TI-Navigator™ Technology and Algebra I
A Study Conducted at the Curriculum Research & Development Group, University of Hawaii

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Executive Summary

The study focused on three research questions:

1. What is the effect of the use of the TI-Navigator technology on eighth-grade Algebra I students' achievement in the areas of graphing, solving systems of equations, and solving linear equations?
2. What is the effect of the use of the TI-Navigator technology on eighth-grade Algebra I students' attitudes and beliefs about the use of calculators and other technology in mathematics, specifically algebra?
3. What is the effect of the use of the TI-Navigator technology on eighth-grade Algebra I students' interactions during mathematics class?

Two eighth-grade algebra classes were matched in terms of gender and achievement levels by a random process used at the project site. One class was randomly selected to be the control group and the other designated as the experimental group. The control group class used calculators as appropriate to their regular curricular program but were not given access to the TI-Navigator technology. The experimental class used the TI-Navigator technology daily for two months during the two chapters designated in this study. The calculator used in both classes with the TI-84 Plus Silver Edition. Each student was assigned a calculator for use at school but may not have had access at home.

Pre-and post-tests on content knowledge were administered at the appropriate times concurrently with an attitudinal survey. Daily classroom observations were also conducted and recorded using an observation protocol.

This summary reports the statistical data taken from the two administrations of the content knowledge tests. The description of how the appropriate statistical procedure was selected is included.

The independent variable is the Group, with two levels of Control and Experimental. The dependent variable is the post-test score, with the pretest score as the covariate. The project team conducted an ANCOVA when two conditions were met. One, the covariate must be unaffected by other independent variables. That is, there must no interaction between the covariate and the independent variable. This condition was shown to hold when tests between-subjects effects showed no interaction (*p*-value $0.682 > 0.05$).

Second, the covariate must be linearly related to the dependent variable. In the tests of between-subjects effects, the *p*-value (0.000) was less than the alpha (0.05) and thus

showed that there is a linear relationship between the covariate and the dependent variable.
When the means were used in the tests of between-subjects effects, no significant difference was indicated between the control and experimental group (*p*-value 0.789 > 0.05). Thus the adjusted population means on the post-test scores for the two groups (control and experimental) are equal.

Therefore, a paired *t*-test was conducted in order to examine the mean differences between the pre- and post-test scores in either the control or experimental group. Within the control group, there was no significant difference between the pre- and post-test scores (*p*-value 0.216 > 0.05). However, in the experimental group, there was a significant difference (*p*-value .040 < 0.05).

Therefore, our preliminary study concludes that, in terms of content knowledge development, the TI-Navigator system had a positive effect on students' understanding of graphing, solving systems of equations, and solving linear equations.

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This research report describes a study funded by Texas Instruments 2004–05. There are six parts in the paper: 1) overview, 2) student sample demographics and description, 3) methodology and instrumentation, 4) data collection procedures, 5) data analyses, and 6) summary, including recommendations and next steps.

Overview

In December 2004, the Curriculum Research & Development Group, Mathematics Section, was awarded a grant from Texas Instruments for the purpose of studying the effects of the use of the TI-Navigator system on eighth-grade Algebra I students. This study was specifically designed to help determine an appropriate means of data collection that could be applied to broader studies with a more encompassing student group.

The study focused on three research questions:

1. What is the effect of the use of the TI-Navigator technology on eighth-grade Algebra I students' achievement in the areas of graphing, solving systems of equations, and solving linear equations?
2. What is the effect of the use of the TI-Navigator technology on eighth-grade Algebra I students' attitudes and beliefs about the use of calculators and other technology in mathematics, specifically algebra?
3. What is the effect of the use of the TI-Navigator technology on eighth-grade Algebra I students' interactions during mathematics class?

Two classes of eighth-grade Algebra I were used in the study. These classes were matched in terms of gender and achievement levels by a random process used at the school. By random draw, one class was determined to be the control group and the other class designated as the experimental group. The control group class used calculators as appropriate to their regular curricular program but these students were not given access to the TI-Navigator technology. The experimental class used the TI-Navigator technology daily for two months during the two chapters designated in this study. The calculator used in both classes with the TI 84 Plus Silver Edition. Each student was assigned a calculator for use at school.

Three data collection procedures were used in both the control and experimental classes. First, students were given a pre- and post-assessment on selected items gathered from released items of the National Assessment for Educational Progress (NAEP). These items were matched to the achievement outcomes for students related to two chapters in their textbook (*Algebra I: A Process Approach, 2nd edition,* 2001). Second, students completed a pre- and post-survey on attitudes about calculators and other technology usage specifically related to mathematics. Finally, classroom observations were conducted to ascertain the level of interaction within and across student groups.

Some significant findings emerged and are summarized here.

- Students’ interactions within groups increased when using the TI-Navigator technology.
- Students’ responses to tasks or items that required expanded responses were significantly longer and more detailed when using the TI-Navigator technology.
- Students’ skill in graphing did not differ significantly between groups but the experimental group had a higher level of correct responses on conceptual items.
- Overall, experimental students’ attitudes about the use of calculators changed to a more positive tenor except on items related to girls’ aptitude for using technology.
- Students’ time on task increased significantly in both groups.

With regard to the use of the TI-Navigator technology, management and instructional issues arose within both classes and may impact the effectiveness of the technology on learning. These issues are summarized and include the following.

- Students must follow specific procedures as they work within the TI-Navigator system. This may cause some students to not have access to data transmitted by the teacher.
- When the hardware or software fails during class, classroom management issues arise. The teacher has to be prepared to either quickly problem solve the situation and/or have alternative plans available.
- Routines for setting up and using the hardware must be established within the classroom to optimize time available for instruction. Getting calculators out or returned and getting connected (and maintaining connections) takes time away from instruction.
- Using the TI-Navigator system within a classroom that has a student-centered instruction can be cumbersome, if the teacher wants to capitalize on students’ discussion points. That is, the time to enter in questions or tasks for students that could not be anticipated prior to class detracts from the instructional flow.
- If, for some technological reason, some students do not receive data or tasks while the rest of the class does, their motivation and interest may wane.
- Using the TI-Navigator system supports a high accountability on students’ participation.

Detailed Description of Study

Methodology

Two sections of Algebra I at the Education Laboratory School (ELS) participated in this research study. There were 25 students in one section and 26 students in the second section, with relatively equal numbers of boys and girls. The students were matched on achievement, socio-economic status, and ethnicity, based on enrollment records per school selection processes.

These students used an algebra program developed at the Curriculum Research & Development Group entitled *Algebra I: A Process Approach 2nd Edition* (2002). This curriculum was the result of findings from the Hawaii Algebra Learning Project that began in 1982. The project focused on how to improve student learning in beginning algebra courses. The works of Krutetskii and Vygotsky influenced the design and development of research protocols in which students were individually and collectively followed through their algebra experience and into later mathematics courses.

