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THE PRACTICALITY OF IMPLEMENTING CONNECTED CLASSROOM TECHNOLOGY IN SECONDARY MATHEMATICS AND SCIENCE CLASSROOMS

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ABSTRACT. Connected classroom technology (CCT) is a member of a broad class of interactive assessment devices that facilitate communication between students and teachers and allow for the rapid aggregation and display of student learning data. Technology innovations such as CCT have been demonstrated to positively impact student achievement when integrated into a variety of classroom contexts. However, teachers are unlikely to implement a new instructional practice unless they perceive the practical value of the reform. Practicality consists of three constructs: *congruence* with teacher's values and practice; *instrumentality*—compatibility with the existing school structures; and *cost/benefits*—whether the reward is worth the effort. This study uses practicality as a framework for understanding CCT implementation in secondary classrooms. The experiences of three science teachers in their first year implementing CCT are compared with matched-pair mathematics teachers. Findings suggest that despite some differences in specific uses and purposes for CCT, the integration of CCT into regular classroom practice is quite similar in mathematics and science classrooms. These findings highlight important considerations for the implementation of educational technology.

KEY WORDS: audience response system, connected classroom technology, educational innovation, educational technology, mathematics education, practicality index, science education, technology implementation, technology integration

Student achievement in mathematics and science education is a continuing global concern. International assessments of student progress highlight the need for improved numeracy and scientific literacy (PISA, 2007; Martin, Mullis, Gonzalez & Chrostowski, 2004). Research programs aimed at identifying effective practices for mathematics and science education hold promise for accomplishing this goal. Educational technologies with the potential to increase student achievement include the broad range of networked classroom communication systems or audience response systems. These systems allow teachers to pose questions and collect instructional data from students through individual handheld devices (Fies & Marshall, 2006; Roschelle, Penuel & Abrahamson, 2004). Merely providing the tool for classroom instruction

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is not enough; rather, the use of such a tool must also be integrated into a teacher's classroom practices (Wiliam, 2006), which are difficult to change (Cuban, 1998).

Related to audience response systems is a set of technologies that facilitate the interconnectedness of students and teachers. Referred to as connected classroom technology (CCT), these devices promote teacher–student communication as well as supply a broader range of assessment and display options. The CCT employed in this study is the Texas Instruments TI-Navigator™ system (Figure 1). Briefly, each student has a *handheld graphing calculator* that is wired to a *network hub* along with three other handhelds. Each hub communicates wirelessly with the teacher's computer through an *access point*. Coupling this system with a digital computer projector allows the teacher to display student responses for the entire class. Specific software applications on this system (Learning Check, Quick Poll) allow the teacher to send forced-choice or open-ended question prompts for the students to answer using the alphanumeric keypad on their individual calculators. Additional software components support students collaboratively creating graphs using data points or equations (Activity Center) and the teacher gathering images from student calculator screens for display (Screen Capture).

The Classroom Connectivity in Promoting Achievement in Mathematics and Science Achievement (CCMS) research project provided secondary mathematics and science teachers with CCT and professional development to support its use. Initial findings from CCMS are promising

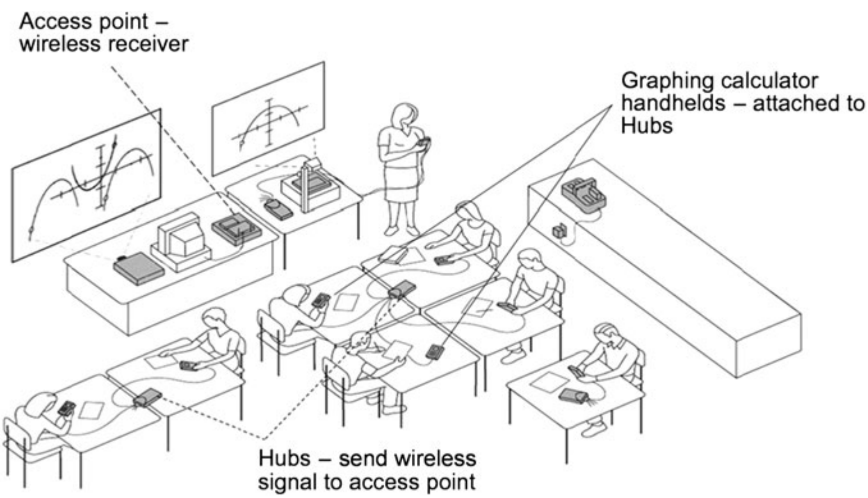

Figure 1. A typical classroom setup for the TI-Navigator™ system. Figure used with permission from Texas Instruments

and suggest a role of CCT implementation in increasing student achievement (Pape, Irving, Owens, Boscardin, Sanalan, Abrahamson, Kaya et al., 2008; Irving, Pape, Owens, Abrahamson, Silver & Sanalan, 2010). Moreover, case study analysis of physical science teachers indicates the potential of CCT to promote teaching and learning more aligned with social constructivist principles, which highlights the importance of understanding how CCT is integrated into classroom practice (Irving, Sanalan & Shirley, 2009). In the present study, we examine the implementation of CCT in science and algebra classrooms and provide a description of the integration experiences of teachers in these areas. Close analysis of CCT implementation sheds light on how teachers in different disciplines approach the use of CCT in teaching.

