

Struggles and Successes Implementing Classroom Communication Technology in a College Pre-Calculus Course

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This case study documents the struggles and successes encountered by a pre-calculus teacher while using classroom connectivity technology (CCT) daily in her community college mathematics course. CCT refers to a wireless communication system that connects a teacher's computer with an individual student's handheld calculator and has been associated with positive academic outcomes (Pape et al., 2011). CCT allows the instructor to send documents, collect student responses, and project student work for classroom discussion. Due to the increased complexity of teaching using CCT, however, teachers often struggle with initial implementation. For example, the instructor struggled with a lack of time to plan and execute activities using CCT. She also had to develop an understanding of how to use CCT effectively and how to resolve technical issues that arose during the lesson. The instructor also experienced numerous successes. CCT was used for formative assessment, to promote involvement among students, and to exhibit and connect multiple representations of a mathematical concept. This case study provides mathematics educators seeking to understand the costs and benefits of implementing CCT with valuable insight into issues of early implementation.

Technology can serve many purposes in the mathematics classroom. Doerr and Zangor (2000) proposed several such purposes. Graphing calculators can act as a *computational tool*, which allows students to carry out complex computations; a *transformational tool*, which transforms a computation-based activity into a conceptually-based activity; a *data collection and analysis tool*, which allows students to collect, analyze, and manipulate data to analyze a situation; a *visualizing tool*, which provides students the opportunity to learn how to examine and utilize graphs and models; or a *checking tool*, which enables students to test and adjust conjectures or solutions. From a pedagogical perspective, technology can allow students to gain more control of their learning, increase opportunities for formative assessment, and provide occasions for students to learn skills useful in an increasingly connected workforce (Fadel & Lemke, 2006).

The classroom connectivity technology (CCT) system that is the focus of this case study, the TI-Nspire Navigator™, incorporates two unique technologies, the TI-Nspire™ graphing calculator and the TI-Navigator™ communication system. This system has a variety of uses that fall within the categories delineated above such as computation, exploration activities, increased engagement, and using multiple representations. In addition, this system has the capacity of the wireless communication system between the teacher's computer and students' graphing calculators. We have argued elsewhere that CCT provides many additional affordances for the classroom including a powerful tool for formative assessment based on public display of students' anonymously contributed responses and a mechanism to project images for mathematical exploration supporting conceptual development (Pape et al., 2012).

The purpose of this case study was to document the struggles and successes encountered by a pre-calculus instructor while using the TI-Nspire Navigator™ CCT system daily in her college mathematics course. CCT allows the instructor to send documents, collect student responses, and project student work for classroom discussion. Due to the increased complexity of teaching using CCT, however, teachers often struggle with initial implementation. This case study provides mathematics educators seeking to understand the costs and benefits of implementing CCT with valuable insight into issues of early implementation. We will begin with a discussion on the benefits of technology implementation and what is required of educators seeking to implement technology in their classrooms.

Benefits of Technology Use

Technology can have a wide range of benefits in the mathematics classroom when it is implemented appropriately. For example, implementation of the TI-Navigator™ technology in a middle school contributed to mathematics achievement three times greater than students who did not use it in their classrooms (McClure, 2006). In a college algebra setting, however, there were no significant achievement differences between students who used the TI-Navigator™ and those who didn't use the technology (Powers & Champion, 2008). When questioned about the impact of the technology on their involvement (learner centeredness¹), the classroom community (community centeredness), assessment practices (assessment centeredness), and construction of knowledge (knowledge centeredness), however, students responded positively. The students also indicated that the TI-Navigator™ played a supplementary role as a source of feedback. Finally, a review of the literature also indicated that technology improved student learning of graphing, multiple representations of functions, problem solving, and spatial skills (Fadel & Lemke, 2006).

In the *Classroom Connectivity for Mathematics and Science Achievement* (CCMS) project, a national randomized control trial, Pape and colleagues (Pape et al., 2010, 2011, 2012) examined the impact of implementing the TI-Navigator™ with the TI-83 Plus or TI-84 Plus series calculators in a wide range of schools. Teachers were randomly assigned to treatment or control classrooms. In Year 1, treatment teachers were provided a one-week professional development (PD) institute. The main focus of the institute was proficiency with the CCT, but a substantial portion of the PD was also focused on effective implementation of the technology. Students in classrooms that incorporated CCT scored higher on the CCMS algebra posttest than students in comparison classrooms that used the graphing calculators without CCT implementation (*Effect Size* = 0.32; Pape et al., 2011) as well as across four years of the project (Irving et al., 2010).