There are five basic premises in the algebra program. First, all new mathematical topics are introduced through problem solving, usually a non-routine problem. Second, communication strategies (reading, writing, speaking, critical listening, and multiple representations) are included in daily lessons. Third, topics are connected through the use of the problem-solving introduction. Students must use prior knowledge to solve transitioning problems that link the old content with new understandings. Fourth, it takes time to learn so topics are presented in such a way that students have 3–5 days to develop conceptual understanding and an additional eight or more days to develop and practice skill. Fifth, all students are challenged through the use of open-ended problems that have either multiple solution methods or multiple correct solutions. The focus of this research project involves three chapters in this book, chapters 4, 5, and 6, each approximately two weeks in duration.

Two chapters (five and six) from the text were selected for the study. In these chapters students explored and investigated: 1) methods for solving linear equations in one variable, 2) graphing linear equations in two variables, 3) slope, 4) intercepts, 5) methods for solving systems of linear equations in two variables, 6) methods for solving linear inequalities in one and two variables. These topics allowed and promoted the use of technology on a daily basis.

The two sections of Algebra I, all of the sections of beginning algebra taught at the ELS, were randomly selected to be either the experimental or control group. Section 1 was designated as the control group; section II was the experimental group. The experimental group had the TI-Navigator system available each day while the control group explored the content consistent with the algebra program, using technology only as recommended in the textbook. Thus the only difference between the two groups was the inclusion of the TI-Navigator system.

Both sections took an attitudinal survey at the start of this research study, January 3, 2005, based on Fennema-Sherman scales. Some of the items were reworded to represent calculator technology rather than computer technology. Items focused on the gender issues of calculator use as well as the calculator's utility and students' perceptions of mathematics. The survey was re-administered at the end of the study, February 25, 2005.

Survey results were evaluated on pre-/post-measures by looking at the distribution of the responses across items and the average score per item. The results of this survey will be used to re-design the instrument for future use as well as to give preliminary indications of the effects of the TI-Navigator system on students' attitudes.

A content assessment was administered as a pre-/posttest to students of both sections on January 5, 2005 and February 24, 2005. The assessment was constructed from released items from the National Assessment for Educational Progress (NAEP), taken from the website. A third party selected the items so that there would be no project bias. The learning outcomes from the two chapters drove the selection process. All 15 items selected for the test required multiple-choice responses.

Throughout the study, students were given journal writing prompts as a means to gather anecdotal data from them regarding the use of calculators, the TI-Navigator technology, and affective perspectives. Students responded on their homework papers using a paper-pencil response mode in both sections.

Two graduate students were trained as classroom observers. Their training was done using the actual classrooms in which they observed and then compared their data. The focus of the observations was on documenting the amount and quality of student interactions related to discourse. Individual observers also included anecdotal data supplementary to the designated variables. As possible, two observers were used in the classroom.

A frequency timing technique was used to gather data on student groups. Since students were seated in and expected to participate in collaborative groups, observers spent 10 minutes at each group, documenting shifts in interactions for that group. Observers used a coding instrument that recorded the level and type of interactions. These recordings tracked student discourse with regard to 1) number of participants in the discourse, 2) quality of discourse and 3) frequency of interactions.

During each lesson during the research project, the tasks presented to students were kept constant. That is, students in both groups were given the same tasks, questions or activities each day. The control group responded to tasks using paper-pencil methods while the experimental group used the keyboard capability or TI-Navigator system technology such as the polling function. Both groups used calculators with typical calculator functions as required by the tasks.

Data Analysis

Each instrument is analyzed with regard to the information gathered from student responses as well as its utility as a data point for studies similar to this one.

Attitudinal Survey

The attitudinal survey indicated changes across student responses. Each response is analyzed below. Any additional response from students in their journal writing may be used to support analysis. See Table 1 for a summary of all items.

I use mathematics in everyday life.
Control group average: 4.4 (4.36)   Experimental group average: 3.92 (4.28)
The control group reported more positive responses before they began using the calculators on a daily basis than in their post-test responses. Interestingly, the experimental group showed a more positive response after using the TI-Navigator technology.

Students (92%) reported in their journal writing from the experimental group that calculators were more like computers. This is not surprising since the students in the experimental used the keyboards with the calculator and thus the calculator would seem to function more like a computer than when the calculator was used for primarily mathematical tasks. The keyboards were a primary response mechanism for expanded response items.

As one student wrote,

> I used to think that calculators were just calculators—you know, just punching in numbers and stuff but now I think that calculators can be a lot of things like a computer. When you use a computer, you can write just like with a paper and pencil. I never thought you could do that with a calculator. That was neat. (K2, 2005)

You have to be smart to learn mathematics.
Control group average: 2.28 (2.32)   Experimental group average: 2.4 (2.64)
Students in both groups were more in agreement with this statement in the post-test survey. In their journal writings, students in both groups (85% in the control group and 72% in the experimental group) indicated that the mathematical topics being studied were ‘hard’ and made them think more. Thus their responses are more related to the complexity of the topics than to the use of the technology.

Mathematics is one of my favorite subjects.
Control group average: 3.48 (3.4)   Experimental group average: 3.16 (3.28)
Students in the experimental group responded slightly more positively on the post-survey than the control group. The students in the experimental group (72%) indicated that using the TI-Navigator technology made mathematics more fun.

As A4 (2005) wrote,

> Algebra's pretty fun most of the time 'cuz we talk to each other and share ideas. But I like it better when we use the Navigator thingies. Dr D can show all of our work and we can see if we agree or not. I like it better when we use it.

Females can learn math just as well as males can learn math.
Control group average: 5.64 (5.6) Experimental group average: 5.44 (5.6)
The technology usage confounded the responses to this question. Students, in their journal writing, mixed the ability to use the calculator and/or TI-Navigator applications with the ability to do mathematics. The control group responses indicated a slight drop in agreement with this statement but the experimental group was slightly more positive.

I'll need to use calculators in my future work.
Control group average: 4.4 (4.08) Experimental group average: 3.88 (4.04)
Students in the experimental group were more positive about this statement in the post-survey, increasing from the pre-survey responses. However, neither group responded in high agreement to the statement.

Calculators are boring.
Control group average: 1.96 (2.4) Experimental group average: 2.24 (2.28)
Both groups surprisingly answered more in the affirmative in the post-surveys. This was surprising because the groups, in their journal reflections, had indicated that using calculators made mathematics more enjoyable.

I think I could handle more difficult calculator tasks.
Control group average: 4.12 (4.36) Experimental group average: 3.8 (4.16)
Both groups were lower in the pre-survey than in the post-survey. Anecdotally, from the teacher perspective, students became much more willing to explore calculator applications and keystrokes as their experience and comfortableness increased. Students began to search for shortcut keystrokes to perform functions as well as to request multiple ways to solve a problem using the technology.

Girls who enjoy calculators are weird.
Control group average: 1.88 (2.04) Experimental group average: 2.4 (2.24)
This item had differing response types—the control group increased somewhat in their agreement while the experimental group disagreed more with the statement.

