NCSM Journal

of Mathematics Education Leadership

FALL 2011 VOL. 13, NO. 2

National Council of Supervisors of Mathematics www.mathedleadership.org

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Improving Student Achievement by Systematically Integrating Effective Technology

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Given the long history of technology in mathematics education and the many differences in approach and application, useful research must now go beyond making claims about technology in general or in isolation from its use; specific approaches must be described—with their entailments, assumptions, and goals—and evaluated on their merits.

—Roschelle, Rafanan, Bhanot, Estrella, Penuel, Nussbaum, Claro, 2010

Our Position

It is the position of NCSM that in order to develop all students' mathematics proficiency, leaders and teachers must take responsibility for the systematic classroom integration of effective technologies to enhance curriculum, pedagogy, assessments, and approaches to equity. Using research informed practices, NCSM members need to identify the technologies and make decisions about when and how to use these technologies in ways that strengthen students' mathematical thinking and learning. This position can be accomplished when leaders and teachers:

- Understand that technology is not an isolated element but a powerful tool that must be fully integrated into the teaching and learning process.
- Use research to guide decisions about what types of technology and how best to use them.
- Provide sustained professional learning opportunities prior to and during all phases of implementation.
- Recognize that learners—both adults and students—progress through varying levels of comfort as they begin to use technology before they can realize its full impact.

Today's world makes a burgeoning array of technologies available to classrooms, ranging from graphing calculators to computers to electronic whiteboards. Unfortunately, not all types and uses of technology lead to meaningful benefits in teaching and learning (Dynarski, Agodini, Heaviside, Carey, Campuzano, Means, 2007). Research can offer useful guidance about effectiveness of various options as well as best practice for technology use (Means, Roschelle, Penuel, Sabelli, & Haertel, 2003). Teachers and leaders who are aware of the research that shows how technology can enhance students' mathematical thinking will be better able to advocate for technology decisions based on the potential impact in the classroom.

Research That Supports Our Position

Growing and strong research literature highlights benefits to mathematics teaching and learning when technologies that are specific and appropriate to mathematics are systematically integrated into classroom practice (Heid & Blume, 2008a). Frequently cited benefits of integrating appropriate technology include increased conceptual understanding (including representing, generalizing, abstracting, modeling and working with symbols), better problem solving, broader participation and deeper student engagement (Heid & Blume, 2008b). Technology can also increase interactivity within the mathematics classroom, enabling students to explore mathematical concepts (Kaput, 1992) and providing immediate feedback to students and their teacher (Bransford, Brophy, & Williams, 2000). Research shows that using technology in this way not only helps students learn the same mathematics better (Roschelle, Pea, Hoadley, Gordin, & Means, 2000); it enables "democratic access" to more important and deeper mathematical thinking (Kaput, 1994).

Mathematics education leaders are likely to be asked to weigh in on the selection of particular products. This can be challenging because technology changes rapidly and specific products may come and go. Further, "gold standard" scientific evaluations of specific technologies are far and few between (National Mathematics Advisory Panel, 2008). The available research supports several important ways that technology can enhance mathematics teaching and learning through the following:

- strengthening the display and presentation of mathematical work;
- enabling dynamic representations of mathematical ideas;
- supporting formative assessment practices; and
- enhancing collaborative learning.

This research can help support good technology choices by identifying mechanisms that link technology to the enhancement of students' mathematical thinking and learning. Each is discussed below.

STRENGTHENING THE PRESENTATION AND DISPLAY OF MATHEMATICAL WORK

A first cluster of enduring and stable findings in research on learning addresses the presentation and focus of student mathematical activity. Display technology, such as projectors, document cameras and electronic whiteboards, can make it easier for teachers to focus on important ideas (Ruthven, 2009). Likewise, contrasting examples of concepts and misconceptions or different solution strategies is a very basic and important technique for advancing student learning. Display technology can make it easier to juxtapose examples and achieve the desired conceptual contrast (Bransford et al., 2000). Further, these technological tools can support rich mathematical tasks by increasing interactivity. Moreover, by handling some of the routine aspects of graphing, a graphing calculator can focus student thinking on the more important higher order concept – such as the relationship between a coefficient of an equation and the shape of the resulting function (Chandler & Sweller, 1991). Simultaneously, the increased interactivity of a graphing tool can engage students in exploration and inquiry and support conceptual learning.

