Towards Highly Interactive Classrooms: Improving Mathematics Teaching and Learning with TI-Nspire Navigator

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Executive Summary

Improving mathematics teaching and learning through and beyond Algebra is one of the most important challenges facing educators worldwide. The powerful capabilities of technology to engage students, support their cognitive effort, represent mathematics insightfully, and better connect teachers and students are important to addressing the Algebra challenge. To leverage technology effectively, teachers need an appropriate pedagogical model.

We propose a pedagogical model based on the concept of interactivity. By *interactivity*, we mean increasing the quality and frequency of back-and-forth interplay among the teacher, her students, and the mathematical content at hand. Technology can enhance many forms of interactivity, especially when:

- students and teachers use technology to explore mathematical models, not just as a calculation tool,

and when:

- teachers use a shared display and instant feedback to increase students' cognitive engagement, not only to demonstrate or assess.

Across these forms of interactivity, the most important goal is to increase student engagement centered on the doing and making sense of mathematics. Application of this principle leads to highly interactive mathematics classrooms, in which teachers:

1. engage their students in mathematically meaningful activities;

2. focus on mathematics with connections;

3. track what mathematics their students know and adapt accordingly;

4. make mathematics learning a shared responsibility of teachers and students.

Implementing a highly interactive mathematics classroom takes more than technology, it requires support for professional development and time for teachers to learn and adapt. For example, the new capability to instantly capture and display students' screens can provide cognitive contrasts that drive learning, but only when the teacher uses classroom discussions to probe the meaning of contrasting screens. We propose an implementation model that proceeds in stages, based on research data that shows what teachers typically accomplish *immediately*, with *experience* and, eventually, as *masters* of the technology-rich classroom.

By thinking in terms of not just technology but also a pedagogical model and implementation in stages, schools can realize deepening benefits over time. Within the

first year, schools can experience increased student achievement and more positive student attitudes. Teachers see immediate benefits from knowing more about their students. Over time, with continued technological support and sustained professional development, schools can make progress in closing achievement gaps and introducing higher-order skills, such as mathematical problem solving, collaboration, and argumentation. Over many years, schools will develop master teachers who can lead further improvement in their regions, aimed at developing students’ passion to pursue and succeed in university level mathematics and on toward challenging STEM careers.

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Introduction

Improving mathematics teaching and learning on the pathway to and beyond Algebra is one of the most important challenges facing educators worldwide. Achieving improvement requires seeing mathematics as multidimensional, for example as including both procedures as concepts, as well as strategies, ways of reasoning, and attitudes and dispositions (Kilpatrick, Swafford, & Findel, 1991). Researchers emphasize the need to develop students' understanding of mathematical connections among topics, across representations, and between contextualized and decontextualized settings. Developing these connections often requires more attention to mathematical discussion and argumentation in the classroom, as well as giving students the opportunity to struggle with challenging mathematics (Hiebert & Grouws, 2007). It also requires supporting students to explore and engage with challenging mathematics, for example by managing cognitive load (Chandler & Sweller, 1991) and enabling a more interactive, exploratory path into difficult mathematics (Kaput, Hegedus, & Lesh, 2007).

Overall, however, no single factor is sufficient to change mathematics education (Roschelle, Singleton, Sabelli, Pea, & Bransford, 2008). Intrinsically, improving mathematics achievement requires paying attention to a three-way relationship in the classroom (Cohen, Raudenbush, & Ball, 2003): the relationship among teachers, students, and instructional resources (where resources include curriculum, assessment and technology). Researchers have repeatedly found that changing one relationship (e.g. giving students a powerful new handheld technology) requires corresponding changes in teacher-student interaction and how teachers use instructional resources to be effective (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). For example, powerful new representations only increase student understanding if teachers engage students in probing the meaning of the representations. Likewise, a change in the teacher-student interaction (e.g. a teacher giving students more responsibility to solve challenging mathematics problems) can be supported by giving students new tools, for example, a new tool that enables exploration of a mathematical construct in terms of actions and consequences (Bransford, Brophy, & Williams, 2000). Of course, aligned and sustained teacher professional development is essential to instructional change (Wei, Darling-Hammond, Andree, Richardson, & Ophanos, 2009).

Research suggests that there is no single "silver bullet" for improving mathematics instruction. Improvement requires systematic attention to new resources, a pedagogical model for using those resources, and sustained teacher professional development to support teacher growth. This paper develops a systematic view of these factors for the powerful new resource of networked handheld and laptop-based representational tools. We suggest a pedagogical model featuring increased interactivity and a framework for sustained support of teachers as they grow into the possibilities of new technologies and appropriate pedagogies.