The goal of this research project was to compare and contrast the cost and benefits of implementing CCT in middle and high school mathematics and science classrooms. Since one criterion for inclusion in the present study is success (as defined below), this project focuses explicitly on how teachers integrated a new innovation into their previous practice and their views of barriers and successes. This study addresses the following research questions with respect to three mathematics and three science teachers in the first year of CCT implementation:

1. What features external to mathematics and science teachers' classrooms demonstrate instrumentality of CCT implementation?
2. What features of successful mathematics and science teachers' classroom practice were congruent with CCT implementation?
3. What relative costs and benefits of CCT implementation are described by mathematics and science teachers?

Literature Review

The introduction and adoption of educational technology in K-12 teaching has been a focus of policy makers for the last 10 years (Trotter, 2007). For example, the US Congress recently appropriated more than $650 million in the economic stimulus package as part of the American Recovery and Reinvestment Act (2009) to support educational technology programs (Ash, 2009). Some reports indicate that US school districts spent $7.87 billion during the 2003–2004 school year on educational technology (Quality Education Data, 2004; Education Week, 2005), thus expanding access to technology as a focus of educational policy

Despite the commitment of government and the increase in computing power and availability, integration of technology into teaching has been slow (e.g. Becker, 2000; Cuban, Kirkpatrick & Peck, 2001). The assimilation of educational technology into teachers' existing classroom practices and routines requires complex changes (personal, organizational, and pedagogical; Ertmer, 1999). Some factors that have been suggested as potential barriers include the availability of resources (e.g. Hew & Brush, 2007; Karagiorgi, 2005; O'Dwyer, Russell & Bebell, 2004), institutional organization (e.g. Fox & Henri, 2005; Becker, 2000), teacher skills (e.g. Hughes, 2005; Lim, Teo, Wong, Khine, Chai & Divaharan, 2003; Snoeyink & Ertmer, 2001–2002), gender preferences (Durndell & Thomson, 1997; Hopkins, 1998), race (Kerka, 1995; Sutton, 1991), and subject subcultures (Goodson & Mangan, 1995; Hennessy, Ruthven & Brindley, 2005; Selwyn, 1999).

Technology Integration in US Schools

The challenges of technology integration may differ among subject subcultures. Members of a given subculture share common understandings that are implicit and explicit among the individuals who make up the subculture. For example, the disciplinary focused departments in middle and high schools represent unique subcultures where members identify as subject specialists and share common assumptions about teaching and learning, teaching practices, and student placement (Selwyn, 1999). These common assumptions influence classroom practice and also extend to local education authorities and even to different countries (Siskin, 1991). As students progress through their K-12 education, the impact of subject subculture increases as teachers become more strongly identified with particular disciplines.

Research indicates differences between the ways that members of diverse disciplinary subcultures integrate educational technology into their teaching (Goodson & Mangan, 1995; Hennessy et al., 2005; Selwyn, 1999). Prescribed curricula and assessment demands that vary for each discipline may exert differential pressures on teachers in unique content specialties. Traditions of collegial interaction versus individualistic working styles may also affect educational technology integration patterns (Hennessy et al., 2005). A weak alignment between technology use and the teacher's conception of what it means to be a learner of mathematics or science may interfere with a teacher's willingness to adopt and integrate an innovative technology within their classroom practice (Selwyn, 1999). Selwyn remarks that "educational computing should thus be seen as a distinct culture, more congruent with some subjects than others" (p. 43). The preexisting norms and values of classroom culture may prove antithetical to the culture of technology use and difficult to overcome.

Frameworks for Technology Implementation

A variety of theoretical frameworks for the implementation of educational innovations have been derived from research. Several of these have been generated specifically regarding the implementation of technology in school settings. Ertmer (1999) uses first- and second-order barriers to explicate the differences between structural conditions in the educational world (administrative dictates, hardware and software, bell schedules, classroom size, and furniture arrangement) and individual internal barriers such as teacher beliefs. Since many teachers have little experiential basis for classroom integration of educational technology, they may bring few preconceived notions about how to best incorporate modern technologies in their teaching practice. Beliefs may range from thinking about technology as simply another tool in their toolbox of educational strategies to resentful acceptance of yet another directive from the central office to adopt the latest reform innovation (Ertmer 2005). Teachers are likely to use technology consistent with their prior beliefs about disciplinary content and instructional practice (Neiderhauser & Stoddart, 2001). The more incongruous the new practice is from prior practice, the more challenging is the integration of the innovation (Zhao, Pugh, Sheldon & Byers, 2002).