ENABLING DYNAMIC REPRESENTATIONS OF MATHEMATICAL IDEAS

The Multimedia Principle of learning (Mayer, 2006) holds that students learn best from linked graphical and linguistic symbols such as graphs and algebraic expressions (National Mathematics Advisory Panel, 2008). In school mathematics, students need support to form meaningful connections between graphical and linguistic representations and to build conceptual connections. Technology supports these best practices of mathematics teaching (Hiebert & Grouws, 2007). Technology can also provide graphical images that accompany expressions, as in the case of graphing calculators, and also can use motion and animation to increase students' access to the mathematical meaning of the graphical notation. For example, in dynamic geometry, animation can help students to see how one particular construction of a circle inscribed in a triangle is an instance of the general case for all triangles, leading students from a single case towards generalization and proof (Laborde & Laborde, 1995).

Mathematics education leaders can ask, "How does this technology provide linked dynamic representations to deepen students understanding of mathematical connections among graphical and linguistic ways of expressing the same mathematics?" Further, once a technology is selected that features linked dynamic representations, leaders can also raise important questions about the teaching practices that leverage this technology. For example, learning with dynamic representations is strongest when teachers emphasize concepts and connections in their teaching and frame curriculum and activities to focus on big ideas (Heid & Blume, 2008a).

SUPPORTING FORMATIVE ASSESSMENT PRACTICES

One of the most firmly established learning principles is that students learn best with immediate feedback that identifies errors, prevents rehearsal of unproductive approaches, and reinforces success (Hattie & Timperley, 2007). A related best practice of teaching is adapting the pace, content, and supports provided to students to match developmental needs and capacity (Corno & Snow, 1986). It is important for this feedback and these adaptive teaching strategies to be informed by the ongoing use of formative assessments (Black & Wiliam, 1998).

Technology can support formative assessment in four complementary ways. First, technology can make it faster to collect and organize assessment information, as in the case with "clickers"—response devices that allow a teacher to poll students' answers (Littauer, 1972). Second, technology can increase the breadth of engagement in assessment by using classroom communication networks to collect work from all students simultaneously, creating pressure for all students to think, allowing responses to be collected anonymously, and providing a view of the variability of whole group to the teacher (Davis, 2003). Third, using handheld computer technology can deepen assessment to include conceptual reasoning by allowing teachers to create tasks that require students to do more than provide a factual answer. For instance, teachers can ask students to submit a graph, an algebraic expression, a sketch, or a snapshot of their work (Kaput, Hegedus, & Lesh, 2007). Fourth, technology can provide more actionable feedback to teachers. For example, technology can help teachers place student work on a learning progression from more basic to more advanced understanding of a concept and provide more targeted support (Anderson, Corbett, Koedinger, & Pelletier, 1995; Feng, Heffernan, & Koedinger, 2006).

A growing body of research has established the powerful role of technology in making it easier to achieve good classroom implementation of formative assessment processes. For example, an independent evaluation of the use of connected networks of graphing calculators for formative assessment found that teachers can deepen their understanding of student thinking and that students can make significant gains in learning algebra, especially when teachers use the technology to ask more meaningful mathematical questions (Owens, Pape, Irving, Sanalan, Boscardin, & Abrahamson, 2008). Likewise, a technology system that supported teachers' use of learning progressions to guide instruction dramatically enhanced student learning (Clements & Sarama, 2008). In general, formative assessment technology can provide teachers with assessment information that can be used to make wise instructional decisions that have a positive impact on learning (Means, Penuel, & Quellmalz, 2000).

Mathematics education leaders can ask, "How does this technology provide teachers and students with assessment information that is more timely, deeper, broader, and more directly useful in guiding further teaching and learning?" Once a technology is selected, leaders can emphasize the quality of tasks given to students, what they are likely to reveal about student thinking, and how teachers can use the assessment information to make instructional decisions that adapt to student needs and leverage the diversity of student ideas.

ENHANCING COLLABORATIVE LEARNING

Collaborative learning is another well-established practice that can accelerate and deepen student learning (Slavin, 1990). Especially with regard to mathematical communication and argumentation, students need to engage in discussing and explaining in order to learn. Explaining to peers and being helped by peers can produce strong learning gains (Webb & Palincsar, 1996). However, collaborative learning must be carefully structured to produce benefits; just asking students to "work together" is not enough (Cohen & Hill, 2001). Technology can help teachers to identify and manage the right structures, for example, by giving each student an individual aspect of a task so that each student has a unique and necessary role in the group (Slavin, 1980). Technology can also provide tools that help focus the collaboration on the important mathematics, for example, by providing tools for sharing diagrams and sketches that support students' explanation and argumentation. Further, the formative assessment technologies discussed above can support student collaboration when incorporated in a system such as Peer Instruction (Mazur, 1997). In such a system, after the classroom sees the diversity of student responses to a conceptual task, students work in pairs to convince each other of "the right way" to think about the problem. Collaborative learning and formative assessment have a strong natural synergy, and providing feedback on the collaborative learning process as well as what is being learned about the mathematics is one way to make it more meaningful and productive (Roschelle et al., 2010).