Implementing CCT following PD also resulted in a change in classroom discourse. Teachers who were using the CCT system asked closed questions 22% less often than those in the control classrooms, and some teachers anecdotally noted that they asked for student explanations more often as a result of students' answers being displayed for the class (Pape et al., 2010). CCT use also supported formative assessment due to increased class participation and engagement, with students responding that it made mathematics class more interesting and engaging. As a result of the increased formative assessment, the researchers also noticed that teachers would alter the

pace of their lessons – going over more examples if students needed reinforcement, and moving on if students indicated mastery (Pape et al., 2012).

Effective Technology Implementation

Technology implementation alone will not produce the intended benefits. Effective implementation is dependent on coupling the technology with appropriate pedagogy and content, using the technology for a long period of time (research suggests at least nine weeks), and incorporating the technology into instruction and assessment instead of merely replacing manual computation (Fadel & Lemke, 2006). Garafalo and colleagues (2000) have proposed five guidelines for successful incorporation of technology into mathematics teaching. Under these guidelines, teachers must: (1) introduce technology in the context of learning about mathematics concepts, (2) couple the use of technology with appropriate pedagogy and worthwhile mathematical goals, (3) use the technology to enhance mathematics lessons by performing tasks previously impossible without technology, (4) connect the mathematics to other mathematics concepts and to the real world, and (5) incorporate multiple representations.

According to Dick and Burrill (2009), there are two different views of how technology can be used in a classroom. Teachers may view technology as purely a computational tool, used only after the mathematical concepts have been learned and are ready to be applied to “real world” problems. Often, this perspective coincides with the opinion that technology such as calculators take away from opportunities to perform computations by hand. An opposing view of technology holds that it may be used to explore concepts in ways not possible without the technology. In five case studies of secondary mathematics teachers’ acceptance and implementation of technology, three teachers who taught using a “content-focused with an emphasis on understanding” approach and one teacher who taught with a “content-focused with an emphasis on performance” approach only perceived technology to be useful for computation or application of previously learned material. Only one teacher who believed students could construct their own knowledge through exploration (“learner-focused”) was willing to use technology to teach conceptual understanding in the future. Reasons cited among the teachers for not using the technology included a view that teaching with technology was not as efficient as direct instruction and a belief that technology could not prepare students for assessment (Norton, McRobbie, & Cooper, 2000).

In order to realize the intended benefits of technology, teachers must possess a special kind of knowledge. To teach effectively, teachers must develop or already possess content knowledge, pedagogical knowledge, and pedagogical content knowledge. Technological Pedagogical Content Knowledge (TPACK) is the intersection between these different types of knowledge and the knowledge required to use technology effectively (Mishra & Koehler, 2006; Niess, 2005; Niess et al., 2009). For example, teachers need to be able to identify a technology's strengths and weaknesses and use this information to inform how they implement the technology in their classroom to present concepts and evaluate student understanding (Koehler & Mishra, 2009).

Pape et al. (2012) specifically lists four necessary components to effectively implement CCT in the classroom:

Teachers must (1) design rich mathematical tasks that create contexts in which students may examine patterns and form generalizations; (2) co-construct norms for interaction that raise students' contributions to a level of object of discourse through which mathematical reasoning may be revealed; (3) enact formative assessment instructional practices that provide teachers and students access to increased knowledge of students' understandings; and (4) sustain students' engagement in mathematical thinking. (p. 193)

As teachers implement the TI-Navigator™, they progress through three phases pedagogically: *immediate*, *experienced*, and *master* (Roschelle, 2009). During the *immediate* stage, teachers will likely discard the technology if they are not sufficiently familiar with the technical aspects of using the technology or incorporating it in their classroom. If they are provided with the proper training, they will likely experience increased student involvement and achievement in their classrooms, but will continue to be concerned about how the seemingly time consuming technology fits into a course already pressed for time. Once teachers progress to the *experienced* stage, they are more likely to focus on a smaller set of functions that can be performed by the TI-Navigator™ that they feel most comfortable with and that they find the most useful. Finally, in the *master* stage, teachers will feel comfortable using a variety of functions of the TI-Navigator™ on a regular basis and have a better understanding of how much time activities will take and which activities are worth spending time on (Roschelle, 2009).

Educators intending to implement technology in their schools or classrooms may possess an overconfidence in their ability to enact reform, have a lack of evidence of the effectiveness of the technology, or underestimate how rapidly technology evolves and requires updating (Fadel & Lemke,

2006). Additional barriers to implementation are teachers having a lack of technical knowledge and support for technical difficulties, limited access to the technology, a limited possession of TPACK, little support or too much control from the administration, or a lack of time - including planning time and time in the classroom due to length of classroom periods and amount of curriculum to be covered (Hew & Brush, 2007). In addition, teachers may not see alignment between a technology and the curriculum or assessment methods (i.e., students should not use calculators because they cannot use them at the end of term exam) (Hew & Brush, 2007).

