons with the IWB, the computer laboratory session took place. Each student had one computer to practice on and the researcher had the main computer, which was connected to a large LCD TV screen. All the computers were pointed towards the screen so that students had a chance to check their answers from the main computer screen reflected on the TV screen. With the activities in the laboratory, students continued doing algebraic, tabular, and graphical representations and translation problems using NuCalc. However, this time the researcher showed only the first activity and the whole class discussed the results together; then the students did the rest of the activities by themselves, individually. Moreover, before drawing the graphs, students were expected to draw by hand first and then to check from the screen. With these activities, students were expected to practice the properties and use the computer as a checking tool.

In the control group, on the other hand, students studied the topic through traditional direct instruction. That is, students took notes from the blackboard and solved the question asked. The teacher explained the concept by writing down the definitions and properties and waited for the students to write. This writing part took more time and so the control group solved fewer problems compared to the experimental group. Nevertheless, they mainly solved the same problems in the same order. More time was spent on drawing and waiting for students to draw the graphs and less time was spent on discussion. Moreover, the control group solved slightly fewer examples compared to the experimental group because the writing and drawing took longer.

Results

Student achievement in graphing and interpreting quadratic functions

To compare changes in students' GAT from pre-test to post-test and to delayed post-test between experimental and control groups, pre-test, post-test, and delayed post-test scores for both groups were calculated (see Table 1). Mean test scores indicate that students in both the experimental and control groups have made significant content knowledge gains from pre-test to post-test, and lost a portion of it between post-test and delayed post-test.

Table 1. Descriptive statistics regarding experimental and control groups' pre-test, post-test, and delayed post-test scores for the GAT

	Pre-test		Post-test		Delayed post-test	
	M	*SD*	*M*	*SD*	*M*	*SD*
EG (n = 31)	10.68	9.24	45.58	5.75	43.26	5.02
CG (n = 34)	10	8.59	35.21	8.64	32.62	7.39

Conducting mixed ANOVA, Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(2) = 20.5$, $p < .001$); therefore, degrees of freedom were corrected using Huynh-Feldt estimates of sphericity ($\varepsilon = .81$). The results show that students' performances significantly changed across times of testing (i.e., pre-test, post-test, and delayed post-test), $F(1.62, 101.97) = 583.97$, $p < .001$, $\eta^2 = .90$. Furthermore, contrasts revealed that the students performed significantly better in the post-test relative to both the pre-test, $F(1, 63) = 783.35$, $p < .001$, $\eta^2 = .92$, and the delayed post-test, $F(1, 63) = 12.5$, $p = .001$, $\eta^2 = .17$.

There was a significant interaction effect between time of testing and groups, $F(1.62, 101.97) = 16.9$, $p < .001$, $\eta^2 = .2$. This indicates that student performance across time of testing was dependent upon the presence or absence of the treatment. Contrasts comparing students' scores in the EG and CG across the three times of testing revealed significant interactions when comparing EG and CG students' scores in the delayed post-test compared to the pre-test, $F(1, 63) = 24.06$, $p < .001$, $\eta^2 = .28$, but not in the post-test compared to the delayed post-test, $F(1, 63) = 0.04$, $p = .85$, $\eta^2 = .001$. This suggests that although in both the EG and CG students' performance increased from pre-test to post-test and then decreased from post-test to delayed post-test, the rate of decrease was about the same and the rate of increase was different, with students showing a greater rate of increase in the EG. The results indicate that only the groups (i.e., intervention factor) exerted a significant effect on students performances, $F(1, 63) = 22.54$, $p < .001$. In other words, the EG achieved better than the CG, averaged across the pre-test, post-test, and delayed post-test.

Students' attitudes toward technology and mathematics

Table 2 shows mean scores for the attitude scales for mathematics and technology (i.e., ATMI and ATTS) administered only to the experimental group before and after the treatment. Results show that the students developed a more positive attitude toward technology and mathematics after the treatment. For example, although 59.4% of the students were undecided about the statement "I concentrate better in class when a whiteboard is used to deliver instruction" prior to the study, 93.8% of the students either agreed or strongly agreed with it after the study.

