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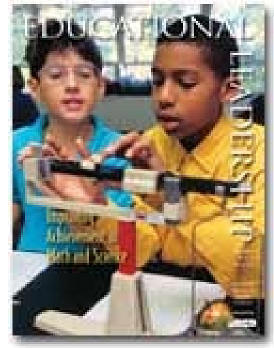

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The Networked Classroom

Electronic classroom networks can enhance student participation and achievement in mathematics and science.

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Technology has the potential to change how and what students learn in science and mathematics (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). Although ordinary schools rarely adopt the best research-inspired uses of technology (Cuban, 2003), they have made an exception in adopting one effective technology: classroom networks. In a networked classroom, students use handheld devices that connect to the teacher's laptop computer; the handheld devices and laptop both connect to a shared display screen. Mathematics and science teachers in settings ranging from K-12 classrooms to university lecture halls have reported improvements in student achievement as a result of using this technology.

On the basis of more than a decade of successful reports from the field and increasing evidence supporting wide-scale adoption, researchers have begun to connect teachers' insights about the technology to education theory and are documenting the technology's effectiveness in enhancing student participation and achievement in mathematics.

Jim Kaput, Chancellor Professor of Mathematics at the University of Massachusetts-Dartmouth, has developed an approach to teaching that actively incorporates affordable graphing calculators connected to a classroom network. His National Science Foundation-funded research (Hegedus & Kaput, 2003) reveals strong improvements for 7th, 8th, and 9th grade students on items found in state achievement tests. He and coinvestigator Stephen Hegedus are excited about more than just the improvement in test scores:

> Classrooms that integrate dynamic software environments with connectivity can dramatically enhance students' engagement with core mathematics beyond what we thought possible. (p. 54)

A glimpse at an 8th grade algebra lesson that Hegedus and Kaput designed shows why these researchers are enthusiastic. After asking each student to "count off" different numbers, the teacher poses a mathematical challenge that varies according to the count-off number. Students work on separate and slightly different challenges. This lesson's challenge is to create a function whose graph starts at the student's given number and goes through the point (6, 12). Using a calculator, each student specifies a mathematical function. Using the classroom network, the teacher rapidly "harvests" all the solutions to display on a projector. The students now see their work on a shared screen, which leads to passionate discussion about the functions they created. The teacher can guide the students in investigating new structures that appear in the aggregated set of lines, such as the varying slopes of the lines. The graphed functions can also control a motion animation on both the students' units and the classroom display. Each student's function thus becomes part of a mathematical model of a race, dance, or parade (www.simcalc.umassd.edu).

Kaput is just one of the education pioneers who have actively explored ways in which teachers can use classroom networks to achieve a motivating, engaging classroom climate and improved science and mathematics achievement. In their foundational summary of cognitive science and education, *How People Learn* (National Research Council, 1999), Bransford and colleagues cite classroom networks as one of the most promising technology-based education innovations. Their positive outlook is based not only on the technology but also on the premise that networks, when used appropriately, can transform the classroom learning environment. Building on an extensive scientific research base, *How People Learn* argues that effective learning environments have four important qualities: They are learner-centered, knowledge-centered, assessment-centered, and community-centered. Classroom networks facilitate learner-centered environments because they require every student to think actively during class and they encourage teachers to address specific needs and ideas. They facilitate knowledge-centered environments because they reveal important contrasts and patterns in mathematical and scientific ideas. They facilitate assessment-centered environments because they provide each student with frequent, helpful feedback while giving the teacher rapid insight into the current level of understanding in the classroom. They facilitate community-centered environments because they connect the learning of each individual to the learning of the group.

What Are Classroom Networks?

Unlike generic uses of the Internet, classroom-specific networks use software designed to enhance communication between teacher and students. The hardware and software, whose displays show what students are doing, thinking, and understanding, enable teachers to enhance the natural communication flows of the classroom. The technology fits within current classroom practice but makes it easier for teachers to engage in such best practices as addressing students' prior knowledge, targeting conceptual understanding, motivating and engaging all students, facilitating group discussion, and questioning students and providing frequent feedback.

Although research strongly suggests that teacher implementation of these practices is the main cause of improved student performance, the technology can facilitate and accelerate assigning, collecting, interpreting, and discussing student work.

From a technological viewpoint, a classroom network enhances an interaction loop between teacher and students. Such a loop traditionally opens when the teacher assigns an activity to a student, continues when the student turns in work to the teacher, and closes days later when the teacher grades and returns the assignment to the student. In a traditional classroom, typically only a few students answer questions and share their work on a mathematical problem, with little discussion afterward. The teacher's response to all students' work must wait until the next class, after he or she has had time to interpret students' responses.