Teacher beliefs and practices play a critical role when considering the implementation of classroom technology. Becker (2000) proposed four conditions necessary for using computers as an important pedagogical aid. In this framework, teachers must have convenient and reliable access to the technology, they must possess adequate skills and knowledge, the use of technology must not overly constrain their curricular freedom, and the technology must support constructivist pedagogical beliefs (Becker, 2000). While all of these components are important for the success of technology implementation, teacher beliefs may be the most challenging to overcome (Ertmer, 2005). Studies of mathematics classrooms have demonstrated a complex relationship between teachers' beliefs about subject matter and beliefs about instruction (Thompson, 1984); teachers' beliefs about the role of technology in instruction are likely to further complicate the relationship between beliefs and practices.

In examining subject-specific technology implementation, Ruthven (2008) describes four factors that influence the adoption of technology.

Identified within the context of technological innovations in mathematics education, this framework includes (1) disciplinary congruence, (2) external currency, (3) adoptive facility, and (4) educational advantage. These features can be used to demonstrate how well a tool supports contemporary mathematics practices as well as the degree to which the use of the tool can be woven into the teacher's pedagogy.

An earlier framework identifies the practicality index to describe the implementation of educational innovations (Doyle & Ponder, 1977). This framework comprises instrumentality—the degree to which the school context makes implementation of an innovation feasible; congruence—the degree to which the innovation matches teacher practices and beliefs; and cost/benefit ratio—the judgment that teachers make regarding whether the innovation is sufficiently advantageous to warrant the difficulties of implementation. While complementary to the frameworks described above, the practicality index provides a broader view of the implementation of innovations rather than being technology-specific. It allows for factors external to the lesson being taught (instrumentality) to be separated from factors more immediately relevant to instruction (congruence). Moreover, it provides a way to understand teachers' decisions to adopt or reject an innovation based on the careful judgments they make regarding the relative costs and benefits of implementation. For these reasons, the Doyle & Ponder (1977) framework was chosen for the present study to support our analysis and description of the implementation of CCT into mathematics and science classrooms.

Methods

CCMS Research Study

The data for this study were collected as part of the CCMS project, over 100 mathematics teachers and 20 physical science teachers representing 28 states in the USA and two Canadian provinces implemented a specific type of CCT, the Texas Instruments TI-Navigator™. As part of the intervention in the larger research study, teachers received training in the use of this CCT as well as the pedagogy of a connected classroom. Teachers also participated in follow-up professional development sessions at an annual technology conference and maintained personal contact with the research team through biannual interviews and, for some, an annual classroom observation. For details of the CCMS research study and interventions, see Owens et al. (2008).

Quantitative data from the first year of this study in mathematics classrooms demonstrate significant differences between treatment group (implementing CCT) and control group posttest achievement (Pape et al., 2008; Irving et al., 2010). However, to identify the factors contributing to the increase in student achievement, understanding how teachers adapt their instructional practices when using CCT is also important. The present analysis uses interview data to examine the practice of six participants (described below) in the first year of CCT implementation.

Participants

The study reported here examines the experiences of a subset of participants in order to gain a better understanding of how CCT fits with their school environments and regular classroom practice. Nine secondary science teachers participated in the CCMS study in the first year of the physical science study. Of these, three were selected for the current analysis based on their perceived success with the technology and the diversity of their classroom situations. These participants had, at the time of a fall telephone interview (described below), managed to set up and begin to use the CCT in their instruction. Moreover, as a further indicator of success with technology implementation, all of the selected teachers returned for the second and third years of the longitudinal CCMS study. Only data from the first year of implementation, however, are considered in the present analysis.

To compare experiences across disciplines, the science teachers were matched to mathematics teachers representing similar school contexts and academic preparation. Eligible matches included the subset of mathematics teachers from the CCMS project who had complete data sets, including telephone interviews and classroom observations. Matches were assigned based on school-level demographic features as well as individual teacher characteristics, such as years of teaching experience. Demographic information for the selected participants is shown in sets of pairs (Table 1), with the data for a science teacher presented first, followed by the mathematics teacher selected as a match. Although the sample of mathematics teachers was generated through matching, the data were considered in aggregate, with the experiences of the three science teachers being considered together and compared to those of the set of three mathematics teachers. The matching process provides groups of science and mathematics teachers that are similar to one another in ways that may affect CCT implementation.