In conclusion, technology can provide opportunities for a wealth of benefits if implemented correctly by the school and in the classroom, with care taken to eliminate any possible barriers to technology adoption. We aim to examine one teacher's experiences including her struggles and successes once she began implementing CCT on a regular basis. Our purpose in this examination is to provide a description of what teachers should expect as they begin implementing CCT in their classrooms.

METHOD

Description of TI-Nspire Navigator™

The CCT system that our teacher incorporated within her pre-calculus course consisted of a class set of TI-Nspire™ calculators and the TI-Nspire Navigator™, which wirelessly connects the teacher's computer with each student's handheld calculator. This technology allows the teacher to communicate with the students through an access point connected to the teacher's computer. In addition to this technology, the teacher was equipped with a computer and a projector that could display the computer's monitor for the class to view. The computer also had the TI-Nspire CAS Teacher Software™ that could be used as a TI-Nspire™ calculator and projected for teacher-led instruction.

The TI-Nspire™ CAS calculator can be used as a traditional calculator, performing complex computations. The graphing function and table of values function are also similar to other graphing calculators, and are able to graph functions and display a table of values for a function or a data set. The CAS (computer algebra system) functions allow the user to compute complex algebraic procedures, but this function was not explored during the present study.

The TI-Navigator™, however, can afford additional uses to the TI-Nspire™. Quick Polls can be sent from the teacher to each calculator in the form of open response or multiple-choice questions that each student an-

swers. The teacher is able to collect each student's answer and anonymously display the results to the class. The instructor may also construct a special type of TI-Nspire™ document, a TNS file, as a quiz or class activity and send to the students' handheld device for use during a class. While Quick Polls provide a tool for teachers to spontaneously ask their class a question to determine their present understanding (Figure 1), quiz documents are TNS files the teacher can have prepared prior to class (Figure 2). TNS activity files are interactive documents with multiple "pages" in each document. Each page can serve one of many functions such as a calculator, a spreadsheet, a graph, or notes. Assembled together in a document, these pages can form an exploration activity for students to complete with instructions and immediate access to the graph, calculator, or spreadsheet functions necessary to complete the activity. Furthermore, teachers can create "action-consequence" programs for the TNS document (Figure 3) that allow students to manipulate a mathematical representation and observe the effects on another linked representation (Dick & Burrill, 2009). Finally, with the Screen Capture function, the teacher can project screenshots of a student's graphing calculator to the class through the projector, and the Presenter function allows the students to project their actions on their graphing calculator for class discussion. Each of these components allows for students' responses, typically contributed anonymously, to become objects of discourse for student and teacher examination and comment. Through careful probing and appropriately constructed classroom norms these discussions can reveal students' thinking about the problem.

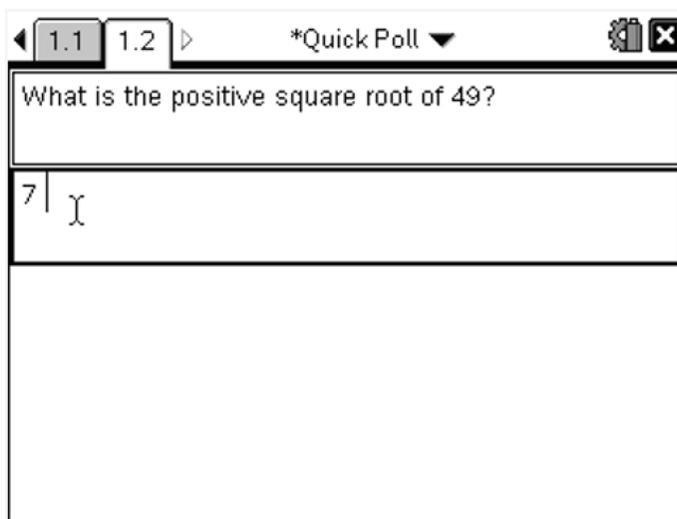


Figure 1. A screenshot of a sample Quick Poll document.

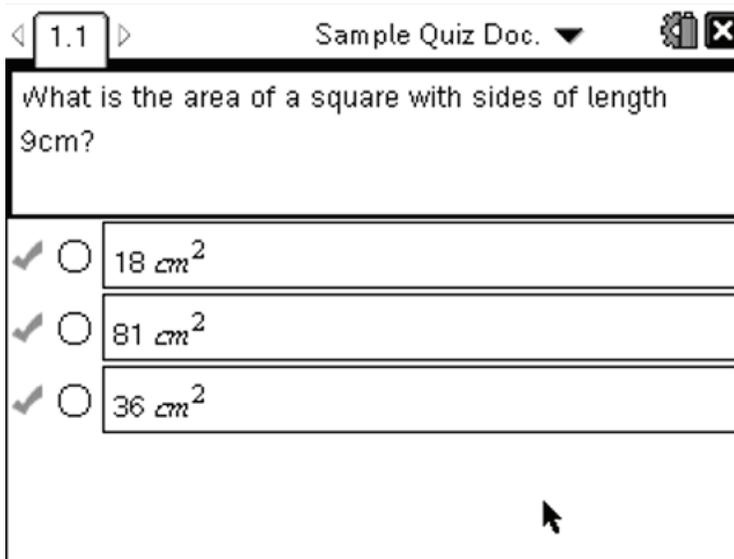


Figure 2. A screenshot of a sample TNS file being used as a quiz.