Linking Technology and Learning

Researchers in the Learning Sciences have identified three primary links between the capabilities of technology and processes of learning:

1. **Offloading calculation** to technology decrease cognitive load and allow students to focus on higher-order mathematics (Roschelle & Singleton, 2008).
2. **Providing multiple representations** that enhance development of conceptual understanding (Heid & Blume, 2008a).
3. **Connecting students** and their teacher via a network, allowing students to rapidly share the mathematical work they are doing on handhelds with the whole class (Stroup, et al., 2002).

In Algebra, the focus shifts from developing students' fluency with arithmetic to developing more abstract reasoning and problem solving. Calculators can help students focus on mathematical problem solving and not the details of calculations. In addition, technology can provide mathematics representations (e.g. graphs, tables, geometric diagrams, etc.) and these representations can be dynamically linked and animated to illuminate mathematical ideas. The calculation and representation roles of technology are distinct and complementary. Calculation support reduces the necessity to focus on the details of mathematical calculations; the availability of multiple representations enables exploration and discussion of the core meaning of mathematical concepts. In addition, classroom networks enable a teacher and students to more rapidly share their mathematical work. As form of formative assessment, the use of a classroom network can increase a teacher's knowledge of her students. A complementary use of a a classroom network is to use student work as the basis for discussions with goals that move beyond memorizing facts and mastering procedures to increasing students' mathematical understanding, communication, and participation in mathematical practices such as generalization.

The TI-Nspire platform brings the necessary technological functionality for calculation, representation and communication together. TI-Nspire includes classic graphing calculator functionality with enhancements so that mathematical notation is presented more faithfully. TI-Nspire also provides multiple representations, such as graphs, geometry, tables, and symbolic expressions. These representations can be linked and animated so that changes in one representation are instantly reflected in other representations. Work is prepared, saved and distributed in a document format. These capabilities are available in both handheld and software versions. Further, TI-Nspire will support classroom networking, allowing the teacher and students to share the work they are doing, rapidly via a wireless network and a classroom projector or electronic whiteboard. Using the network, a teacher can assign and collect documents rapidly and can also capture and project students' screens instantly. The network also implements a convenient real-time system for quick polls and online testing.

Teachers can use these capabilities in a variety of productive modes, which collectively can contribute to a more interactive mathematics classroom.

- **Calculating.** TI-Nspire can be used as a familiar tool in a supportive role.

- **Demonstration.** Teachers can project the TI-Nspire display to demonstrate Algebraic concepts using one or more mathematical representations and to make students' work the focus of classroom discussion.
- **Exploration.** Students can explore mathematical models, investigating the variables and mathematical relationships across representations.
- **Participation and Collaboration.** Because the wireless network allows work to travel among students and the teacher, students can participate in classroom-wide activities and develop mathematical ideas through collaborative discussions.
- **Assessment.** The wireless network capabilities allow student work to be more readily collected and instantly analyzed, providing additional feedback to the teacher as an integral component of the fabric of interaction

Research supports the effectiveness of these modes and is summarized in series of Research Notes, available at: http://education.ti.com/research. In the next sections, we build on an important lesson that has emerged across the research: effective use of technology requires attention to appropriate pedagogical models, and implementation requires sustained professional development. We will suggest that "interactivity" can be a central organizing concept in a pedagogical model for the effective use of this technology.

The Interactive Mathematics Classroom

Classrooms are complex learning environments. There are many specific pedagogical routines and practices that can leverage technology effectively in classrooms. We argue, however, that underlying these pedagogical details is a shared goal: increasing the quality and frequency of interactivity in the mathematics classroom. By *interactivity*, we mean *the cycle of back-and-forth interplay among the teacher, her students, and the mathematical content at hand*. As we will discuss, interactivity can take many productive forms, but underlying them all is more frequent and meaningful interplay among teachers, students and the mathematical content.

"Interactivity" is a popular term. It can be used to make simple distinctions; for example, one might observe that the World Wide Web is more interactive than TV because the web sites respond to mouse clicks, whereas TV is watched more passively. However, to the extent that users remain passive viewers, this distinction misses the point of the interactive math classroom. Our use of the term in the context of teaching and learning is both broader and deeper: we use the term "interactivity" to describe the cycle of back-and-forth interplay aimed at increasing students' active participation in doing mathematics, thinking mathematically, and seeing mathematical activity as meaningful and useful.