C3, in the experimental group, explained her response this way:

> I doen't (sic) like to do computer stuff but I like the calculator. Everybody and not just boys like them. Sometimes the boys think they can do anything on the calculator but they doen't always no stuff. Its (sic) good that girls can have fun and the boys don't make us feel wired (sic) with it.

I expect to have little use for calculators when I get out of school.
Control group average: 2.84 (2.8)   Experimental group average: 2.84 (3.0)

The experimental group, even though slight, responded more in agreement on the post-survey than they did on the pre-survey. Part of the shift in their responses can be attributed to the use of the TI-Navigator technology rather than only the calculators.

64% of the students responded similarly to the response from L1.

> The calculators are good but sometimes using the navigator thingie (sic) was not good. I can't see using that in any thing I will do when I get out of school. I will probably use a calculator, though, because it can be used for banking and other things. Not the navigator, tho. I can't ever think of when or where it would be used.

I usually feel secure about trying new things on a calculator.
Control group average: 4.6 (4.48)   Experimental group average: 4.44 (4.32)

The data from this item are contradictory to a previous item concerning the ability of the student to handle more complex tasks. In the previous item, students were more positive about attempting more difficult tasks while on this item, they were less positive about feeling secure when trying new things.

I don't understand the enjoyment some people get from working with a calculator.
Control group average: 2.88 (3.12)   Experimental group average: 3.08 (3.48)

As with the previous question, students responded somewhat contradictorily as compared to other questions. In both groups, their responses were more in agreement on the post-survey than on the pre-survey.

I would trust a woman just as much as I would trust a man to help me figure out a calculator problem.
Control group average: 2.88 (3.12)   Experimental group average: 3.08 (3.48)

This item was confusing for students and will potentially be eliminated from future surveys. The wording of the item was difficult for students to understand if they were saying they trusted males and females equally the same or if they should assume that men could already figure out calculator problems (issues) better than women. Thus the results on this item are not necessarily indicative of students' thoughts.

Knowing how to use calculators or computers will help me get a job.
Control group average: 4.48 (4.28)   Experimental group average: 4.36 (4.72)

Students in the experimental group responded more positively on the post-survey than the control group. The control group responded more negatively.

I do not do well working with calculators.
Control group average: 2.32 (2.36) Experimental group average: 2.48 (2.36)

The experimental group responded more favorably to this item on the post-survey as compared to their pre-survey average. The two groups' averages are equal but the control group responded more favorably on the pre-survey than on the post-survey.

M2 from the experimental group explained her response this way:

> When I first used the calculator, I was always behind. Everybody was able to figure out what to do with the directions that Dr. D gave. But I couldn't. Now I know how to use it and get the right answer and everything.

I would like to learn more about using calculators.
Control group average: 4.84 (4.72) Experimental group average: 4.44 (4.8)

Students in the experimental group were more positive about learning more about using calculators. In fact, the experimental group's average increased more positively while the control group's average dropped in that respect. In this case, it would appear that the use of the TI-Navigator technology was directly responsible for students' more positive view.

Females are just as good as males at working with calculators.
Control group average: 5.28 (5.48) Experimental group average: 5.44 (5.4)

Much like the previous item related to male and female abilities to work or problem solving with calculators, this item was confusing for students. Students confused the problems encountered with TI-Navigator technology and the problem solving related to that with the actual use of the calculator.

This is how LK1 described his thinking on this item.

> Sometimes the hub things didn't work and Dr. O (the guy) would help us or Dr. O (the woman) would help us. Dr. O (the man) didn't always know what to do but he could figure it out. So could Dr. O (the woman) but she gave better directions. So I don't know who was better at working with calculators.

Learning to use calculators is a waste of time and money.
Control group average: 2.08 (1.92) Experimental group average: 2.0 (1.875)

Both groups were in disagreement with this item at the pre-survey administration, and increased their disagreement in the post-survey.

Although I try hard, using a calculator is frustrating to me.
Control group average: 2.4 (2.08) Experimental group average: 2.48 (2.34)

Both groups were in disagreement with this item at the pre-survey administration, and increased their disagreement in the post-survey. However, student responses in their journals focused on other aspects.

This is S2’s response in relation to this item:

> Using the calculator was harder when we first started in January but its easier now. What is frustrating to me is when the computer doesn’t work and we can’t see our work. Sometimes, I don’t get the poles (sic) or other things Dr. D sends me because my calculator doesn’t work but I like using it.

As an adult, I will use calculators in many ways.
Control group average: 4.6 (4.56)   Experimental group average: 4.04 (4.52)

The experimental group responded more positively in the post-survey regarding the use of calculators as an adult. The use of the TI-Navigator technology may have contributed to this as students do view the technology as more closely related to computers than calculators.

I have a lot of self-confidence when it comes to using calculators.
Control group average: 4.4 (4.32)   Experimental group average: 4.44 (4.32)

Both groups dropped in their response to this item. This is contradictory to the item that referred to students’ perception of the difficulty of tasks that they could handle with the calculator. In subsequent use of this item, it may be reworded so that students can better assess their self-confidence as well as their ability to do more difficult items.

Working with calculators is a task for men.
Control group average: 1.56 (1.6)   Experimental group average: 1.6 (1.6)

Students in both groups disagreed that tasks with calculators are primarily for men. Little, if any, change was noted in the groups’ average.

Solving calculator problems is not fun.
Control group average: 2.04 (2.36)   Experimental group average: 2.6 (2.64)

Students disagreed with this item even though there was less disagreement in the post-survey than in the pre-survey. In the experimental group, the change is related to hardware and software difficulties experienced as shown by the response from C1:

> Most of the time, it was fun using the silver calculators. But it wasn’t fun when I couldn’t receive some of the problems from Dr. D. Our hub quit working and we had to just wait until somebody could fix it. I didn’t like that—especially when everybody’s answer was shown on the board but our group’s didn’t show up. Some people might think that we didn’t do it but we couldn’t ‘cuz we didn’t ever get it.

In the control group, students had different issues with the calculators related to this survey item. By not using the TI-Navigator technology, students could not experience the full benefit of the calculators. As G1 indicated,

> I wish we could have seen what other students had on their calculators for some of the problems. It was okay to have students go up to the ELMO and show their work but I think we could have done better if we had a way to show everybody's work at one time. I like to find patterns or compare other answers and I couldn't do that.

Knowing how to use calculators will not be important in my future career.
Control group average: 2.12 (2.68) Experimental group average: 2.76 (2.44)

Both groups were in relative disagreement with this item and felt that it would be important for them to know how to use calculators for their future career goals. The experimental group was in more disagreement than the control group.

I'm good at most subjects but when it comes to calculators I'm terrible.
Control group average: 2.12 (2.08) Experimental group average: 2.24 (2.24)

This item was difficult for students to understand. They were not clear as to the intent. For example, L1 in the experimental group asked, Does this mean that if I disagree with the item I am saying that I'm good at most subjects and with the calculator? Or does it mean that I'm not good at most subjects but I'm good with a calculator? I don't know how to answer!