TABLE 1

Teacher- and school-level demographics

Pairs	*Participant (pseudonyms)*	*Years teaching*	*Course taught (grades)*	*% Low SES (school level)*	*Student demographics (school level)*
1	Mrs. C	16 (5 in science)	General science (7, 8)	50	57% Caucasian 1% Hispanic 36% African American 0% Asian
	Mrs. T	11	Algebra I (8)	53	51% Caucasian 2% Hispanic 47% African American 1% Asian
2	Mrs. R	21	Conceptual physics (10, 11, 12)	8	89% Caucasian 0% Hispanic 7% African American 3% Asian
	Mr. P	22	Advanced algebra (9–12)	9	84% Caucasian 8% Hispanic 2% African American 5% Asian
3	Mrs. S	3	Physical science (9)	5	98% Caucasian 0% Hispanic 1% African American 0% Asian
	Mr. W	5	Algebra I (9)	3	95% Caucasian 1% Hispanic 2% African American 2% Asian

Data Sources

In the first semester following implementation of the CCT, all participants were contacted to conduct a fall telephone interview (FTI), which lasted approximately 30–40 min. The purpose of this initial phone contact was to understand any successes or challenges that the teacher experienced in initial setup and use of the equipment. A more thorough spring telephone interview (STI) near the end of the school year probed for additional details regarding specific lessons and instructional tasks implemented through the CCT system as well as other aspects of teaching in a connected classroom. Interviews were audio-recorded and transcribed.

A subset, including all six of those included in this analysis, of the participants who had successfully implemented the CCT by the time of the fall telephone interview were selected for a 2-day classroom observation visit by a research team member. During this observation visit, the researcher videotaped at least one class period on two successive days. A post-observation teacher interview (POI) prompted the teacher to reconstruct his or her lesson planning and relate perceptions of teaching with connected classroom technology. Interviews were audio-recorded and later transcribed verbatim and analyzed using the NVivo ™ software package.

Data Analysis

A priori codes were developed using the three constructs that comprise the practicality index: instrumentality, congruence, and cost/benefit ratio (Doyle & Ponder, 1977). Two coders used the constant comparison method (Strauss & Corbin, 1998) to analyze interview transcripts to identify subcategories within each of these broader themes. Each coder independently reviewed a subset of interview transcripts to identify emergent categories aligned with instrumentality and congruence constructs. Codes developed by each coder were discussed to clarify the distinctions between categories. Following reconciliation of codes, one coder analyzed the complete data set in NVivo 8™ for instrumentality-related evidence, while the second coder applied the congruence codes to the entire data set. Both coders identified components of the cost/benefit ratio throughout the coding process. Evidence in each coding category from mathematics teachers and science teachers were analyzed separately to determine preliminary assertions and identify similarities and differences based on disciplinary subcultures. Preliminary assertions were then compacted to generate a final set of assertions.

Findings

Findings were initially categorized with respect to their relation to the three components of the practicality index (Doyle & Ponder, 1977). Instrumentality refers to how well a given innovation fits within the school setting. Systematic difficulties, such as a lack of adequate technological infrastructure or district mandates to not use calculators, would prevent the implementation of CCT. Clearly, all six of these participants worked in schools with at least a basic level of support for technology, or they would not have been able to implement the technology at all. Therefore, our findings are limited to the practicality of CCT within classrooms where initial support is provided and successful use was realized. Teacher reports, however, shed light on the particular issues they faced.

Congruence refers to how well the innovation matches a teacher's typical teaching practices. Innovations that do not match the instructional and assessment strategies that teachers use are unlikely to be sustained in any meaningful way. Although mathematics and physical science teachers used the technology in different ways, CCT was found to be congruent with many aspects of classroom practice.

The final construct in the practicality index focuses on the judgment that teachers make regarding the relative costs and benefits of implementing a given innovation. Costs and benefits are tightly linked to, and span, the notions of instrumentality and congruence. Costs occur when additional challenges related to lack of instrumentality or congruence accompany the implementation of the innovation. Just because an innovation is found to demonstrate instrumentality or congruence, however, does not mean that it will be interpreted as a benefit to the adoption of the technology. Rather, the teacher must weigh the costs of implementation against the potential benefits, such as increased student learning. If the benefits are found to be greater than the costs of implementation, the teacher is likely to implement the innovation.

In the sections that follow, we present assertions related to these three constructs of instrumentality, congruence, and cost/benefit ratio. Accompanying each assertion is evidence from teacher interviews. Detected differences in the experiences of the three mathematics and three science teachers are indicated within the context of each assertion as appropriate.