Moreover, although most of the students were undecided about "Interactive whiteboard and computer would help me to learn mathematics better" prior to the study, 80% of the students either agreed or strongly agreed with it at the end.

Table 2. Descriptive statistics regarding the ATMI and ATTS scores for the experimental group (n = 31)

	Pre-test		Post-test	
	M	*SD*	*M*	*SD*
ATMI	33.37	7.90	65.78	3.58
ATTS	55.09	19.27	103.18	11.4

Regarding the ATMI, on the other hand, students' positive attitudes and feelings could be concluded. To illustrate, prior to the study, for example, regarding Item 21, "I feel comfortable in mathematics lessons," no students selected strongly agree, 6.3% selected agree, 31.3% selected undecided, 37.5% selected disagree, and 25% selected strongly disagree, showing that most of the students felt uncomfortable in their mathematics lessons. On the other hand, after the treatment, strongly agree increased to 37.5%, agree increased to 50%, and undecided decreased to 12.5%, showing that the students were more comfortable in mathematics lessons when IWB and computer technologies were used.

The related sample t-test was run in order to examine whether students in the EG developed more positive feelings and attitudes toward mathematics and technology. The results revealed that the EG post-ATTS scores were significantly higher than those of pre-ATTS: $t(31) = 24.303$, $p < .001$.

Students' performance in drawing and interpreting graphs of quadratic functions

Although students in both groups improved their achievement in drawing and interpreting graphs of quadratic functions, it was found that students in different groups had different solution strategies. Considering Items 1, 2, and 3, students in the CG were good at drawing graphs from equations by following the steps/procedures given in the lessons (i.e., finding ordered pairs, plotting them onto coordinate system, and drawing the equation). However, considering Items 4, 7, 8, 9, and 10, they could hardly transfer/integrate other knowledge like the discriminant, symmetry axis, and coefficients. On the other hand, the students in the EG were also good at drawing graphs considering Items 1, 2, and 3. However, along with following step-by-step instructions, they also used translation, coefficient of functions, discriminant, and symmetry axis for Items 6, 7, 8, 9, and 10. For example, in Items 7 and 8 students were expected to relate a given graph with its equation among the alternatives (see Figure 1).

Table 3. Frequencies of student answers for Items 7 and 8 in pre-test, post-test, and delayed post-test of the GAT in control and experimental groups

	Item 7						Item 8					
	CG			EG			CG			EG		
	0	1	2	0	1	2	0	1	2	0	1	2
Pre-GAT	20	9	4	31	0	1	31	1	1	31	1	0
Post-GAT	1	14	18	7	8	17	18	14	1	7	8	17
Delayed Post-GAT	8	11	14	4	18	10	25	8	0	4	17	10

Note. 0: incorrect; 1: correct; 2: correct with complete explanations.

Regarding Item 7, while most of the students had difficulty in choosing the correct equation in the pre-test, the majority of them were able to find the corresponding equation. However, in the delayed post-test, the number of students who found the correct answer in the CG decreased more compared to that in the EG (see Table 3). Most of the CG students attempted to solve it by trying to draw the corresponding graphs for each equation in the alternatives. The rest tried to substitute 0 for x in each alternative and compare with the given graph. Two students found the correct equation by substituting –1, 0, and 1 for x and finding the coefficients a, b, and c in ax^2+bx+c. On the other hand, 10 students in the CG used an x^2 graph to find the desired equation. They translated the graph 1 unit downwards and found the correct choice. The rest of the students preferred using the y-intercept to find the coefficient c. They reasoned that since the graph passes $x = –1$, then $c = –1$, and thus they eliminated alternatives A and D. They then substituted 1 and –1 in the remaining alternatives and found the correct answer. On the other hand, while Item 8 assesses the same knowledge as Item 7, it was more difficult since the graph did not cross the x-axis and students could not easily eliminate the alternatives. Thus, most of the students had difficulty in finding the correct answer (see Table 3). The CG students mostly choose A, a distractor. They easily eliminated alternatives B, C, and E, where the constants are –1 and the graphs passes through 1 on the y-axis. After eliminating these alternatives, they could choose between A and D. Most of them chose A, since it was more familiar to the students and they did not take the effect of the leading coefficient in the equation into account. On the other hand, students in the EG also eliminated alternatives B, C, and E for the same reasons. However, most of them compared the given graph with the one in Item 7 and concluded that the leading coefficient needed to be larger than zero as the graph was closer to the y-axis. Also, 7 students picked certain points on the graph and tried substituting those in the alternatives to find the correct one. Two EG students' answers for Items 7 and 8 are provided in Figure 1. Those students approached the problem more visually rather than from an algebraic manipulation point of view as they used translation of the graph of $y = x^2$ to relate the given graph with an equation.