Similar journal responses were given in the control group as well. This item, if used in future surveys, will be reworded so that students can better respond.

When performing a task on a calculator I prefer to work with students of the same sex.
Control group average: 3.08 (3.2) Experimental group average: 2.52 (2.72)

Even though both groups felt that boys and girls could both work with calculators, they both more positively responded that they would prefer to work with students of the same sex on calculator tasks. Both groups' journal responses attributed this preference to working styles.

A1, a female from the experimental group, responded in this fashion.

> I don't mind working with boys on the calculator but if I can't remember how to do something, they won't let me figure it out by myself. They tell me what to do and I don't like that. I would rather figure it out on my own. They are just too bossy.

A1, a male from the control group, responded from a different perspective.

> I don’t care if I work with boys or girls on the calculators but girls sometimes take too long to do something. There’s a faster way to do some things but they will take more time. That’s frustrating to me so sometimes I would rather work with other boys.

When a challenging calculator problem arises I stick with it until I find a solution.
Control group average: 4.48 (4.24)   Experimental group average: 3.8 (3.76)

This statement was difficult for students to respond to in that they were not clear about what a calculator ‘problem’ meant. Some students interpreted it to mean a task given to them to work out on the calculator. Other students thought it meant a hardware issue with the equipment, such as a TI-Navigator hardware problem with the hubs or the calculator not receiving a task. Thus this statement requires rewording for future surveys.

Women are better at working with calculators than men.
Control group average: 2.6 (2.56)   Experimental group average: 2.44 (1.96)

In responding to this item, both groups felt that men and women were equally ‘good’ at working with calculators. Some control group students specifically referred to some girls that they felt were better than some specific boys in working with calculators. The experimental group students often confused the issue of working with calculators with the ability to problem solve and fix any glitches that arose when working with the Navigator technology. This item will be deleted from future surveys.

Working with calculators is exciting.
Control group average: 4.36 (4.2)   Experimental group average: 3.48 (3.52)

Overall, students in both groups were positive in their responses. As J1 indicated in his response from the control group,

> Calculators add something different to our class. I like how our class isn’t like a regular math class but when we use calculators, it’s even better.

S3 from the experimental group wrote in her response that,

> . . . it’s a good thing to use calculators in our class because it makes our discussions better. When we can see everybody’s answers or take a poll, it makes you think more.

Playing with video games is one of my favorite hobbies.
Control group average: 4.04 (3.88)   Experimental group average: 3.24 (3.56)

Students were relatively positive in their response to their item. Without further statistical tests not intended for this study, it is unclear whether or not there is a correlation between playing video games and calculator usage or other issues.

Females can play video games as well as males can.
Control group average: 4.48 (4.84) Experimental group average: 4.44 (4.36)

Overall, students positively responded to this item. As in the previous, the relationship between playing video games and calculator usage is not clear. Students noted in their journal responses that sometimes they played video games and sometimes they did not. The cycles of playing video games depended upon the new games that were available and if the older games had been mastered.

I think video games are an important part of growing up.
Control group average: 3.24 (3.4) Experimental group average: 2.68 (2.28)

The two groups responded differently to this item. Rather than being related to calculator usage, students in both groups' journal responses related the role of video games in the growing up process to the priorities that they had at the moment of the survey. In the experimental group, at the time of the survey, were faced with conflicts within their own student group that took precedence over other issues.

You have to be smart to play video games.
Control group average: 2.12 (2.0) Experimental group average: 1.96 (2.28)

Students' responses were relatively consistent on this item. In a previous item in which students responded to the 'smartness' required to do mathematics, they disagreed less than they did in this item.

As N1 in the control group responded,

> Anybody can play video games—you don't have to be smart. But you do have to be smart to win a video game. Some people are better at that than others. So I guess you can play a video game without being smart but to win one, you have to be smarter.

Each item of the attitudinal survey was compared between control and experimental groups. The journal responses in which students clarified their responses to the survey items helped to provide a context for the interpretation of data as well as to provide information for the revision of items in the next administration of the survey.

Table 1: Attitudinal Survey Summary Data: Group Comparison by Averages

	Average Control Group	Average Experimental Group
1. I use mathematics in everyday activities.	4.4 (4.36)	3.92 (4.28)
2. You have to be smart to learn math.	2.28 (2.32)	2.4 (2.64)
3. Mathematics is one of my favorite subjects.	3.48 (3.4)	3.16 (3.28)
4. Females can learn math just as well as males can learn math.	5.64 (5.6)	5.44 (5.6)
5. I'll need to use calculators in my future work.	4.4 (4.08)	3.88 (4.04)
6. Calculators are boring.	1.96 (2.4)	2.24 (2.28)
7. I think I could handle more difficult calculator tasks.	4.12 (4.36)	3.8 (4.16)
8. Girls who enjoy calculators are weird.	1.88 (2.04)	2.4 (2.24)
9. I expect to have little use for calculators when I get out of school.	2.84 (2.8)	2.84 (3.0)
10. I usually feel secure about trying new things on a calculator.	4.6 (4.48)	4.44 (4.32)
11. I don't understand the enjoyment some people get from working with a calculator.	2.88 (3.12)	3.08 (3.48)
12. I would trust a woman just as much as I would trust a man to help me figure out a calculator problem.	5.36 (5.16)	5.2 (5.16)
13. Knowing how to use calculators or computers will help me get a job.	4.48 (4.28)	4.36 (4.72)

(XX) indicates post-survey results

	Average Control Group	Average Experimental Group
14. I do not do well working with calculators.	2.32 (2.36)	2.48 (2.36)
15. I would like to learn more about using calculators.	4.84 (4.72)	4.44 (4.8)
16. Females are just as good as males at working with calculators.	5.28 (5.48)	5.44 (5.4)
17. Learning to use calculators is a waste of time and money.	2.08 (1.92)	2.0 (1.875)
18. Although I try hard, using a calculator is frustrating to me.	2.4 (2.08)	2.48 (2.34)
19. As an adult, I will use calculators in many ways.	4.6 (4.56)	4.04 (4.52)
20. I have a lot of self-confidence when it comes to using calculators.	4.4 (4.32)	4.44 (4.32)
21. Working with calculators is a task for men.	1.56 (1.6)	1.6 (1.6)
22. Solving calculator problems is not fun.	2.04 (2.36)	2.6 (2.64)
23. Knowing how to use calculators will not be important in my future career.	2.12 (2.68)	2.76 (2.44)
24. I'm good at most subjects but when it comes to calculators I'm terrible.	2.12 (2.08)	2.24 (2.24)
25. When performing a task on a calculator I prefer to work with students of the same sex.	3.08 (3.2)	2.52 (2.72)
26. When a challenging calculator problem arises I stick with it until I find a solution.	4.48 (4.24)	3.8 (3.76)
27. Women are better at working with calculators than men.	2.6 (2.56)	2.44 (1.96)
28. Working with calculators is exciting.	4.36 (4.2)	3.48 (3.52)
29. Playing with video games is one of my favorite hobbies.	4.04 (3.88)	3.24 (3.56)
30. Females can play video games as well as males can.	4.48 (4.84)	4.44 (4.36)
31. I think video games are an important part of growing up.	3.24 (3.4)	2.68 (2.28)
32. You have to be smart to play video games.	2.12 (2.0)	1.96 (2.28)