Instrumentality of Implementation

Assertion 1: Teachers Experienced Initial Challenges in Setting up Computer Equipment. Although Individual Teacher and Student Skills Improved Throughout the year, Lack of Familiarity with the Technology Sometimes Impeded Instruction. In the beginning of the school year, teachers reported difficulties with setting the equipment up in their classrooms. Mr. W listed some of the many tasks involved, such as “getting it into the classroom, programming everyone’s calculators, getting all the programs on there and installing all the hardware and software on my computer” (Mr. W; FTI). Teachers faced problems with computer memory, such as when “the computer would freeze up and I would not be able to do what I wanted to do” (Mr. P; FTI). Moreover, teachers had to relocate other furniture in their classrooms or, as with immovable laboratory benches in science classrooms, put the CCT system in an inconvenient location. Mrs. S explained that

> The way my room is set up, my projector has to be right next to my computer, and my screen is on the other side of the room …I had to be up in the corner of the room, trapped by this cord. (Mrs. S; FTI)

In order to connect other pieces of technology used in her classroom, Mrs. S had cords that made it difficult for her to move around the room in her usual manner.

Later in the year, teachers had worked out many of these initial frustrations, but saw other difficulties with implementation. Occasional problems with the wired or wireless communication signals caused information to be lost; the on-screen message when this happens is often described as a “link error.” As one example, Mr. P had situations arise where he attempted to send electronic questions but a communication error in the system prevented them from being transmitted properly, saying that “some kids didn’t get the [question prompt] even though they …were in the right spot” (Mr. P; STI). He acknowledged that despite students’ having followed the correct procedures and navigated to the proper screen on their handheld calculator, a communication error prevented them from receiving the question prompt.

In general, students responded positively to using the system in their classes. In some classrooms, difficulties arose for students who were unfamiliar with the handheld graphing calculator. Moreover, communication errors between the devices sometimes slowed student progress and led to a sense of frustration. Mrs. T explained that "there are some kids who have had trouble because of the technology" (Mrs. T; FTI). Mrs. R also pointed out that "the other thing to note is that the kids get frustrated when things don't work. They don't like it, and they don't like having a teacher that can't fix it" (Mrs. R; POI). However, teacher reports indicated that students learned to manage occasional technology mishaps. As one teacher said, "once they get used to it, they like it" (Mrs. S; POI). Similarly, Mr. P related that many of his students "liked to use [the technology], and it was kind of fun for them to …see what [a graphing calculator] could do" (Mr. P; STI).

Despite the initial challenges, participants in these mathematics and science classrooms persisted. Mr. W shared a bit of his philosophy on implementing technology: "I think it's one of those things with the [CCT], the more you use it the more you're going to understand it" (Mr. W; FTI). Students became more familiar with the system and how to troubleshoot common difficulties. According to Mrs. S, "[my students] know that if they can't login and everyone else at their table can, they need to unplug the cord and plug it back in" (Mrs. S; POI). Mrs. C summed up her experience: "I have just been fearless with it …I try to use it all the time and just keep at it" (Mrs. C; STI).

Assertion 2: Teachers Attributed their Success to Strong Administrative and Collegial Support. Any new technology can be daunting for a novice. In the case of CCT, teachers faced unfamiliarity with both hardware and software components, as well as how to embed CCT use in their curricula. For several of the participants, colleagues who also used the TI-Navigator™ technology provided a source of support and lesson plan sharing that mitigated some of the difficulties of implementation. Mr. P described how he found that it "helps to have another person in the building do the same thing. We can talk to each other [about] technical problems or things we are learning and it helps to share with another person" (Mr. P: FTI). In a similar situation, Mrs. C was struggling with how she could use CCT with her students to conduct a laboratory investigation. She described how:

> I had a lot of good ideas, but I wasn't quite sure how to pull it all together. Someone came in yesterday and saw me …and [said] you have the right idea. You just need to do this, this and this …so I get a lot of support. (Mrs. C: FTI)

On-site or otherwise easily accessible mentors and troubleshooters played a significant role in these participants' success.

Participants also had strong support from district administrators. In some cases, additional technology was required for full CCT implementation, and building administrators facilitated the acquisition of such technology. In a situation where two teachers were implementing TI-Navigator™ and might have been asked to share the equipment between two classrooms, Mr. P explained that “we talked to the principal, and we were able to buy two systems for the school” (Mr. P; FTI).

Assertion 3: When Teachers Felt Pressured to Follow Local Curriculum and Pacing Guides, their Flexibility and Creativity was Negatively Impacted. While both mathematics and science are core academic content areas subject to high-stakes testing, mathematics teachers were more vocal about and appeared to be more conscious of testing pressures. All three of the mathematics teachers reported the need to remain at an appropriate place in the pacing guide for their class. Mr. P explained that “sometimes I was reluctant to slow down because of the pressures of trying to get to a certain place in the curriculum” (Mr. P; STI). Furthermore, Mr. W related that “the difficult part is that I don’t feel I can be extremely creative because there’s a certain ‘what I have to do, is what I have to do’” (Mr. W; POI).