Pedagogy in the interactive mathematics classroom builds on what we know about good teaching (Heid & Blume, 2008b; Hiebert & Grouws, 2007; Stein, 2008):

- Good teachers *engage their students*; teachers in an interactive classroom can motivate through getting students involved in meaningful activities, not just by entertaining students or by use of external incentives such as grades.

- Good teachers *highlight mathematical connections;* teachers in an interactive classroom can use the opportunity to explore linked representations to develop students sense of mathematical meaning.
- Good teachers *press students for explanations;* teachers in an interactive classroom can link opportunities for independent mathematical explorations to promoting students ability to develop conjectures, make mathematical arguments, explain mathematical ideas, and justify problem solving steps.
- Good teachers *know their students*; teachers in an interactive classroom can use more rapid flow of students mathematical work to the teacher to understand what their students know and can do.
- Good teachers *make learning a shared responsibility* of students and teachers; teachers in an interactive classroom can encourage students to take charge of their own learning and to develop ability to self-regulate learning.

The interactive mathematics classroom can help teachers strengthen each of these practices. But research shows that pedagogy does not instantaneously improve when technology is introduced to the classroom. Teachers gradually increase and improve interactivity in their classrooms over time. In addition, existing pedagogical routines and practices often limit and constrain the opportunities technology could provide to enhance learning. The table below suggests some of the new pedagogical practices that technology can inspire and support. As teachers experiment with these and related practices and integrate them into their everyday instruction, they move towards a more effective interactive mathematics classroom.

How TI-Nspire and TI-Navigator Can Enable Better Teaching

What Research Says	What Mathematics Teachers Can Do
Effectiveness	
Graphing calculator use increases student achievement. In particular, students who use calculators daily or weekly learn more.	Use TI-Nspire's calculator, algebra, graphing, table, and geometry features to: • Emphasize problem solving and concepts, not just right answers. • Engage students with interactive exploration. • Focus students who have mastered underlying calculations on mathematical concepts, strategies and justifications.
Formative assessment increases student achievement.	Use TI-Nspire's ability to involve all students in a quick assessment and to instantly capture and project student screens to: • Pose questions that stimulate student reasoning and explanation. • See what students are thinking and doing to help them improve. • Give students feedback more often and more quickly than is possible through graded homework. • Gauge whether the pace of instruction is too fast or too slow.
Enhanced representation of important mathematics	
Linked multiple representations (e.g., equations, graphs, tables, geometric sketches, words) enable students to master difficult concepts.	Use TI-Nspire's clear and expressive representations to: • Reinforce the meaning of a representation (e.g., what each axis in a graph represents). • Focus attention on the same mathematical idea across representations. • Explore the effects of changing variables across representations. • Integrate geometric tools into the teaching of graphical concepts (e.g., construct a rectangular area under a curve). • Introduce topics, such as modeling, that were previously too time consuming.
Students learn more when they have more academic learning time, tasks are neither too easy nor too hard, and they experience early and frequent success.	Use TI-Nspire documents that pre-arrange appropriate representations to: • Prepare a context for student work so they can start mathematical work quickly. • Organize a sequence of tasks so students succeed early and frequently (e.g., differentiated instruction). • Reduce the class time spent explaining the activity.
Students learn complex knowledge and skills best when teachers provide scaffolding—supports and resources that fade as students gain mastery.	Use TI-Nspire documents that provide interactive content to: • Provide worked examples for students to use as models. • Demonstrate the steps or phases in a mathematical investigation. • Examine the connections between and across rich mathematical problems.

How TI-Nspire and TI-Navigator Can Enable Better Teaching	
What Research Says	**What Mathematics Teachers Can Do**
Enhanced Connectivity and Communication in the Mathematics Classroom	
Classroom networking engages students in doing and communicating important mathematics.	Use TI-Nspire with TI-Navigator's classroom network to: • Engage all students in learning important mathematics. • Compare students' prediction to what happens in an exploration; compare students' screens to reveal different solution strategies. • Accelerate student thinking by sending mathematical ideas, models and tasks to students and rapidly collect their work for discussion. • Allow students to communicate with multiple representations—words, equations, graphs, or geometric sketches. • Base classroom discussions on student work by projecting students' screens, and, through attention to student work, show that mathematical communication is valued.
Students can help each other to learn and **collaborate to improve ideas**; participatory activities are a powerful resource for accelerating learning.	Use documents and a classroom network to: • Help students to work together productively, for example, by building on each others' mathematical ideas, offering constructive critiques, and taking complementary roles in a shared project. • Encourage students to collaborate on a presentation of a shared solution to a complex problem. • Develop complex mathematical ideas through participatory simulations—shared simulations in which each student plays a unique role in the group experience of a mathematical phenomenon. • Build knowledge of mathematical meanings and strategies by contrasting diverse examples of student work. • Explore generalizations across different levels of a task that have been assigned to students of varying abilities.
Teachers can instantly gather and examine student work to **adapt** and **differentiate** instruction.	Use the ability to share mathematics via a classroom network to: • Aggregate students' individual work as the basis for group discussions and teaching decisions • Decide what to teach next on the basis of what students know or don't know right now • Assign different mathematical tasks to small groups. • Create opportunities to revise and improve students' mathematics understanding. • Make learning the shared task of the whole class.