Mathematics education leaders can ask, "How does this technology organize productive structures for collaborative learning and increase student participation in mathematical explanation and argumentation?" Once collaboration technology is selected, leaders can productively focus on new assessment opportunities afforded by the technology, including assessment of mathematical communication as students work on collaborative tasks. Leaders can also focus on how to make sure all students are meaningfully engaged and accountable throughout their collaboration together (Slavin, 1990).

Integrating Technology into Classrooms

Technology use cannot be an isolated element of instruction. Rather, teachers must integrate technology with their approaches to curriculum, pedagogy, and assessment (Borko, Whitcomb, & Liston, 2009; Roschelle et al., 2000). Doing so successfully requires sustained teacher professional development (Zbiek & Hollebrands, 2008) and steady support from school and district leadership (Honey, Kulp, & Carrigg, 2000). Research can offer guidance to teachers and leaders in choosing goals and strategies to shape their efforts towards systematic integration of appropriate technology (Confrey, Sabelli, & Sheingold, 2002). Teachers and leaders who are aware of research will be better able to guide the formation of policies and plans that contextualize technology within a broader vision of improving mathematics classrooms.

When adopting new technology for use in the classroom, the challenges and changes a teacher experiences are numerous and perhaps daunting. Researchers have identified ways to understand the concerns teachers have about technology, the process teachers go through as they begin to incorporate technology into their instruction, the kinds of professional development support teachers need in order to be able to use technology successfully, and the importance of support from colleagues and school leadership during this ongoing process of learning to use technology in the classroom. Attending to all of these issues makes it more likely that teachers will be well prepared to use technology successfully to support mathematics teaching and learning.

Other Technologies in Mathematics Education

Social networking is also a prominent theme and fits with the recognition that learning is a socially-mediated process. When used effectively, Web 2.0 technologies can support mathematical communication and collaboration among students and with mentors (Renninger & Shumar, 2002; Stahl, 2009). In addition, online forums can be very helpful to teachers. As yet, the needed research to strongly guide practice in this area is still emergent.

Ready-at-hand informational resources are another emerging trend. For example, students can now type in a textbook page and problem and see a related video tutorial. Students can also access sites such as the MathForum, Wikipedia, and online calculators and tools. From the limited research available, it appears that "just in time" support can be very helpful to students (Renninger, Farra & Feldman-Riordan, 2000). Of course, it is also possible to spend a lot of time online with little educational benefit and some informational resources emphasize a very procedural approach to mathematics that does little to deepen mathematical understanding.

Other emerging areas of research on technology in mathematics education include the use of games, mobile phones, virtual realities, tangible computing and force-feedback (haptic) devices. Research is not yet sufficiently advanced to provide strong evidence on when and how these technologies are effective for learning.

Features of Technology in the Classroom and the Teaching and Learning Opportunities it Supports

Table 1 (see next page) summarizes the features of technology discussed thus far, the teaching opportunities they provide, the learning opportunities created, and examples of the technology.

The Process of Learning to Teach With Technology

To better understand technology adoption, researchers have sought to identify stages a teacher goes through during the implementation process. Zbiek and Hollebrands (2008) identify the PURIA model (Beaudin & Bowers, 1997) that characterizes how teachers learn to teach with technology. The PURIA model consists of five modes a teacher experiences as they begin to understand and use technology in their classrooms. The five modes are:

- Playing with the technology without a purpose;
- Using the technology for personal purposes, perhaps as a learner of mathematics;
- Recommending the technology to others, including a peer or a student, and beginning to explore informally together;
- Incorporating the technology into classroom instruction; and
- Assessing students' use of technology, including what are they doing and what are they are learning about the technology and about the mathematics.

The PURIA model reflects the needs of teachers as adult learners. One key insight of the process of implementing

Table 1

FEATURES OF TECHNOLOGY IN THE CLASSROOM AND THE TEACHING AND LEARNING OPPORTUNITIES IT SUPPORTS

Technological Feature	Teaching Opportunities	Learning Opportunities	For example
Enhanced Display	Access to data, answers, problems, tasks, lessons More efficient use of time Customized presentations	Shared attention More effective time on task	Document cameras Shared access to websites Interactive white boards
Linked Dynamic Representations	Conceptual development Modeling Visualization	Meaningful connections Engagement in richer tasks More powerful access to multiple representations	Interactive software (e.g. Fathom, Geometer's Sketchpad, ConceptuaMath)
Classroom Connectivity	Explanation and justification	Collaboration and discussion	TI-navigator Clickers
Instantaneous, Non-judgmental Feedback	Formative assessments	Responsiveness to student thinking	Instructional courseware
Differentiation and adaptivity	Adaptive and customized assignments Multiple activities Responsive to student thinking Scaffolding	Individualization Linked to dominant learning style Hints	Learning Management Systems
Social Networking	Provides real-time learning support	Access to help/support	Class blogs Virtual coaching
Embedded Resources	Audio and video prompts Online calculators Dictionary and thesaurus Translator	Seamless access to supports	Embedded links Spellcheckers