Congruence with Classroom Practice

Assertion 4: CCT was used to Support District- and State-level High-stakes Testing and Initiatives. A central concern in many school districts is student performance on state-mandated achievement tests. Preparation for these tests is a focus of curricular efforts for much of the school year, particularly at specific grade levels. CCT supported several teachers’ implementation of practice for these high-stakes tests. Mrs. T explained that in her class, she used “a lot of spot checking …for our state test … [using] multiple choice [questions] …That is a huge benefit to me and as well to [the students] because they could get their feedback quicker” (Mrs. T; STI). In this middle-school algebra classroom, the teacher rehearsed the state testing format with students so that they were more familiar with the style of question when the test day arrived. Rapid scoring, facilitated by the aggregation capabilities of the CCT system, gave her and her students a way to quickly assess students’ progress toward their achievement goals.

In some cases, participants were able to support district achievement goals in a broader setting than their own classrooms. Mrs. S described how she led a group of ninth grade teachers in her building to use CCT to administer a practice state science achievement test.

> I had all my freshmen do it …I had them put their answers in [a quizzing application] … so that we could get a breakdown of each question for all four classes combined. [Then] we had the other teachers in the building do it also …so we combined all the teachers' results onto one analysis …We could see where [the students'] weaknesses are and where their strengths are in the whole freshman class. (Mrs. S; FTI)

School improvement is a timely concern, and CCT can support improvement initiatives.

Assertion 5: Teachers used CCT to Monitor Student Behavior, Student Learning, and Class Progress. A feature of the CCT used in these classrooms is the ability for the teacher to take a "snapshot" of the display screen of each student's handheld device. The teacher can display these to show students how everyone is solving a problem, or can choose not to reveal the information. This feature allows the teacher to monitor student behavior as well as their work progress. Mrs. C used this feature frequently with her middle school students.

> If I send them a [question], I immediately go to Screen Capture. And …as soon as I walk by my computer, I just tap the refresh [button]. It gives me an idea where they are. And actually it works really well to keep them on task. Because they really buy into the idea that I know what they are doing all the time. (Mrs. C; STI)

The ability to monitor students for off-task behavior is an important feature of this teacher's classroom management plan. Mr. P also took advantage of the Screen Capture to "see what's on their calculators rather than going to each kid and to see if they get the idea" (Mr. P; POI).

Teachers were also able to use CCT to monitor student learning and provide appropriate remediation to address student needs. Rather than assume that students have comprehended a concept, teachers "have a better understanding that a nodding head doesn't necessarily mean they know what's going on …I go back and do another example, re-explain something, have them write it down or explain it to each other" (Mrs. R; STI). Similarly, Mr. P pointed out that "if half the class got the wrong answer that's a problem and I need to do some more instruction so they can understand (Mr. P; STI).

Assertion 6: Rapid Aggregation and Display of Student Learning Data Enhanced Instruction and Class-wide Discussions. Most or all of the Students Contributed Responses to any Given Prompt. In a traditional, non-networked classroom, students experience a time delay between when they complete a task and when they receive feedback on their work. Both mathematics and science teachers recognized that using CCT allowed them to provide feedback more rapidly. Mrs. T explained that CCT allowed her to provide "quicker feedback on their understanding. That has been very beneficial to them as well as to me. I think it helps with understanding where their misunderstandings are" (Mrs. T; STI). Similarly, Mrs. C used CCT to send electronic quizzes to students so she could monitor their understanding. She reported that "I like to use Learning Checks because …it allows me to see right away what things they know and what things they are not catching on to" (Mrs. C; POI). The rapid feedback cycle afforded by the use of CCT gave the teacher and students more timely information about student learning.

Teachers in both mathematics and science classrooms recognized that students became more involved when CCT was used. Mrs. S discussed the involvement she saw from her students when she reviewed homework and quizzes.

> When I'm going over the answers that they can see—oh, I'm not the only one who chose "C." Other students chose it also …It makes the whole going-over process not as boring as [me] standing up there reading off the question and explaining it. [Students] get a little more involved when they can see [that] two other people picked "C". (Mrs. S; POI)

Mrs. S often used an application that had students indicate choices on a projected image by using their handheld calculator keys to manipulate an individualized pointer. She related that with CCT applications such as this, "it is easier to interact with my students. There is more of a community in my classroom; it's more fun. Students like [moving their cursor]; they like to find each other and work together" (Mrs. S; STI).

Mr. W contrasted the use of CCT with his traditional classroom practice. Rather than ask students verbally which homework problems the class should review, he sent a prompt to have students respond on their handheld devices.