In the post-tests, the EG did not depend on the step-by-step solution; they used translation among graphic, tabular, and algebraic forms. They also considered the effect of coefficients on graphs and properties of quadratic equations like the discriminant and symmetry axis. They provided explanations about the graphs that they drew. This provides evidence that the EG students used critical properties related to quadratic equations/functions and their understanding was deeper.

EG students did better in interpreting items involving classification and translation tasks as compared to those in the CG. As emphasized by Leinhardt, Zaslavsky, and Stein (1990), the major difficulty for students of all ages is the translation between algebraic, graphical, and tabular representations. Students find it very hard to understand relationships and translate among representations because each representation and translation among them requires a different psychological process. For example, most items in the GAT required translations from an equation to graphs and from graphs to an equation. Concerning these two translations, movement from graphs to their equation would be a more difficult task because it involves pattern detection.

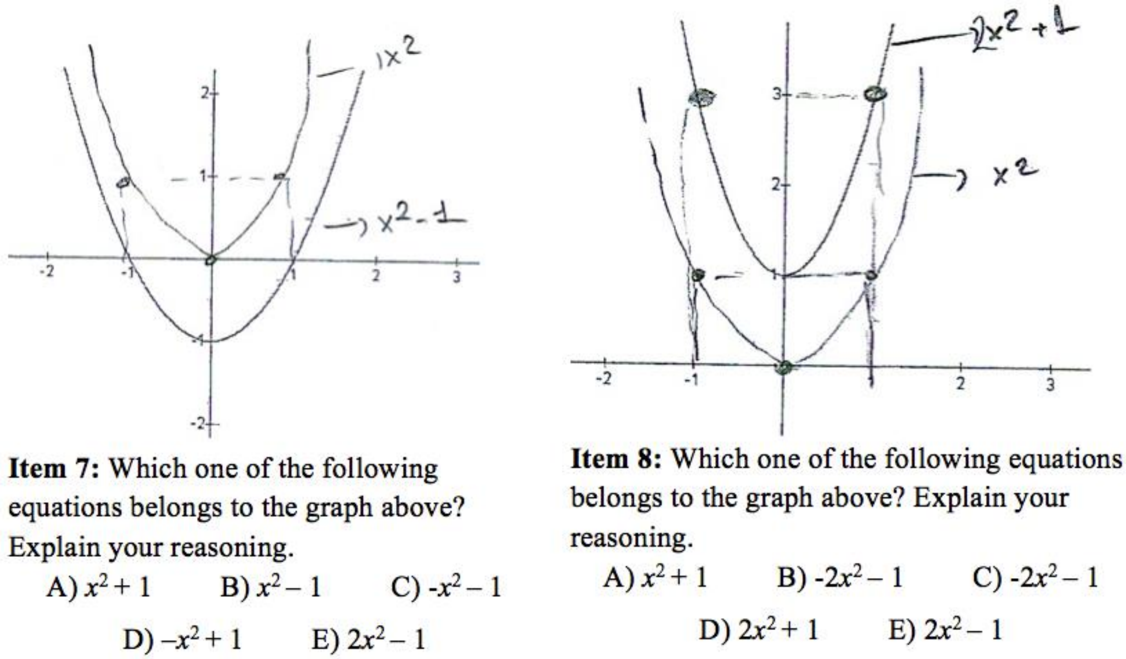

Figure 1. Two EG students' solutions for Items 7 and 8

For drawing graphs from the algebraic form, students followed the steps (i.e., finding ordered pairs, plotting them onto coordinate system, and drawing the equation). For finding the equation from a given parabola, students had more difficulty. For matching-type items, students attempted to draw graphs for the equations without attempting to make a connection between the graphs and the equations. This conclusion had some similarities to Barton's (1997) study, where he also found that the group that used technology made more connections to their previous knowledge (i.e., transfer), suggested better (or well-formed) explanations, and made better predictions (or conjectures) as compared to the CG.