technology that PURIA reveals is how teachers experience the first three modes—*play, use, and recommend*—and need to feel comfortable in each before they incorporate technology in their classrooms. When teachers aren't given a chance to feel comfortable and explore informally cases show it can be counterproductive for them to bring technology in their classroom (Zbiek & Hollebrands, 2008). In addition to feeling comfortable with the technology, many teachers need time to change their views about the role of technology, to understand what technology can bring to an understanding of important mathematics concepts, to feel ready to act as a collaborator with students during the process of using technology, and to be comfortable in new methods of instruction that incorporate technological tools.

One way to support teachers in gaining the skills, views, and dispositions necessary to successfully bring technology into their mathematics teaching is to create time for teachers to work with technology outside of formal workshops. It takes time to *play* with and *use* technology and then, as teachers are ready, it takes time and opportunities for teachers to work together to discuss, recommend, and explore technology with their colleagues The process teachers go through as outlined in the PURIA model often helps deepen their understanding of mathematics as well as the technology itself.

Indeed, researchers have articulated the concept of "Technological Pedagogical Content Knowledge" (TPCK) to highlight how expert teachers intertwine their knowledge of technology, pedagogy, and mathematical content (Mishra & Koehler, 2006). To develop TPCK, teachers need both formal professional development and opportunities to collaborate with other teachers while they are moving from early exploration *play* and *use* to *incorporating* and *assessing*. Time and opportunity for such interactions to occur is essential. Online communities, like Tapped In or the Math Forum can either provide a space for teachers from a school to work together online or connect teachers to technology innovators in other locations. The support a community provides, either on line or face-to-face or both, helps provide the support needed to solidify important understandings around new innovations (Schlager & Fusco, 2003).

Finally, it is worth noting that effectively using technology in the classroom often involves addressing a broad range of changes (Ruthven, 2009). Necessary changes can include re-arrangement of the physical space of the classroom, integration of technology with books and other curricular resources, adoption of new activity formats, and emphasis on new or different pedagogical skills.

How NCSM Members Can Support the Improvement of Student Achievement by Systematically Integrating Effective Technology

The opportunity to integrate technology into mathematics classrooms on a broader scale can be a catalyst for much-needed improvements in all aspects of mathematics teaching and learning. Alternatively, inappropriate, ill-conceived, or poorly-supported technology initiatives can be a wasteful distraction from the core practices of mathematics teaching and learning. NCSM members have the potential to make the difference by undertaking the following practices:

1. Advocating for the systematic integration of appropriate technology in all mathematics classrooms by:
   a. Using conversations about technology as opportunities to educate others about best practices in mathematics teaching and learning.
   b. Preventing technology fads from driving pedagogical decisions.
   c. Articulating the specific needs of mathematics teachers within technology polices and building relationships with IT leaders so that mathematics teachers garner the needed access and support.
   d. Securing buy-in, commitment, and necessary funding from administrative leaders for a systematic, integrated, long-term approach to incorporating technology in mathematics classrooms and providing necessary training in the effective use of this technology.
2. Promoting the unique value of technology in mathematics teaching and learning, including asking questions such as:
   a. How does this technology promote more effective classroom presentations and display of mathematical ideas?
   b. How does this technology provide dynamic representations to deepen students understanding of mathematical connections among graphical and linguistic ways of expressing the same mathematics?
   c. How does this technology enable formative assessment that is quicker, deeper, broader, and more directly useful in guiding further teaching and learning?
   d. How does this technology organize productive structures for collaborative learning and increase student participation in mathematical explanation and argumentation?
3. Developing and implementing detailed plans to support teachers in systematically integrating technologies as part of their permanent repertoire of improved classroom practices by:
   a. Providing high quality professional development, involving long-term engagement in professional communities and collaborative opportunities for teachers to informally explore new technologies.
   b. Promoting integration of technology within curriculum, pedagogy, and assessment and avoiding the temptation to see technology as an independent, isolated component.
   c. Seeking continuous learning about best practices in the use of technology in mathematics classrooms including keeping up with rapid evolution of applications of technology and the expanding research base for its use in improving teaching and learning.

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