(XX) indicates post-survey results

Table 2: Attitudinal Survey Summary Data: Control Group

	Strongly Disagree	Disagree	Mildly Disagree	Mildly Agree	Agree	Strongly Agree	AVERAGE
1. I use mathematics in everyday activities.	0 (0)	1 (0)	1 (2)	13 (14)	7 (7)	3 (2)	4.4 (4.36)
2. You have to be smart to learn math.	5 (7)	12 (10)	4 (2)	4 (5)	0 (1)	0 (0)	2.28 (2.32)
3. Mathematics is one of my favorite subjects.	0 (1)	2 (7)	12 (4)	8 (8)	3 (3)	0 (1)	3.48 (3.4)
4. Females can learn math just as well as males can learn math.	0 (0)	0 (0)	0 (0)	2 (1)	5 (8)	18 (16)	5.64 (5.6)
5. I'll need to use calculators in my future work.	0 (1)	2 (1)	3 (6)	8 (5)	7 (11)	5 (1)	4.4 (4.08)
6. Calculators are boring.	9 (5)	9 (13)	6 (2)	1 (3)	0 (1)	0 (1)	1.96 (2.4)
7. I think I could handle more difficult calculator tasks.	0 (0)	2 (1)	3 (4)	11 (8)	8 (9)	1 (3)	4.12 (4.36)
8. Girls who enjoy calculators are weird.	13 (12)	6 (5)	3 (5)	2 (2)	1 (0)	0 (1)	1.88 (2.04)
9. I expect to have little use for calculators when I get out of school.	3 (5)	9 (7)	5 (5)	5 (4)	3 (4)	0 (0)	2.84 (2.8)
10. I usually feel secure about trying new things on a calculator.	0 (1)	3 (2)	3 (2)	1 (2)	12 (15)	6 (3)	4.6 (4.48)
11. I don't understand the enjoyment some people get from working with a calculator.	2 (2)	8 (5)	9 (11)	3 (4)	3 (1)	0 (2)	2.88 (3.12)
12. I would trust a woman just as much as I would trust a man to help me figure out a calculator problem.	0 (0)	1 (1)	1 (0)	1 (5)	7 (7)	15 (12)	5.36 (5.16)
13. Knowing how to use calculators or computers will help me get a job.	0 (0)	2 (1)	2 (5)	8 (9)	8 (6)	5 (4)	4.48 (4.28)

(XX) indicates post-survey results

	Strongly Disagree	Disagree	Mildly Disagree	Mildly Agree	Agree	Strongly Agree	AVERAGE
14. I do not do well working with calculators.	3 (3)	15 (13)	3 (7)	4 (1)	0 (1)	0 (0)	2.32 (2.36)
15. I would like to learn more about using calculators.	0 (0)	2 (1)	0 (1)	5 (8)	11 (9)	7 (6)	4.84 (4.72)
16. Females are just as good as males at working with calculators.	0 (0)	0 (0)	1 (0)	3 (1)	9 (11)	12 (13)	5.28 (5.48)
17. Learning to use calculators is a waste of time and money.	3 (5)	18 (17)	3 (3)	1 (0)	0 (0)	0 (0)	2.08 (1.92)
18. Although I try hard, using a calculator is frustrating to me.	4 (4)	11 (16)	7 (4)	2 (1)	1 (0)	0 (0)	2.4 (2.08)
19. As an adult, I will use calculators in many ways.	0 (0)	0 (0)	2 (5)	10 (6)	9 (9)	4 (5)	4.6 (4.56)
20. I have a lot of self-confidence when it comes to using calculators.	0 (0)	2 (0)	3 (5)	7 (9)	9 (9)	4 (2)	4.4 (4.32)
21. Working with calculators is a task for men.	14 (13)	8 (9)	3 (3)	0 (0)	0 (0)	0 (0)	1.56 (1.6)
22. Solving calculator problems is not fun.	8 (5)	10 (11)	5 (4)	2 (5)	0 (0)	0 (0)	2.04 (2.36)
23. Knowing how to use calculators will not be important in my future career.	8 (5)	9 (7)	6 (7)	1 (3)	1 (2)	0 (0)	2.12 (2.68)
24. I'm good at most subjects but when it comes to calculators I'm terrible.	8 (4)	9 (16)	5 (4)	3 (1)	0 (0)	0 (0)	2.12 (2.08)
25. When performing a task on a calculator I prefer to work with students of the same sex.	3 (2)	7 (8)	5 (5)	5 (4)	5 (5)	0 (1)	3.08 (3.2)
26. When a challenging calculator problem arises I stick with it until I find a solution.	0 (0)	0 (3)	5 (1)	7 (11)	9 (7)	4 (3)	4.48 (4.24)
27. Women are better at working with calculators than men.	5 (4)	6 (10)	10 (8)	3 (0)	0 (2)	1 (1)	2.6 (2.56)
28. Working with calculators is exciting.	0 (0)	0 (0)	5 (6)	11 (10)	4 (7)	5 (2)	4.36 (4.2)

29. Playing with video games is one of my favorite hobbies.	3 (4)	4 (4)	3 (2)	3 (4)	3 (2)	9 (8)	4.04 (3.88)
30. Females can play video games as well as males can.	4 (0)	0 (2)	1 (3)	4 (3)	7 (6)	9 (11)	4.48 (4.84)
31. I think video games are an important part of growing up.	4 (3)	4 (4)	6 (4)	5 (9)	5 (4)	1 (1)	3.24 (3.4)
32. You have to be smart to play video games.	9 (11)	9 (8)	2 (2)	5 (3)	0 (1)	0 (0)	2.12 (2.0)