Adapting and Differentiating Instruction

In the classroom. teachers make moment-by-moment decisions about what to say and do next. Research shows that the more teachers know about the state of their students' learning, the better these decisions are and that better decisions result in improved learning (Fuchs & Fuchs, 1986). A major advantage of the interactive math classroom is that it makes possible a range of strategies based on this principle.

The most familiar strategy is based on giving students tests before and after instruction. Teachers can pose pretest questions to determine the need for instruction on a given topic, and at the end of the lesson, a post-test can show the lesson's success. In the interactive math classroom, the technology provides instantaneous summary of class results. Teachers can then efficiently *adapt* their instructional plan by re-teaching to the whole class only the mathematical content that students had difficulty with (Roschelle, Penuel, & Abrahamson, 2004).

But the interactive math classroom also supports a much more granular, diagnostic approach to *differentiate* instruction (Tomlinson, 2001). The instantaneous distribution and collection of questions, answers and student work with mathematics makes it possible to embed assessment in the fabric of instruction. Assessment is no longer a discrete event which interrupts the flow of the lesson. This kind of embedded interaction leads teachers and students both to come to realize that most errors are caused by misconceptions. These can be directly addressed by the whole class, or by peer discussion in small groups. In this way, each student's learning experience uniquely addresses their specific needs, and the whole class builds a deeper understanding of the mathematics. Gains in efficiency and effectiveness result.

A Path for Professional Growth

Teachers who are new to technology can realize important benefits in the first year. For example, research shows that using graphing calculators increases conceptual understanding and problem solving skills (Ellington, 2003). Data from the National Assessment of Educational Progress in the United States further shows that students around the age of 13-15 benefit from ready availability and frequent use of calculators both in the classroom and for homework; such students are more likely to show mathematical proficiency on national tests (National Center for Education Statistics, 2001). Further, teachers who used classroom networking in the first year said they developed deeper awareness of their students' knowledge and their students scored higher in Algebra on an end-of-the-year test (Owens, et al., 2008). Students' attitudes also improved in the first year; students were more likely to put effort into mathematics learning (Owens, et al., 2008).

But not all benefits occur in the first year. In the hands of a master teacher, the interactive mathematics classroom can produce profoundly different learning experiences than occur in commonplace, traditional classrooms. However, teachers who are new to technology do not become master teachers in a day. This suggests a co-evolution of teaching beliefs and practices and use of technological capabilities in the mathematics classroom that occurs over years of experience and professional development. We see increasing and improving interactivity as a common thread throughout that evolutionary process; one thing that a visitor to the classroom of a master teacher who is using technology is almost certain to notice is the heightened levels of student activity in doing mathematics and the increased responsiveness that students' experience from a combination of interactive technology, fellow students, and their teacher.

Below, we suggest a framework for thinking of professional growth as occurring in three levels, (1) immediate, (2) experienced and (3) master. In each, teachers can realize benefits of interactivity and experience the interactive mathematics classroom as providing opportunities for their further growth. Professional development needs to be on-going and recognize that as teachers develop confidence and experience, they will become ready for new levels of growth. Across these levels, Ruthven's (2009) framework suggests attention to five dimensions of what teachers need to effectively use technology:

1. Attention to how technology use intersects with the time demands of teaching.
2. Incorporation of reliable and easy-to-use support into the working environment.
3. Fit with other key resources, such as their textbook and standards.
4. Activity formats that leverage the unique features of new technology capabilities.
5. New routines for their own role in interacting with students that enhance the benefits of technology.

The **immediate level** fits many teachers in their first year of using new technology in the mathematics classroom. In the first year, by supplementing their curriculum with technology, teacher can experience increased student engagement and learning. However, they will likely see time spent with technology as potentially competing with time they need to address their require scope, sequence and pacing. Professional development should address "fitting technology in" in ways that are comfortable and non-threatening.