> I get more participation.if you just stand up in the front of the class and [ask] which [homework problem] do you want to go over and three kids say I'd like to see [problem number] 2. And that's all you get. (Mr. W; POI)

In this excerpt, Mr. W described how he is able to obtain more students' opinions, as opposed to few students who may respond louder or faster when asked verbally. Mrs. T echoed this notion when she related "I know where everybody stands as opposed to one or two on certain problems" (Mrs. T; POI). Similarly, Mrs. R said "with Navigator everybody answers the question" (Mrs. R; STI). Responses from all or most of the students are expected and acknowledged, allowing the teacher to adapt instruction based on the needs of the class rather than the needs of a select few.

Assertion 7: Mathematics and Science Teachers had Different Subject-dependent Approaches to Integrating CCT into the Curriculum. An essential feature of the particular type of CCT implemented in the CCMS project is the interface with a commonly used graphing calculator. These devices permit students to use digital sensors and probes to collect laboratory data, such as measurements of temperature, speed, or force. Complementary to the capabilities of the handhelds, the CCT implemented in this study features the ability to display and work with Cartesian coordinate graphs. In mathematics classes, teachers tended to have students manipulate functions to understand how coefficients in expressions affected the appearance of the graphed equation. In physical science classes, teachers also worked with Cartesian graphs, but in the context of having students plot data. Teachers collected data from individual students, aggregated the data, and electronically sent data sets back to the entire class for further analysis, including determination of lines of best fit. This was the case in science classrooms more so than in mathematics classes. For example, Mrs. C explained how she would "aggregate all of their data when they send it to me. And then I can put it into a graph and have all of their plots" (FTI). Similarly, Mrs. R described a physics lesson using CCT where the students "collected data with toy trucks and stopwatches …the first time they sent in ordered pairs, and the second time they sent in equations …we looked at their equations and how they were different and what the different variables meant" (FTI). However, physical science teachers faced an additional challenge in that their students, particularly younger students, were less familiar with the graphing calculator, and required additional instruction to implement these features.

Cost/Benefit Ratio

Assertion 8: Many of the Costs Associated with Implementing CCT Centered on Factors Related to Instrumentality. As described in Assertion 1, teachers experienced initial challenges in setting up the technology. The additional time required for teachers to become sufficiently comfortable with the CCT to be able to use it in their teaching was a cost. Furthermore, other adjustments to the existing technology or classroom infrastructure had to be made to accommodate the use of CCT. Ongoing communication errors interrupted the flow of the lesson in some cases; the frustration experienced by teachers was another cost to implementing CCT.

Many of these teachers were subject to high-stakes testing and accountability pressures, as discussed earlier, which appears to have been a cost as well as a benefit. Teachers perceived a cost in implementing CCT with respect to district- and state-level mandates: they felt constrained by the need to adhere to pacing guides and a rigid curriculum. They were concerned that to implement new lessons or provide supplemental instruction when they identified student knowledge gaps would cause them to "get behind" in their schedule.

Assertion 9: Mathematics and Science Teachers Identified Benefits Primarily Related to the Congruence of CCT with their Instructional Practices and Beliefs. Despite the pressures of pacing and adherence to curricula, teachers saw strong alignment between using CCT and preparing students to be successful on high-stakes tests. This often took the form of using CCT to rehearse test-taking skills. For example, teachers embedded test practice questions into their daily or weekly routines; CCT provided a way of quickly aggregating student responses. They perceived CCT to facilitate the instructional goal of test review and practice.

As identified above, mathematics and science teachers both identified a number of ways in which CCT was congruent with their everyday instruction. Teachers perceived this match as a benefit. They recognized the impact on their instruction of having rapid and accurate data about each student's learning. Additionally, teachers appreciated the role of CCT in encouraging engagement and participation of all students.

Assertion 10: Teachers' Overall Judgment of CCT was that there were more Benefits than Costs Involved in its Implementation. Both mathematics and physical science teachers experienced challenges in setting up and using connected classroom technology in this first year of implementation. However, they found enough advantages in using it to overcome the various barriers they encountered. One physical science teacher remarks, "[In] the first quarter, I used it very little, because it was more of a problem than it was a benefit …But when I did use it, it went really well" (Mrs. S., FTI). Similarly, Mrs. R. explained that "if I didn't like using it as much …I could see where it would end up by the wayside all of the time …I do like how it works well enough to fool with it and make it work" (Mrs. R; POI).

The costs of implementing this technology appear to be high in the first year. Teachers struggled with obtaining required equipment and setting up computer connections. Finding time to become proficient with the technology and adapt lessons was challenging for these teachers. However, for these six teachers, the benefits of their own professional development and the changes they perceived in their students and classes, coupled with a high level of collegial support, helped them to persist.

Discussion

The purpose of the present analysis was to describe the implementation of CCT in mathematics and science classrooms through the lens of the practicality index (Doyle & Ponder, 1977). Our methodology allowed us to detect potential similarities and differences in sets of mathematics and science participants matched by demographic and contextual factors. In this study, we have presented the experiences of six teachers who were successful at implementing CCT into their science or mathematics classrooms. We have identified ways in which these teachers found CCT to fit within their local context and with their own pedagogical practices.