(XX) indicates post-survey results

Table 3: Attitudinal Survey Summary Data, Experimental Group

	Strongly Disagree	Disagree	Mildly Disagree	Mildly Agree	Agree	Strongly Agree	AVERAGE
1. I use mathematics in everyday activities.	1 (0)	4 (3)	4 (4)	7 (6)	5 (7)	4 (5)	3.92 (4.28)
2. You have to be smart to learn math.	5 (5)	12 (7)	4 (7)	1 (4)	3 (2)	0 (0)	2.4 (2.64)
3. Mathematics is one of my favorite subjects.	4 (7)	3 (2)	8 (3)	6 (6)	3 (4)	1 (3)	3.16 (3.28)
4. Females can learn math just as well as males can learn math.	0 (0)	0 (1)	1 (0)	3 (1)	5 (4)	16 (19)	5.44 (5.6)
5. I'll need to use calculators in my future work.	0 (1)	5 (1)	4 (6)	7 (9)	7 (4)	2 (4)	3.88 (4.04)
6. Calculators are boring.	7 (10)	10 (6)	4 (3)	3 (5)	1 (0)	0 (1)	2.24 (2.28)
7. I think I could handle more difficult calculator tasks.	1 (1)	2 (3)	7 (4)	9 (3)	3 (11)	3 (3)	3.8 (4.16)
8. Girls who enjoy calculators are weird.	10 (12)	4 (6)	5 (2)	4 (1)	1 (2)	1 (2)	2.4 (2.24)
9. I expect to have little use for calculators when I get out of school.	3 (5)	9 (8)	7 (4)	3 (2)	1 (2)	2 (4)	2.84 (3.0)
10. I usually feel secure about trying new things on a calculator.	1 (2)	1 (2)	3 (1)	6 (5)	9 (11)	5 (4)	4.44 (4.32)
11. I don't understand the enjoyment some people get from working with a calculator.	5 (3)	3 (5)	8 (6)	5 (4)	2 (2)	2 (5)	3.08 (3.48)
12. I would trust a woman just as much as I would trust a man to help me figure out a calculator problem.	1 (0)	0 (1)	1 (2)	3 (2)	6 (7)	14 (13)	5.2 (5.16)
13. Knowing how to use calculators or computers will help me get a job.	1 (0)	0 (2)	3 (2)	11 (4)	5 (10)	5 (7)	4.36 (4.72)

(XX) indicates post-survey results

	Strongly Disagree	Disagree	Mildly Disagree	Mildly Agree	Agree	Strongly Agree	AVERAGE
14. I do not do well working with calculators.	4 (7)	11 (9)	4 (5)	6 (2)	0 (1)	0 (1)	2.48 (2.36)
15. I would like to learn more about using calculators.	0 (0)	2 (0)	4 (2)	5 (5)	9 (14)	5 (4)	4.44 (4.8)
16. Females are just as good as males at working with calculators.	0 (1)	0 (0)	1 (1)	3 (2)	5 (3)	16 (18)	5.44 (5.4)
17. Learning to use calculators is a waste of time and money.	7 (10)	12 (9)	5 (3)	1 (2)	0 (0)	0 (0)	2.0 (1.875)
18. Although I try hard, using a calculator is frustrating to me.	6 (6)	10 (10)	3 (3)	3 (1)	3 (3)	0 (0)	2.48 (2.34)
19. As an adult, I will use calculators in many ways.	0 (0)	4 (0)	3 (5)	8 (5)	8 (12)	2 (3)	4.04 (4.52)
20. I have a lot of self-confidence when it comes to using calculators.	0 (1)	2 (0)	3 (4)	7 (9)	8 (7)	5 (4)	4.44 (4.32)
21. Working with calculators is a task for men.	17 (16)	4 (6)	2 (2)	1 (0)	1 (0)	0 (1)	1.6 (1.6)
22. Solving calculator problems is not fun.	7 (5)	7 (10)	4 (4)	4 (2)	2 (3)	1 (1)	2.6 (2.64)
23. Knowing how to use calculators will not be important in my future career.	2 (7)	10 (7)	8 (6)	3 (3)	1 (2)	(1) (0)	2.76 (2.44)
24. I'm good at most subjects but when it comes to calculators I'm terrible.	7 (9)	9 (8)	7 (4)	1 (2)	0 (1)	1 (1)	2.24 (2.24)
25. When performing a task on a calculator I prefer to work with students of the same sex.	8 (5)	8 (10)	2 (4)	3 (1)	3 (3)	1 (2)	2.52 (2.72)
26. When a challenging calculator problem arises I stick with it until I find a solution.	0 (1)	3 (2)	9 (8)	6 (8)	4 (3)	3 (3)	3.8 (3.76)
27. Women are better at working with calculators than men.	8 (11)	9 (8)	2 (3)	3 (2)	1 (1)	2 (0)	2.44 (1.96)

28. Working with calculators is exciting.	3 (4)	3 (5)	5 (1)	8 (6)	5 (7)	1 (2)	3.48 (3.52)
29. Playing with video games is one of my favorite hobbies.	5 (6)	8 (4)	1 (3)	3 (2)	3 (2)	5 (8)	3.24 (3.56)
30. Females can play video games as well as males can.	3 (4)	2 (0)	3 (3)	1 (3)	5 (6)	11 (9)	4.44 (4.36)
31. I think video games are an important part of growing up.	7 (5)	9 (6)	1 (3)	3 (2)	3 (1)	2 (7)	2.68 (2.28)
32. You have to be smart to play video games.	14 (13)	6 (5)	1 (1)	2 (2)	0 (1)	2 (3)	1.96 (2.28)

(XX) indicates post-survey results

The survey also asked students to respond to the type of calculator, if any, that they used outside of the mathematics class and to indicate the usefulness of a calculator with regard to specific topics. In the control group, 17 students had access to a scientific calculator while 5 had a graphing calculator. Three students had no calculator. Twenty-three of the control students on the pre-survey indicated that the calculator helped them learn things related to number. Two students wrote that the calculator is only a tool; it is the teacher that helps them learn.

On the post-survey, the control group students indicated that six of them had a graphing calculator and 19 students had a scientific calculator. For all students, the calculator was useful in helping them learn how to graph as indicated by their post-survey responses.

In the experimental group, the pre-survey revealed that 16 students had a scientific calculator but one student indicated he would not use because it is ‘like cheating’ if you use a calculator to help you do homework. One student had only a computer to use and the computer had a calculator function. Two students had no calculators or computers. Six students had graphing calculators but three indicated they do not like to use the calculator because they were not sure how to or because it was not appropriate to use a calculator to do homework.

Six of the experimental group on the pre-survey indicated that the calculator is not useful at all. One student wrote that the calculator helped him do trigonometric functions even though the algebra course does not deal with trigonometry. Eighteen of the experimental students noted that the calculator helped them do numerical calculations faster.

On the post-survey, 19 students had a scientific calculator and consistently used it to help solve problems. Three students indicated that they used the calculator in both mathematics and science. Six students had a graphing calculator and used it in a similar fashion as noted by those with a scientific calculator.

Twenty-three of the experimental group students wrote that the calculator helped them perform graphing functions with both linear and inequality graphs. Two students focused on the numerical help that a calculator could provide in solving integer computations.

Overall, students' attitudes toward calculator technology were affected by the use of the TI-Navigator technology in the experimental group but calculator usage in general impacted students' attitudes. In subsequent usage of a survey similar to this one, some changes in item statements or presentation will be done so that the items are clearer for students. The use of journal prompts in conjunction with the survey helped to interpret the items rather than rely solely on the Likert scale of the survey.

Content assessment

Fifteen items taken from released items of the National Assessment for Educational Progress (NAEP) were presented in both the pre-and post-tests. The items related directly to concepts and skills presented during the research study's duration.

In the control group, 12 students improved their overall score from the pre- to the post-test while in the experimental group, 15 students improved their overall score. Eight students in the control group had more errors on the post-test than on the pre-test; seven of the experimental group students had more errors. Three of the experimental group students had no change in their score and five of the control group students had no change.