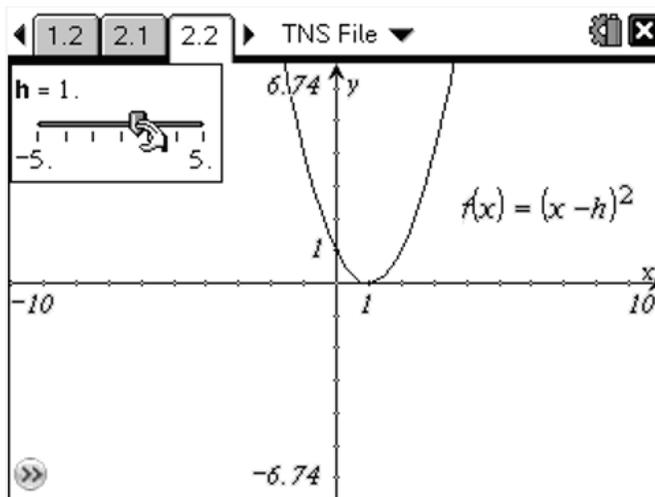


Figure 3. A screenshot of a sample TNS file being used as an “action-consequence” activity. Students can use the slider in the upper left corner to manipulate the value of h in the function $f(x) = (x - h)^2$ and instantly see how it changes the graph of the function.

Participants

The teacher observed, Ms. A (a pseudonym), was an instructor at the community college for eight years and had served as faculty coordinator of the mathematics and science department for six years at the time of the study. As coordinator, she scheduled all mathematics and science courses, hired all adjunct faculty, handled departmental issues raised by faculty, and evaluated all mathematics and science adjunct faculty. Finally, she served as the director of the Quality Enhancement Program being implemented at the school. This program was the impetus for the school to purchase the CCT for the mathematics classrooms. Ms. A is also a part-time doctoral student in education who is well informed of the current research on instructional methods.

It is important to note that because of these roles, she was extremely motivated to implement CCT in her classroom. She also recognized that she felt pressure that if she did not implement CCT effectively in the summer session, the technology would seem less appealing to other faculty members, who would thus be less likely to implement CCT in their classrooms in the future.

She taught two classes over the Summer B semester, and the classroom observed was a 3-credit pre-calculus undergraduate level course with 12 students enrolled. The class met for 2 hours a day, 4 days a week, for 6 weeks. This summer semester was shorter than a typical semester and therefore met more often during the week.

Data Sources

Several forms of data were collected during the study. The primary source was observation field notes collected by a single observer nearly every day during the first two and a half weeks, and twice a week for the remaining weeks as the data became saturated. A total of 14 out of 18 instructional days were observed, with the remaining four days dedicated to exams. Classes were not held on two days during the semester. The observation field notes logged the uses of the technology, all instructional activities with or without the technology, any technological difficulties experienced by teachers or students, and the amount of time each use of the technology took during the class period.

In addition, Ms. A recorded journal entries daily reflecting her teaching experience. On five days in the first half of the semester, the observer and

Ms. A discussed the day's lesson directly after class, and these conversations and the observer's reflections were recorded in the observer's journal. Daily course handouts printed for each student during every class period served as a reference for the observation field notes. The classroom notes also allowed for analysis of how Ms. A modified the lesson while it was being taught.

Data Analysis

The observation field notes were reviewed in conjunction with the daily course handouts to provide a comprehensive view of classroom events. Following several reviews of the data, several themes emerged that were used to code the data more systematically. Each instance of a productive digression, correction of a misconception, formative assessment, attempt to increase student involvement, use of multiple representations, or technological issue while using the technology was coded. Ms. A's journal entries and interviews were then examined for these same codes and new codes emerged. For example, the interviews were coded to note the teacher-described struggles with planning time, creating effective formative assessment, limited instruction time, and technological issues. Finally, Ms. A's journal entries were coded for these themes and the additional themes of suitability of certain mathematics topics for CCT and recognizing progress in using CCT during instruction emerged. These data provided insight into Ms. A's perceptions of her struggles and successes and provided triangulation for the themes that emerged from the observation field notes and daily course handouts.