Students' views about graphing

All six students interviewed expressed that they developed positive feelings and attitudes toward graphs and graphing in mathematics after IWB use and expressed that their explanation and reasoning skills improved. They indicated that they could comment on and make interpretations regarding a given problem about the quadratic functions.

> Before taking this lesson, I wouldn't even guess what the shape of a quadratic function looked like. But after the lessons I can now visualize the drawings [*i.e., the graphs*] even when we talk. I can explain now that the coefficient of x^2 indicates whether the parabola is closer to or far away from the y-axis and the constant shows the y-intercept and each unit that we add the x, the parabola changes the place on the x-axis. Moreover, I learned the relation between the discriminant and the x-intercepts of the parabola. So in any question just by knowing this I believe that I can draw any graph without calculation and in the test I can find the correct answer. So I am not afraid of seeing a graphic in the test now. (Student A) [*italics added*]

> At first, I was just thinking that graphing consists of a given algebraic expression and drawing it and vice versa. However after the lesson, I realized that I was spending too much time drawing the graph and if I could not find the intercepts I was giving up drawing. Also, if the [*multiple-choice*] question required writing the equation of a parabola I was checking the equations given in the alternatives and drawing the matching graph for each to see if any one of those matches with the graph given in the question. However, I learned that drawing [*graphs*] includes more than this. Now I can use different representations: tabular [*i.e., numerical*], graphical, and algebraic to find the correct answer. I can easily translate among different modes of representations. This takes less time and sometimes I can find the correct choice without writing or calculating anything. (Student F) [*italics added*]

One of the students (Student D), on the other hand, explained her views by using her hand as the shape of a parabola and moving her hand as if the coefficients changed. She was very enthusiastic about describing what each shape means based on the changes in the parameters. While talking about reasoning skills, Students D and E explained that they could also apply their knowledge gained during the study to various graphs other than quadratic functions. They indicated that they could solve problems involving graphs of the first and third degree as well as some

Students' views about learning with IWB

Analysis of student interviews revealed that students found doing mathematics with IWBs more interesting (n = 4) and fun (n = 5). Students mostly mentioned the visualization (n = 6) and the efficiency and ability to save time for discussion and examples (n = 5). Except for Student B, the others had positive comments about the IWB.

> The IWB is good only for saving time. Since I do not have to write down all the things on the board I have more time to solve more examples. Other than that I do not think that the IWB helped me to understand better. Because I cannot easily understand things in class; in order to understand them I need to study by myself. I need to apply what I learn. (Student B)

He explained that the computer and the NuCalc software helped a lot more with drawing and translation. He could study alone with the computer so that he could think more about examples and connect them with the lesson. In this sense, he thought he would benefit more from the computer (i.e., the software) than the IWB, yet he found that the IWB made the lessons more interesting. Unlike Student B, on the other hand, Student C insisted that the IWB should be used in every mathematics lesson, basically because of the fact that students can use the extra time to focus on the solutions instead of trying to write down everything on the board.

> I cannot imagine a lesson without the IWB. It is great because the teacher's notes are reflected on the board and we have copies and so we have time for more examples, for more talking. We especially discussed why and how questions helped me to improve my learning. In other lessons, we try to write down everything on the board, and if we are late in finishing writing we skip the example without really understanding it. Also, I can say about the IWB that I especially love using different colors in drawings of graphs. Seeing different

> graphs with different colors in one coordinate system helped me to understand the relation between the changing coefficients and the corresponding graphs. …Now I have started to like mathematics. Before using the IWB, I sat at the back of the classroom and did not want the teacher to ask me any questions. I just listened to the teacher without thinking. But now, the IWB makes me think about the lesson, because I start to have fun and that makes me interested in the lesson. And I found myself waiting for another question, checking my answers. I think the IWB motivates me in the lesson. (Student C)

Students' views about learning with computers

Analysis of interview data indicated that students found that drawing graphs is quicker (n = 4) and more fun (n = 3) with NuCalc. They also mentioned the visualization (n = 3) and immediate feedback (n = 3) that the software enabled. Prior to the study, some students indicated that they had difficulties using computers. However, all students interviewed expressed that they found it very easy to use the NuCalc software. As Student-A expressed, "Anyone who can type the equation and press the enter key can use the program; there is no need to know anything about the computer itself." During the computer sessions, however, some students had difficulty entering the correct formula, particularly those including brackets. However, they either asked for help or tried to enter the equations again by themselves. All of the students expressed that they loved being able to draw a graph in a flash.