Table 4 shows the number of errors on each item for the two groups in both pre- and post-test forms.

Table 4: Content Assessment Error Summary

Item Number	Control Pre-test	Experimental Pre-test	Control Post-test	Experimental Post-test
1	11	13	10	6
2	5	7	6	7
3	17	17	16	19
4	22	18	22	19
5	8	9	5	4
6	16	15	16	14
7	1	6	3	2
8	2	6	1	2
9	16	20	15	15
10	6	10	5	O
11	10	13	9	12
12	10	16	12	14
13	9	16	16	13
14	6	5	2	3
15	10	6	9	4

Item 1 is a skill item: A straight line on a graph passes through the points (3,2) and (4,4). Which of these points also lies on the line? In order to solve the problem, students typically were observed graphing the two points and then looking for the points given in the multiple choices. Three students created an equation of the line and then checked the other choices in the answer. The experimental group made the better improvement on this item.

Item 2: The table represents a relation between *x* and *y*. What is the missing number in the table? In both groups there was little improvement, if any. The control group did worse on this problem-solving item that required students to identify the pattern and then apply the pattern in a working backwards strategy. Even though neither group showed gains on this item, the experimental group neither gained nor lost and thus had the best performance at the post-test on the item.

Item 3: A rubber ball rebounds to half the height it drops. If the ball is dropped from a rooftop 18 m above the ground, what is the total distance traveled by the time it hits the ground the third time? This item was difficult for both groups. The control group neither gained nor lost and thus performed better. The experimental group did worse on this item on the post-test than they did on the pre-test.

Item 4: The table shows the values of *x* and *y*, where *x* is proportional to *y*. What are the values of *P* and *Q*? This was one of the most difficult items on the pre-test but both groups performed better on the post-test. As a multi-step problem, this problem would naturally be more difficult. However, in analyzing the errors on the item, students confused the values of *P* and *Q* as the multiple choice answers had one selection in which the values of *P* and *Q* were switched. This may have influenced student performance.

Item 5: Matchsticks are arranged as shown in the figures. If the pattern is continued, how many matchsticks would be used to make Figure 10? In this conceptual/problem-solving task, students in the experimental group improved their performance.

Item 6: Graham has twice as many books as Bob. Chan has six more books than Bob. If Bob has *x* books, which of the following represents the total number of books the three boys have? Both groups improved on this skill item but the experimental group improved more.

Item 7: (3, 6), (6, 15), (8, 21) Which of these describes how to get the second number from the first number in every ordered pair above? On this skill item, the control group did worse on the post-test than on the pre-test. However, the experimental group improved on the post-test.

Item 8: The graph represents the distance and time of a hike taken by Joshua and Liam. If they both started from the same place and walked in the same direction, at what time did they meet? In both groups, performance was worse on the post-test than on the pre-test. However, taking into account the percent of students who answered incorrectly, the experimental group performed better.

Item 9: If $y = 3x + 2$, which of these expresses x in terms of y? Students in both groups had difficulty with this skill item. The purpose of the item is to have students rewrite an equation in slope-intercept form to one with x as the subject. Even though the experimental group's score was unchanged from pre- to post-test, their performance would be considered better than the control group's performance.

Item 10: If $x + 3y = 11$ and $2x + 3y = 13$, then y =? Students in the experimental group out-performed the students in the control group on this item. No student in the experimental group missed this item that represented both concept and skill.

Item 11: If $x – y = 5$ and $\frac{x}{2} = 3$, what is the value of y? This item is one in which students could use the substitution method to solve. Rather than solving the second equation for x before substituting into the first equation, students tried to use the rational expression. This created difficulties in solving the skill item. Both groups did worse on the post-test than on the pre-test.

Item 12: If $\frac{a}{b} = 70$, then $\frac{a}{2b}$ = ? Students had difficulty with this item in both groups. Because these algebraic equations use rational expressions, they inherently would be difficult. However, the experimental group had the better performance on this concept item.

Item 13: Brad wanted to find three consecutive whole numbers that add up to 81. He wrote the equation $(n – 1) + n + (n + 1) = 81$. What does the n stand for? The experimental group outperformed the control group on this conceptual item. The experimental group had more correct responses on the post-test than on the pre-test while the control group made more errors on the post-test.

Item 14: If m represents a positive number, which of these is equivalent to $m + m + m + m$? The experimental group scored better on the pre-test and on the post-test than the control group. However, the experimental group had fewer students score correctly on the post-test and thus their performance actually declined on the post-test.

Item 15: The objects on the scale make it balance exactly. On the left pan there is a 1 kg weight (mass) and half a brick. On the right pan there is one brick. What is the weight (mass) of one brick? The experimental group's performance was better on both the pre- and post-test responses. More students responded correctly on the post-test than on the pre-test for this conceptual item.

Overall, the experimental group's performance was better on the post-test than the control group's performance. Students in the experimental group made better gains with respect to their performance on the two administrations. In journal prompts related to student understanding, students in both groups discussed how they felt their learnings had been affected by the use of technology in their respective groups.

A control group student, M5, said,

> I think the calculator helped me learn better because I could think about the answer first and then check myself with the calculator. That was good in the graphing and systems of equations parts. I wish we could use a calculator all the time because when I don't use it like on some of the test things, I don't feel as confident about my answers.

T3, an experimental group student, wrote,

> I always like using a calculator when I do math because it keeps me from making stupid mistakes. Sometimes I don't pay attention to my calculations and make mistakes. With the Navigator, I feel like I really learned the math because it made me think even more than normal in our math class. I liked looking at other people's work from their calculator and having to figure out if they had made a mistake or not. I could remember some of the math problems more because we did that.

From the observers' perspective, students in both groups wanted to use the calculators for all tasks regardless of the efficient or effective use of the technology. This included using the calculator for computing simple numerical operations such as adding, subtracting, multiplying or dividing by a power of 10. Some students recognized that this was not an effective use of the calculator but others automatically reached for the calculator whenever a problem was presented.

As students became more comfortable with the technology, they used it as a tool for other more conceptual problems as well. In particular, this included tasks that required higher-order thinking as well as to integrate multiple functions of the calculator.

Observation data

Observers in the classroom noted the time on task, types of interactions in groups, and the quality of the interactions. Additionally, they recorded other observations related to student performance across tasks in both groups.

Overwhelmingly, students in the experimental group responded faster to teacher directions or presentation of tasks than students in the control group. The average time for students to begin a task, once presented, in the experimental group was 1.5 seconds while the time to begin tasks in the control group averaged 19.75 seconds. The difference between these two start time averages is remarkable in that students using the TI-Navigator technology make better use of time. This is a critical point because teachers have to optimize the class time. TI-Navigator technology may provide one means by which time is maximized.

The quality of the interactions in the small groups in the two classes varied. Students in the experimental group tended to work more independently when first given a task.

Typically, they would begin a task and work with it for a period of time before discussing it with other group members.

In the control group, students were more apt to discuss the problem before they began the task or to discuss it as they worked on it. In both groups, it was evident that the calculator technology provided discussion points in the small groups.