The observation field notes also logged the number of times and duration that each function of the technology was used. The total time that technology was used in instruction during each class period was calculated to provide the average length of use. Each function of the technology was tallied by class session to provide an understanding of how Ms. A used CCT throughout the semester.

RESULTS

The results section will be framed around the research questions. First, the rate of use will be examined providing a quantitative perspective on the use of the CCT. Next, we will discuss the struggles Ms. A experienced using

the technology. Finally, we will discuss the successes Ms. A experienced, including how she progressed throughout the semester.

CCT Use

CCT was used on average 30 minutes ($SD = 18.99$) out of each 110-minute class period with a range from 5 to 63 minutes. The Quick Poll function was the only component that was used every day observed, with an average of 3-4 Quick Polls administered during each lesson. The calculator function was used during 6 (out of 14 observed; 0.43) lessons, TNS files and the graphing function were used during 5 lessons (0.36), screenshots were used during 4 lessons (0.29), quiz documents were used during 3 lessons (0.21), and the Presenter function was used during 2 lessons (0.14).

Struggles

Ms. A struggled to find the time required before class to plan technology use, as well as to find the time during class to incorporate technology due to the number of concepts needing to be covered over the course of the semester. She also struggled to overcome technological issues that arose during her lessons. Finally, she occasionally implemented the technology ineffectively, likely due to her developing Technological Pedagogical Content Knowledge (TPACK).

Planning time. When teachers begin to plan with CCT in mind, they struggle to know how to implement the technology to support students' understanding of specific concepts. Their focus is at the level of the specific concept versus larger pedagogical guidelines that might support student understanding. Thus, they have to search the Internet (i.e., TI-education website) to find appropriate lesson ideas. Finding, revising, and creating TNS files, associated student documents, pre-determined Quick Poll questions, and quizzes takes time and is typically not integrated into the planning of the remaining lesson components. Experience teaching with the technology, we hypothesize, will decrease this disconnection as the instructor begins to incorporate the technology into his or her thinking about teaching mathematics. Initially, however, this extended time for planning to implement CCT contributed to the limited use of TNS files (i.e., both quizzes and activities). Ms. A used spontaneous Quick Polls (i.e., created while teaching instead of in advance) even after she recognized that she should create the poll

questions with multiple choice responses prior to class. As will be discussed below, the exclusive use of open-response, spontaneous quick polls resulted in additional difficulties due to the need to interpret student responses. In terms of TNS activity files, Ms. A occasionally encountered difficulties in finding or constructing suitable classroom activities for topics such as during the concepts of determinants or partial fraction decomposition. Either these activities were not included in existing materials or she wasn't able to develop these activities on her own.

Instructional time. The number of topics within the curriculum created a context in which time for instruction limited Ms. A's perception of the technology's potential uses. While she recognized that TNS exploration activities would be beneficial for the students' understanding, these activities took a great deal of time. Ms. A expressed tension between allowing the students to create knowledge through interaction with the TNS files and the need to complete the curriculum in a timely manner. As the semester progressed, attempts to integrate TNS files into the lectures in a guided-exploration format to save time still left her feeling behind schedule and dissatisfied. Due to the compact nature of the course, when a TNS activity takes longer than planned, it often forces the teacher to rush through the other topics scheduled for the day. For example, Ms. A noted that:

We worked through the Geometric sequence and series [TNS] document. ... It took us about an hour to go through the document. This left me with an hour to cover both binomial expansion and mathematics induction. I felt rather rushed and was not happy. I feel that I was not able to spend as much time on the last two sections as I wanted to spend. (Instructor journal, August 5, 2010)

Even when TNS files were not used during instruction, Ms. A expressed worries about the technology causing the class to be behind schedule, which was somewhat unfounded. In one lesson, her journal entry commented that she "did a lot of Quick Polls for the concept of sequences – too many. I feel like I wasted a lot of time" (Instructor journal, August 4, 2010). Field notes from this lesson, however, indicated that she only used two Quick Polls (less than the average number per class) for a total of 18 minutes. This included the question prompt presentation, student work to solve the problem or answer the question, review of the Quick Poll results, evaluation of the student responses, and explanation of the solution. Thus, Ms. A's comments suggest that she may have perceived that 18 out of 110 minutes dedicated to formative assessment with technology was too much.

Technological issues. Technological issues also posed a struggle for Ms. A as she taught her lessons. Occasionally, the technology would not

work as planned, and she would have to unexpectedly adjust her lesson to eliminate a planned use of the technology or would attempt to fix the technological error while simultaneously teaching, which she indicated in her interviews caused anxiety. These technological issues ranged from 30 seconds to address the unfamiliar task of deleting previous graphs on the graph page to adjusting an entire lesson after the TI-Navigator™ would not communicate with the TI-Nspire™ calculators. However, there was only one instance of a technological issue interfering with the entire lesson – most technological issues were resolved very quickly. Another technology-related issue was the task of instructing students on how to use the calculator and learning how to identify and correct their technical errors. While this may take instructional time (usually 1-2 minutes), it can also be considered a success as students became more competent in using the technology.