> Drawing a graph with one click is amazing. After a couple of questions before I hit the enter key, I tried to visualize the shape of the equation: where it passes, downward or upward, intercept points, and after a couple of tries a lot of the time I guessed the correct shape. This was wonderful for me because at first I did not know what a parabola looked like but now I can draw them in my mind. This will be very helpful for me while selecting the correct equation and correct graph. (Student B)

Concerning attitudes and feelings, all students expressed that they were very happy to learn the subject with computers.

> I am very enthusiastic when sitting in front of a computer, checking my own answers, interpreting my graphs and results. I like to do the lesson by myself, because I learn more and also learn more easily. It arouses my curiosity. I try to guess the next step and I see all representations on one page. Comparing the IWB and the computer, the computer increases my learning a lot more. I can think more clearly when I use a computer to do mathematics and I want to do more graphs using the computer. (Student B)

> When I first sat in front of the computer, it scared me a lot, because I did not know anything about computers. It looked so complicated until the teacher explained the first example. Before doing the activities, we practiced. After this work I feel comfortable using the computer. I enjoyed drawing graphs at the computer. It made mathematics more interesting and fun. (Student C)

Discussion and conclusions

The results indicated that both EG and CG students' performances increased from pre-test to post-test and then decreased from post-test to the retention test. The rate of decrease was about the same; however, the rate of increase was different, with students showing a greater rate of increase in the EG, where students were instructed in an IWB- and computer-supported environment. Furthermore, the treatment positively affected students' attitudes towards technology and mathematics in EG. The students in the EG were enthusiastic about the technology use and were actively involved in the lessons, asking questions and making connections between what they learned before. Students in the CG got bored easily after drawing only a couple of graphs as they thought all such graphs were nearly the same. Moreover, reasoning and interpretation skills of CG students did not improve as much as those in the EG.

It is more likely that students are willing to engage with learning tasks and motivate themselves to learn materials when IWBs are employed (Painter, Whiting, & Wolters, 2005; Smith, Hardman, & Higgins, 2006), but nevertheless it would be fair to say that instructional technology is only as good/effective as why and how we use them. Confirming Condie and Munro (2007, p. 5), the results of this study support that better IWB integration in mathematics classrooms should consider supporting IWBs with appropriate software and, in particular, dynamic environments that the teacher might use for demonstration and whole-class discussion purposes and that students might use for investigations or inquiry. Furthermore, such tools are only good in the hands of a teacher who actually knows the responsible use of technology. It is the skills and professional knowledge of the teacher that determines how much value would be gained from the use of IWBs in the classroom (Clarkson, 2011; Higgins, Beauchamp, & Miller, 2007).

Various studies (e.g., Beaucamp, 2004; Glover & Miller, 2001; Hennessy, Fung, & Scanlon, 2001; Şad & Özhan, 2012; Wood & Ashfield, 2008) provide evidence for the relationships among students' views, perceptions, attitudes and IWBs. Generally speaking, using IWBs or similar technology in the classroom is perceived as a tool that enhances interests, motivation, and enthusiasm, as well as providing prolonged engagement with the learning materials. Consistent with the literature, the present study revealed that students in the EG were enthusiastic about the use of technology. They were actively involved, asking questions and making connections with the knowledge that they had learned before. In the CG, however, students got bored after drawing a few graphs and they thought that all the graphs were nearly the same (i.e., as if they were doing the same things over and over again). Furthermore, students interviewed described the IWB and computers as enjoyable, interesting, and more fun, although they were undecided or did not agree that the IWB and computer could help them to learn mathematics prior to the treatment. The students indicated that they concentrated better in class when the IWB was used and that the IWB and computers helped them to learn mathematics better. Similar results were reported by others (e.g., Beaucamp, 2004; Glover & Miller, 2001; Hennessy, Fung, & Scanlon, 2001; Wood & Ashfield, 2008). Furthermore, data indicated that while no students selected "strongly agree" or "agree" for Item 21 in the attitude scale prior to the study, these answers increased considerably (e.g., 37.5% for "strongly agree") after the study.