In terms of the quality of the interactions, the TI-Navigator technology provided more in-depth discussion points for the experimental class. The context of the algebra I class before the research study began was student-centered. That is, the students led problem discussions with the teacher functioning as a facilitator and mediator, asking higher-order, clarifying or summarizing questions as appropriate. Teacher talk time averaged 7.5 minutes in a 45-minute class period. This classroom context or environment continued into the TI-Navigator research study.

Thus the quality of the discussions improved with the use of the TI-Navigator technology. When student work was shared via the TI-Navigator technology, students quickly began to compare and contrast responses. As patterns across student responses were identified, they were then used to push the level of the content so that all students felt challenged. In the control group, student responses were shared by having students bring their calculators to the ELMO™ visualizer but this method did not allow students to see multiple solutions across the class at one time. Therefore, the TI-Navigator technology had an effect on student discussions and the depth of student observations.

It was immediately evident that the TI-Navigator technology kept students focused on the discussion. When student work was displayed, observers noted that students turned their attention to the display almost immediately. Without being asked by the teacher, students began to compare responses and to identify error patterns or to note similarities across responses.

This focus impacted the type of student interactions. Multiple observers external to this research project noted that the control group students were deeply involved in high-level conversations centered on the problems or tasks presented in the class. However, there was a notable difference in the experimental group discussions in that these students consistently focused on even more in depth conversations about the mathematical patterns and generalizations. Being able to see your own work displayed and then review it in comparison to other responses allowed students a self- and peer-assessment opportunity that is not always available in classes that do not have the TI-Navigator technology.

When the Activity Center and Learn Check components of the TI-Navigator technology, including the keyboards, were used, students in the experimental group wrote longer and qualitatively better responses to tasks than students in the control group who used paper-and-pencil response methods. On one such task, students were asked to respond to the following:

> Kara said, “The slope of a line tells you a lot of information.” “Yes, it does,” said Thom. “But the *y*-intercept tells you a lot, too.” What information could Kara and Thom be referring to? Describe with as much detail as you can and support your answer.

Students in the control group gave responses similar to this one from G1.

> The slope tells you whether it goes up or down on the graph and the *y*-intercept tells you where it crosses the *y*-axis. This information is given in the slope-intercept form of the equation.

By contrast, students in the experimental group typed lengthier and qualitatively better responses as indicated by the following response to the same prompt from L1.

> You can tell which quadrants the line will go thru [sic] if you know the slope and the *y*-intercept. For example, if the slope is –2 and the *y*-intercept is 4, the line will go thru quadrants II, I, and IV. The size of the slope also tells you how steep the line is. If the slope is ½, then the line isn’t very steep but if it’s 7, then the line is really steep. That’s because slope means rise over run so in the first slope the rise is only 1 and the run is 2 but in the second one the rise is 7 and the run is 1 so it goes up faster than it goes across. That makes the line steep.

In both cases, students were given five minutes to respond to the prompt. The ability to use a keyboard did have some bearing on the length of the response but students more often requested to come in during out-of-class time to finish their response than when they used paper-pencil methods.

Summary

Overall, the TI-Navigator technology had a positive effect on student achievement and on their attitudes regarding the use of technology in the classroom. Calculators alone did not appear to have the same impact on equivalent tasks.

The use of TI-Navigator technology supports the development of a collaborative classroom environment by enhancing student interactions, focusing students’ attention on multiple responses, and providing opportunities for students to peer- and self- assess student work. The ability to display a full class set of data or task responses supports a problem-solving approach to developing skills and concepts.

Students in the experimental group maintained or improved their perception of calculator usage. While there were confounding issues surrounding the use of the technology itself, students overall in both groups were positive about the inclusion of calculators and/or the TI-Navigator technology in the mathematics classes.

Limitations of the study

Because the study used a beta version of the TI-Navigator 2.0 software, the effects described in the previous sections may have been impacted. Frequent downloads of new beta versions were required and, in some cases, this created some glitches in the interactions between and among the hardware and software components. Now that the final version of the TI-Navigator 2.0 software has been released, new studies should be designed and implemented to test similar research questions.

The hardware used in the study was not new and therefore there were occasions when the hardware failed. When hardware failure was combined with software glitches, this resulted in downtime in the class. In some cases, data were missing from student responses because not all students received transmissions from the teacher’s computer. When this happened, it affected the students’ perceptions of the software. They became frustrated because they wanted to participate and could not. At times, the tasks could not be replicated and thus the students who could not get connected would have to wait. If the Quick Poll function was used, students felt even more left out because the responses to a Quick Poll were so quick to be displayed.

The items on the attitudinal survey were piloted during this study as were the instruments for observation coding and the content test items. Each item and responses of both control and experimental groups should be evaluated for reliability and validity. Changes should be included for any subsequent administrations or use of the instruments.

Recommendations

The Texas Instruments product development division should pay careful attention to the ease of use in the classroom for both the hardware and the software. In terms of hardware, for classes that are more than 25 students in size, the hardware has to be durable and able to withstand students moving about the class. The blue hubs clamp securely to desks but they are more difficult to reset if they go to sleep. No white hubs were available for this study.

For the teacher, there are cables required to connect the router to the computer and the hook-up requires space for such an arrangement. It would be easier if the router could communicate with the computer through a wireless connection so that the computer could be moved to more convenient areas in classrooms that have limited space.

Since a PC is required for the software, there is not the ease of use that is built into the Apple (Macintosh) computer system. All of the connections and any troubleshooting related to problems are easier with MAC technology. Since many schools use Macs as their sole computer source, it would be appropriate for TI to consider adapting the technology for MAC products.

The software should link well with common word-processing programs. However, when some tasks were copied from Word and Equation Editor (Math Type) programs into

Learn Check, some symbols were occasionally changed in the task. It appeared fine on the screen but when the tasks were sent to students, symbols did not appear as they should have and thus influenced the outcomes of the task.

Because the calculators were used with middle grades students in an Algebra I class, some of the keystrokes for using the TI-Navigator technology were troublesome for some students. They had difficulty remembering some of the smaller details, such as being in TI-Navigator in order to receive Quick Poll or to 'leave' the network through keystrokes. This would result in students having difficulty receiving or sending information and took class time to resolve. It would benefit students if there were reduced keystrokes or processes related to using the keyboard or moving across applications on the calculators.

Using the TI-Navigator system within a classroom that uses a student-centered instructional approach can be cumbersome, if the teacher wants to capitalize on students' discussion points. That is, the time to enter in questions or tasks for students that could not be anticipated prior to class detracts from the instructional flow. While it is important for the teacher to plan ahead for typical or anticipated questions, there are moments during the class discussion when a student or students may raise questions that would allow explorations through problems that support problem-solving or investigatory processes. While Quick Poll is a quick and easy way to gather information from students, it does not allow the expanded responses or in-depth responses that carry student discussions to a higher-level. Thus the ease in typing in new questions and transmitting them to students efficiently is a needed process for the TI-Navigator technology.