- Professional development should highlight the simplest, easiest-to-use, and most reliable interactive capabilities of technology, and pre-prepared applications, because if technology is perceived to be too hard to use, teachers at this stage will simply stop using it.
- Research suggests that success is most likely if professional development gives teachers time to practice using specific materials and activities that they will also do with their students and if these are not a big stretch from what teachers already do.
- The provided materials and activities should feature the integration with textbooks and other standards, giving teachers confidence that the time will be well spent.

Of course, it should be highly likely that teachers will directly experience the benefits of the interactive mathematics classroom when they try the recommended activities. Overall, professional development should be very focused on achieving specific, positive experiences and not just broader, long-term goals.

At an **experienced level**, a teacher feels comfortable with the mechanics of using technology and is ready to take ownership of the opportunity to adapt their teaching to better fit student needs and to enrich opportunities for deep student learning. Teachers at this level will likely be making choices about the time required and the benefits of using technology. They may, however, not have a very good basis for making those choices – and may inadvertently overlook technology where it could really pay off or apply it in such small or infrequent doses that the benefits become marginal. As with the immediate level, teachers still probably have less confidence with more complex or advanced features; they are likely to desire to strengthen their practices around a smaller set of well-understood features that they see as very beneficial.

- Professional development needs to start providing teachers with a basis for decision making about how and when they will use technology as well as supporting their transition to more adaptive instruction.

- Teachers should deepen their understanding of research on productive teaching practices – such as a cycle of predicting, exploring, and explaining – so that they can employ recommended activities with a sense of why and how the activities should advance learning.

- Professional development at this level can help teachers integrate technology with a broad range of curricular opportunities but shouldn't necessary dwell on every possible feature of the technology.

Keeping in mind that the overall goal of new pedagogical practices is to make the students' experience more interactive may help teachers understand what they are trying to achieve. Further, teachers will still likely look to others to suggest a tight fit between technology and their textbook and standards; professional develop should continue providing this information

At a **master level**, a teacher welcomes the full range of advanced interactive capabilities technology offers and makes innovative use of these in her classroom teaching to deepen student understanding and differentiate instruction to support all learners. Teachers at this level assume technology in their working environment and are willing to take chances with trying things out, because they feel confident they can handle any unexpected results. They are also have a good sense of the time required to use technology and feel more freedom to allocate time when they sense opportunities to pursue important mathematics in depth. They also have likely firmly established new, more interactive routines for using technology with their students and invent ways to use favorite activity structures for new topics.

- Professional development for master teachers can make them deeply aware of all the possibilities of the technology, including some that they may not yet have experienced.

- Professional development can also give master teachers tools to author new resources and activities with the technology (for their own use or use of other teachers).

- Master teachers may work together with other teachers to address pressing challenges, such as ways to cover particularly difficult mathematical concepts, multiple strategies for working with struggling learners, and new ways to organize the curricular sequence to support learning.

Although not all teachers will necessarily become master teachers, cultivating leaders who deeply understand the value of the interactive mathematics classroom and can share and spread what they have learned can be particularly value within a school or district.

Conclusion

We have argued that new technological capabilities can be very important to meeting the challenge of increasing success in Algebra, and that leveraging these capabilities requires attention to pedagogical models, not just technological capabilities. We suggest that the concept of *interactivity* is the core link between technology and pedagogical models; technology can increase the quality and frequency of back-and-forth exchanges between students and tools and also between students and teachers. Pedagogy can leverage these exchanges to engage students more deeply in doing mathematics, thinking mathematically and having extended discussions about mathematical meaning. The benefits of the interactive mathematics classroom arise when the new technological capabilities are complemented by appropriate pedagogical moves and routines that increase interactivity around core mathematical practices of representing, problem solving and justifying.

We further argued that a pedagogical model for using technology evolves in each teacher's classroom over time. Therefore, professional development can best be thought of as sustained support for teachers' growth over time. Teachers need different professional development support when they are new to the interactive classrooms, experienced with interactivity and masterful innovators in the interactive classroom. At all levels, professional development must consider the important dimensions of time, a reliable working environment, fit with textbooks and standards, activity formats, and teaching moves and routines.

Schools and districts that adopt the aspiration of creating more interactive mathematics classrooms can employ technology to realize increasing benefits with sustained professional development over time. Initially, they can expect some important improvements in student learning and attitudes and teachers' knowledge of their students. Later, as teachers become experienced, progress to more interactive mathematics classrooms can address the curriculum more comprehensive and attack important challenges like closing achievement gaps. As a school or districts' support for interactive mathematics classrooms matures, master teachers will likely emerge and provide new levels of customization of technology to local needs and leadership for other teachers.

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