Technological and pedagogical knowledge. Creating formative assessment tasks within the context of CCT requires not only content knowledge and knowledge of common student misconceptions, but knowledge of how to use the technology effectively to uncover students' present understandings. At times, Ms. A experienced difficulties constructing Quick Poll questions that provided useful information. Some questions don't lend themselves well to the analysis that is needed to make instructional decisions. For example, sending Quick Polls that require a "yes" or "no" answer are not very informative and do not give deep insight into student understanding. Similarly, using the Quick Polls to determine how many students correctly answered a problem or question places less emphasis on understanding how the students arrived at the answers and may hide student misconceptions. Ms. A noted halfway through the semester, however, that she was "quickly learning what is NOT a good quick-poll [sic] question and what is a good quick poll question" (Instructor journal, July 19, 2010).

Open response Quick Poll questions that require students to type their answers took longer for students to input and Ms. A to analyze than multiple choice questions. Ms. A had to decipher different formats of similar student answers and determine how many students actually obtained the correct response. It is important to note that it was Ms. A who felt she was responsible for deciphering the students' responses. This process might be facilitated if the students were given the responsibility to analyze the responses. Ms. A recognized that multiple choice questions would be easier to assess, but as discussed previously, a lack of planning time hindered her ability to create these questions prior to class. However, the students' responses to these open-ended questions sometimes provided insight into student understanding in a way that the multiple choice format could not. For

example, when students were asked to solve $\log(x) + \log(x+3) = \log(10)$, two students entered “ $\text{sqrt}(10-3x)$ ” as their answers. This led to a valuable discussion related to why a solution to the equation cannot have x in the answer when the question requires one to solve for x .

Ms. A sometimes used the technology in other inefficient ways that highlighted her increasingly integrated but still fragile TPACK. For instance, some activities could have been presented as a TNS file that would serve as the exploratory lesson during which the students might discover mathematics concepts. During one lesson, to explore translations she had some students plot $f(x) = \log(x \pm c)$ and some students plot $f(x) = \log(x) \pm c$ for a c of their choice. Then, she presented the screenshots of each calculator on the board so that the class might engage in discussion about the different graphs. To help them notice the patterns in the translations, she asked the students to also plot $f(x) = \log(x)$ for reference. While this nearly ten-minute activity likely helped students construct a deep understanding of this concept, there are more pedagogically and technologically sophisticated ways to present this mathematics concept. A potentially more efficient way to present this concept might have been to create a simple TNS file with 2 graph pages – one graph page for $f(x) = \log(x \pm c)$ and one graph page for $f(x) = \log(x) \pm c$. Both of these pages could have a slider (i.e., a toggle that is associated with the value of variable parameter of an equation or expression) that students could manipulate to change the value of c . Changes in the value of c would be linked to a graphical representation that would be translated accordingly. In this way, students could see the relationship between the value of c and the translations of the graph $f(x) = \log(x)$.

Progression During The Semester

Throughout the semester, Ms. A showed evidence of overcoming some of these struggles. Quick Polls at the beginning of the semester were largely spontaneously created during the lesson with no question prompts displayed on the students’ calculators. This created confusion among students and occasionally students would submit answers to a question different from that posed by Ms. A. She recognized this and added prompts to the Quick Polls, which increased her ability to evaluate student understanding.

Additionally, Ms. A reported in her interviews feeling less anxiety toward the end of the semester when technological issues arose. The technology also became more seamless and integrated into the daily classroom activities as soon as a week after the semester began. For example, students

automatically picked up a calculator when they entered the classroom and signed in. They indicated greater comfort and efficiency at using the technology by, for example, using the calculator during class without teacher direction.

Perhaps most importantly, Ms. A began incorporating the technology in varied ways as the semester progressed. For example, she began using screenshots of the students' calculators to increase student involvement and explanation. She also used the Presenter function to help students explain how to resolve technical issues to each other. Finally, she adapted activities for a guided exploration format as a compromise between improving student understanding and staying on time with planning the curriculum.

Successes

Formative assessment. Perhaps the most salient successful aspect of Ms. A's use of the technology was the increase in formative assessment within her teaching. Each Quick Poll or quiz allowed her to evaluate how many students understood the current topic. This knowledge supported subsequent instructional decisions as exemplified below. For example, Ms. A would spend limited time reviewing the solution to a problem that all students answered correctly but would ask students to explain their solution methods when only 60% of them answered correctly. Ms. A could also provide Quick Polls to evaluate additional instruction on a topic. On one occasion, seeing that only half the students answered a Quick Poll question correctly, Ms. A provided additional instruction on the concept. In a subsequent Quick Poll, she was assured that this additional instruction had helped more students understand this concept when over 80% of the students answered correctly. Finally, she could identify errors among students' responses and thus take steps to correct them. For example, when one student answered in a Quick Poll that a circle had a radius of -2 , Ms. A was able to discuss the meaningfulness of a negative radius for a circle.