Instrumentality

Environmental features, such as the provision and maintenance of hardware and software and training in appropriate uses of educational technology, present initial challenges to the integration of technology into science and mathematics classrooms. Both mathematics and science participants in the present study experienced a number of challenges with fitting CCT into their local contexts. With a high level of support from administrators and mentors, these participants were able to identify solutions that enabled them to proceed. Ertmer (2005) points out the importance of a professional community in providing examples of the effective use of technology. As the availability and variety of technology expands, the educational community needs to remain aware of instrumentality concerns and seek additional ways to facilitate the integration of technology into classrooms and its use to support the broad goals of education.

Congruence

Several authors have described the importance of an instructional technology complementing both the teacher's pedagogical philosophy as well as subject-specific norms (Selwyn, 1999; Becker, 2000; Goodson & Mangan, 1995). The form of CCT implemented in the CCMS study had a high degree of congruence with these participants' classroom practice. Alignment of an innovation with teachers' beliefs has been demonstrated to play a significant role in the implementation of innovations (Thompson, 1984; Ertmer, 2005); the present study demonstrates this in the implementation of CCT in mathematics and science classrooms.

Comments from teachers indicate a high level of awareness of student learning. Moreover, teachers described a number of ways in which they used CCT to carry out a variety of assessments, including formative assessments (FA) as well as summative assessments. FA entails components such as the provision of high-quality instructional tasks, the rapid aggregation of student responses, and enhanced awareness of student learning by both teachers and students, and has been shown by others to result in increased student achievement (Black & Wiliam, 1998). Although this study does not specifically investigate the role of CCT in carrying out FA, many of these aspects of FA are described by mathematics and science teachers in this study (see particularly Assertions 5 and 6). Moreover, other work related to the CCMS project has identified characteristics of FA in science classrooms where the teacher employs CCT (Irving et al., 2009; Shirley, 2009). Future studies will center on elucidating the specific ways in which FA is supported by the use of CCT in both mathematics and science classrooms.

Cost/Benefit Ratio

Teachers in this study identified mixed costs and benefits of implementing CCT. A number of key features were identified as costs: specifically, teachers were hampered by technology infrastructure of the school and had varying levels of difficulty setting up and using the equipment. The additional time required to feel comfortable with the technology placed an additional burden on these teachers. Despite these costs, overall, teachers were quite positive about the role of CCT in their classrooms. They perceived CCT to provide them with additional evidence of student learning in the form of rapid aggregation and display of student responses, allowing the teacher to change instruction as needed.

Implications

While the implementation of CCT was found to be very similar in mathematics and science classrooms, a few differences in the way teachers chose to integrate CCT with their instructional practices became apparent. For example, as described in Assertion 7 above, CCT had a high degree of alignment with authentic data collection and analysis in the context of science laboratory investigations and with representations of functions in mathematics lessons. These differences in CCT implementation between mathematics and science classrooms may reflect differences in subject subcultures (Selwyn, 1999). The primary difference between mathematics and science classrooms identified in the present analysis relates to the specific content-driven instructional practices found in these disciplines. While both mathematics and science teachers experienced congruence between their teaching and the CCT, the ways in which the congruence is exhibited appears to be different. This remains an area of further exploration.

Whether a technological innovation is worthwhile to adopt entails a number of complex factors. If the innovation is frustrating or difficult to integrate into existing school infrastructure, teachers are not likely to persist. The presence of support systems, such as technology experts and a community of learners, was important in the present study to help teachers overcome specific implementation barriers. Similarly, an innovation that requires significant changes in core educational procedures is not likely to be embraced by teachers. Ultimately, teachers make decisions based on the merits of the innovation compared to the challenges it presents. These judgments of costs and benefits do not appear to be separate from notions of instrumentality and congruence. A lack of instrumentality or congruence is a cost to the teacher who becomes frustrated while attempting to implement a technology innovation. Furthermore, when coupled with perceived or measured improvements in student factors such as achievement, engagement, or motivation, the integration of technology with instruction provides significant student benefits.

In the present study, mathematics and science teachers perceived advantages of using CCT that outweighed the challenges they experienced. Within the entire CCMS research study, however, some participants (not included in the present analysis) did not persist with CCT implementation, citing personal or professional conflicts that prevented their continued project involvement. An alternative explanation might be that participant attrition is linked to insufficient benefits compared to the challenges experienced in their contexts. The Doyle & Ponder (1977) framework and the present analysis provide a tool to investigate this possibility further by identifying which features of CCT were found to be not instrumental or not congruent with teachers' instructional settings and practices. Such future work is important to developing an understanding of the factors that affect teacher implementation of technology innovations.

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