In this study, the use of computer-based graphing allowed learners to practice newly acquired skills or reinforce previous knowledge. For finding an equation from a given parabola, students had more difficulty. For matching-type items, students attempted to draw graphs for the equations without attempting to make a connection between the graphs and the equations. This result is similar to those of Barton (1997), who also found that the group that used technology made more connections to their previous knowledge (i.e., transfer), suggested better (or well-formed) explanations, and made better predictions (or conjectures) as compared to the CG. The reason for this difference might be the visualization and experimentation brought by the technological environment (Archavi & Hadas, 2000). The IWB and NuCalc created an environment in which students could visualize the graphs together in all three forms. Students see the changes in graphs by changing coefficients and this helps them visualize the translation of graphs to desired units (especially the animation and drawing of multiple graphs) and interpret the changes of coefficients on graphs. This conclusion can be drawn from the students' GAT results and interviews, as well. On the other hand, in the CG the teacher drew graphs on the board and informed students about the properties and how to draw the graphs. Then, similar to the other class, the teacher drew multiple graphs in one coordinate plane to show the translation. However, it can be concluded from the students' answers from questions that involved translation that this was not enough for the students to develop their reasoning and interpretation skills.

According to Higgins, Beauchamp, and Miller (2007), "The research literature has yet to demonstrate the direction that teachers need to move to ensure that the proven changes the IWB can bring about in classroom discourse and pedagogy are translated into similar and positive changes in learning" (p. 221). In the present investigation students in the experimental group (EG) had access to IWB and NuCalc software by which multiple representations could be used. Students were also situated in a classroom environment where they had more opportunities to discuss and interpret graphical representations compared to those in control group (CG). Thus, teachers should realize the significance of students' participation in learning activities and they should give primary emphasis to activities that enable students to become actively involved in classroom participation so that students perceive representations as processes rather than end products (Greeno & Hall, 1997). Specifically, if students take part in activities to construct tables and graphs that enable them visualize the changes in their variables, and if they use these representations to justify, explain, and interpret the meaning between the patterns of variables, then they approach representations as thinking tools by which they can build their conceptual understandings. However, if students perceive the purpose of activities as being only to write equations or construct tables and graphs for completing their assignments, they might not develop the view that representations are tools for communicating and understanding sophisticated relationships among concepts. Thus, when the teacher places primary emphasis on teaching technical and conventional representations for succeeding on a test rather than for communicating and understanding concepts, students might not find opportunities to apply what they learn using forms of representations as resources in thinking and communicating in the classroom context.

In conclusion, this study provides further evidence that effective integration of technology into classroom instruction can positively impact students' motivation, engagement, and interest in learning while fostering an active, explorative, and investigative style of learning resulting in improved knowledge in mathematics. In this context, IWBs can make a difference in students' achievement, but the extent of this difference seems dependent on how we use them. Last but not least, the authors of this paper believe that teachers and schools should make good use of what can be a significant investment; effective uses of IWBs should be more thoroughly and robustly explored.

Limitations

There are two main limitations to this study: the duration of the study and the two different settings (i.e., lecture with IWB and computer lab with NuCalc) in the EG. Although the delayed post-test provides more evidence regarding the retention of the achievement gains, the improvement in students' achievements in favor of those in the EG and their strong interest and positive attitudes towards learning with the IWB and graphing technology might be attributable to some novelty factor or Hawthorne effect. Thus, the findings and conclusions of this study should be interpreted accordingly. Additional research efforts with longitudinal studies would give a better picture of how students react and what gains they might have from learning mathematics in similar settings (Digregorio & Sobel-Lojeski, 2010; Hennessy & London, 2013). On the other hand, it is difficult to isolate treatment effects from each other. Thus, when interpreting the results of this study, the learning environment in the experimental group should be conceptualized as a technology-supported (i.e., IWB and NuCalc) student-centered collaborative inquiry.

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