In addition, Ms. A occasionally began a lesson with a quiz related to previous content. This practice allowed her to evaluate students' prior knowledge and ensure that all students started out with an understanding of the basic concepts needed to be successful in the day's lesson.

Spontaneous productive digressions. Spontaneous productive digressions were episodes that veered from the intended content as a result of something occurring within the class discussion. These were typically initiated when a student did not understand something or a student brought up

a tangential topic. When student misconceptions surfaced as a result of formative assessment or classroom discussion, Ms. A would sometimes use a graph page or calculator page to help the student visualize or test out the situation in question. For example, Ms. A reflected about one lesson:

At one point in the class a student suggested we ‘distribute the \ln ’ when trying to solve an equation involving $\ln(x+9)$. I was able to snatch up the opportunity to dispel that misconception by having students plug in a number for x to see if $\ln(x+9) = \ln x + \ln 9$. All were able to ‘see’ that this would not work. (Instructor journal, July 13, 2010)

Ms. A reported feeling that this quick digression enhanced by the TI-NSpire™ had more impact on student understanding than simply saying that one cannot “distribute the \ln ”. While Ms. A’s quick demonstration was worthwhile, her digression could have been taken one step further by asking students to consider the value $x=9/8$, which satisfies the equation $\ln(x+9) = \ln x + \ln 9$. This could have led into a valuable discussion about how one value cannot prove that something is an identity, even though one value can prove that something is *not* an identity.

Increased involvement. The technology provided many opportunities to promote increased involvement among the students. The Screen Capture function forced students to stay on task during explorations by allowing the teacher and the class to see if particular students were completing the activity. A few weeks into the semester, it was also discovered that the Presenter function allowed students with troubleshooting questions to simultaneously see solutions and hear explanations on how to work the technology from other students. For example, during one lesson, a student used the Presenter function to show the class how to perform a 2×3 matrix addition problem on the calculator.

Ms. A also used Quick Poll questions to stimulate student involvement by requiring the entire class to submit a response before she would move on with the lesson. When she wanted to review solutions to the prior day’s test, Ms. A also used Quick Polls to have students vote anonymously on which test questions they would like reviewed—this was especially helpful for shy or embarrassed students to seek help when they may not have otherwise asked questions. Finally, Quick Polls helped Ms. A press students for more active involvement during discussions. During one lesson, when no student volunteered an answer to a question, she informed the class that they would answer that question in a Quick Poll.

Finally, while used on a limited basis, TNS files gave students the opportunity to make conjectures about mathematical concepts and test their conjectures. One TNS exploration activity guided students through several examples and asked them to make conjectures about the end behavior of the graph of a polynomial function based on its degree and the sign of the leading coefficient. This allowed students an opportunity to actively explore concepts and construct their own knowledge instead of being taught passively through direct instruction.

Multiple representations. The technology provided many opportunities to project and explore multiple representations of a concept. Graph pages provided graphical representations of algebraic equations or symbolic representations. For example, during a lesson on systems of equations, Ms. A asked students to graph a system of two equations and to identify the number of solutions and the coordinates of the solutions of each system. The class then solved the same systems algebraically using the substitution and elimination methods and made connections between these different solution methods.

The ability to show multiple representations also allowed Ms. A to direct students to examine patterns. For example, in one lesson students examined patterns in the horizontal asymptotes by plotting polynomials and finding the value of the asymptote from the graph. The teacher then guided the students to make connections to the algebraic representation by asking: “What happens when the degree is bigger on the bottom? What if they’re the same? What if the degree is bigger on top?” This short exercise enabled students to build their understanding of this concept.

DISCUSSION

Over the course of the semester, Ms. A struggled with finding the time to plan for CCT use and implementing it without the perception that it was causing the class to fall behind schedule. She occasionally encountered technological issues, and, likely due to her developing TPACK, she sometimes used CCT in ineffective ways. Regardless of these struggles, however, Ms. A succeeded in many aspects of her CCT implementation by using the technology to incorporate multiple representations, formative assessment, exploration activities, productive digressions, and increased involvement within her lessons. In retrospect, Ms. A summarizes:

I feel that I had a lot more success in this class than in previous terms. I had a lot more A’s, no withdrawals, and only one unsuc-

cessful student. I believe the technology had a lot to do with this success. I'm really glad I tried it and look forward to continued success in its implementation. (Instructor Journal, August 10, 2010)

We also believe that her overall implementation of technology was successful and worth overcoming the struggles she faced over the semester. It is important to note that all technology is not beneficial, and many times benefits from technology cannot easily be replicated in different schools. Thus, educators are advised to perform comprehensive research on a technological innovation and implement in test cases before deciding to implement it in their school (Fadel & Lemke, 2006).

References

- Bransford, J. D., Brown, A. L., & Cockings, R. R. (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.
- Dick, T., & Burrill, G. (2009). *Tough to teach/tough to learn: Research basis, framework, and principles for a practical application of TI-Nspire™ technology in the Math Nspired series*. Dallas, TX: Texas Instruments.
- Doerr, H. M., & Zangor, R. (2000). Creating meaning for and with the graphing calculator. *Educational Studies in Mathematics*, 41, 143-163.
- Fadel, C., & Lemke, C. (2006). *Technology in schools: What the research says*. Cisco Systems & Metiri Group. Retrieved from <http://www.cisco.com/web/strategy/docs/education/TechnologyinSchoolsReport.pdf>
- Garofalo, J., Drier, H., Harper, S., Timmerman, M.A., & Shockey, T. (2000). Promoting appropriate uses of technology in mathematics teacher preparation. *Contemporary Issues in Technology and Teacher Education* [Online serial], 1. Available: <http://www.citejournal.org/vol1/iss1/currentissues/mathematics/article1.htm>
- Hew, K., & Brush, T. (2007). Integrating technology into K-12 teaching and learning: Current knowledge gaps and recommendations for future research. *Educational Technology Research and Development*, 55, 223-252. doi: 10.1007/s11423-006-9022-5
- Irving, K. E., Pape, S. J., Owens, D. T., Abrahamson, A. L., Silver, D., & Sanalan, V. A. (2010, May). *Longitudinal study of classroom connectivity in promoting mathematics and science achievement: Years 1-3*. Paper presented at the Annual Meeting of the American Educational Research Association, Denver, CO.

- Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, 9(1). Retrieved from <http://www.citejournal.org/vol9/iss1/general/article1.cfm>
- McClure, A. (2006). Problem/Solution. *District Administration*, 42(9), 76.
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108, 1017-1054. doi: 10.1111/j.1467-9620.2006.00684.x
- Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education*, 21(5), 509-523. doi: 10.1016/j.tate.2005.03.006
- Niess, M. L., Ronau, R. N., Shafer, K. G., Driskell, S. O., Harper S. R., Johnston, C., Browning, C., Özgün-Koca, S. A., & Kersaint, G. (2009). Mathematics teacher TPACK standards and development model. *Contemporary Issues in Technology and Teacher Education*, 9(1), 4-24.
- Norton, S., McRobbie, C., & Cooper, T. (2000). Exploring secondary mathematics teacher's reasons for not using computers in their teaching: Five case studies. *Journal of Research on Computing in Education*, 33, 87-109.
- Pape, S. J., Bell, C. V., Owens, S. K., Bostic, J. D., Irving, K. E., Owens, D. T., ... Silver, D. (2010, May). *Examining verbal interactions within connected mathematics classrooms*. Paper presented at the Annual Meeting of the American Educational Research Association, Denver, CO.
- Pape, S. J., Irving, K. E., Owens, D. T., Boscardin, C. K., Sanalan, V., Abrahamson, A. L., ... Silver, D. (2011). *The impact of classroom connectivity in promoting Algebra I achievement: Results of a randomized control trial*. Manuscript submitted for publication.
- Pape, S. J., Irving, K. E., Bell, C. V., Shirley, M. L., Owens, D. T., Owens, S. K., ... Lee, S. C. (2012). Principles of effective pedagogy within the context of connected classroom technology: Implications for teacher knowledge. In R. N. Ronau, C. R. Rakes, & M. L. Niess (Eds.), *Educational technology, teacher knowledge, and classroom impact: A research handbook on frameworks and approaches* (pp. 176-199). Hershey, PA: IGI Global. doi: 10.4018/978-1-60960-750-0
- Powers, R., & Champion, J. (2008). *Teaching and learning college algebra with the TI-Navigator wireless handheld network*. Proceedings of the Twentieth Annual International Conference on Technology in Collegiate Mathematics, San Antonio, TX.
- Roschelle, J. (2009). *Towards highly interactive classrooms: Improving mathematics teaching and learning with TI-Nspire Navigator*. Menlo Park, CA: Center for Technology and Learning, SRI International, Inc. Retrieved from: <http://ti-researchlibrary.com/Lists/TI%20Education%20Technology%20Research%20Library/Attachments/205/InteractivityWhitePaper%20v9.pdf>

Notes

1 Learner centeredness, assessment centeredness, knowledge centeredness, and community centeredness are terms from Bransford, Brown, & Cockings (2000).

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