In the networked context, however, interaction happens far more quickly and with smaller tasks. The assigned activity may be a request to answer a question, solve a problem, state a position, write an equation, or give a reason. The students enter their responses into a personal computing device, such as a graphing calculator, a palm-size computer, a laptop, or even a special-purpose device known as a response pad, which is similar in appearance to a TV remote control. The next step is crucial: The teacher's desktop computer collects the students' work, processes it into a meaningful graphic that the teacher and students can quickly interpret, and displays this graphic to the whole class.

From a pedagogical point of view, this rapid accumulation of student feedback enables the teacher to adjust instruction as needed. The teacher may call attention to the work of individual students, for example, or lead a discussion about common patterns across a variety of student work. The teacher can display student work anonymously and use the emerging comparisons to drive students to discuss, explain, elaborate, and seek comprehension. Indeed, Harvard's Eric Mazur, an early leader in developing the pedagogical use of classroom networks, calls his approach Peer Instruction (1997), signaling that real learning occurs when students engage with one another conversationally about the similarities and differences revealed by the shared display.

Teachers and researchers have found that immediately harvesting student work has a range of applications. In the simplest case, a teacher can pose a multiple-choice question and rapidly produce a histogram showing the distribution of responses in the classroom. This practice enables teachers to determine what they need to teach and helps students focus on what they need to learn. In a slightly more sophisticated case, students can mark a point on an image or show the line that they graphed. The teacher can instantly aggregate these points, lines, or even motions to reveal higher-order patterns.

In some of the most advanced uses of classroom networks so far, students can engage in a simulation. For example, each student can control a traffic light in a classroom simulation of traffic patterns shown on the public display, and the class as a whole can collaborate to develop some of the principles of operation that would enable traffic to flow smoothly (Wilensky & Stroup, 2000).

What Does Research Say About Classroom Networks?

We have identified 26 studies that report benefits from early implementations of classroom networks. The main benefits reported are greater student engagement (16 studies), increased student understanding of complex subject matter (11), increased student interest and enjoyment (7), heightened discussion and interactivity (6), increased student awareness of individual levels of comprehension (5), and increased teacher insight into student difficulties (4).

Using today's "evidence-based education" framework (Whitehurst, 2003), we could say that there is significant professional wisdom on how best to support learning by using classroom networks. Existing studies, however, are not designed rigorously enough to support a strong conclusion about the technology's effectiveness. In many cases, teachers have conducted studies in their own classrooms, limiting objectivity.

The best available empirical evidence on the effectiveness of classroom networks comes from university-level physics instruction because these studies have employed a suitable measure of program success. In particular, investigators evaluated program success with the Force Concept Inventory, a widely used and well-calibrated instrument that measures students' conceptual understanding (Hestenes, Wells, & Swackhamer, 1992).

For example, Mazur shows that successive classes of students using his Peer Instruction pedagogy (Crouch & Mazur, 2001) have experienced 10 years of steady improvement in pre-test/post-test gains on the Force Concept Inventory. Mazur has also produced a concise teacher handbook for implementing his Peer Instruction approach with classroom networks (1997). The University of Massachusetts-Amherst developed a related pedagogy, and investigators have documented a variety of improvements in student attitudes and classroom participation (Dufresne, Gerace, Leonard, Mestre, & Wenk, 1996). Students reported that the technology made the class more interesting and encouraged them to think ideas through. The group discussions helped clarify students' understanding, and the anonymity of the classroom network enabled those students who were shy or less confident to more fully participate.

Other empirical evidence shows that classroom networks have similar promise in K-12 classrooms. Hegedus and Kaput (2003) reported strong gains from using classroom networks in teaching algebra. In addition, Owens and colleagues (2002) conducted a preliminary study measuring classroom climate changes—whether or not the classroom became more learner-centered, knowledge-centered, assessment-centered, and community-centered—across a broad range of subjects among teachers adopting classroom networks. They offered a professional development program in classroom networks to 10 teachers of mathematics, physics, chemistry, and social studies in grades 8–12. The teachers used the technology for one school year. In a comprehensive report (Owens, Demana, Abrahamson, Meagher, & Herman, 2002), the investigators suggest that the teachers accomplished an overall positive shift in classroom climate even after only one to three months of part-time use of the system.

Research is still in an early stage and does not constitute proof of a systematic effect. One area in which evidence does exist, however, is formative assessment. Formative assessment is a powerful lever for improving learning (Black & Wiliam, 1998; Crooks, 1988; Fuchs & Fuchs, 1986). Guskey (2003) has argued that teacher-generated assessments yielding immediate and easy-to-analyze results are most likely to improve student learning. Classroom networks overcome one of the greatest hurdles to improving classroom assessment: the collection, management, and analysis of data. The networks make it easier for teachers to provide frequent formative assessment to all students.

Another area in which converging evidence exists is motivation. Davis (2002) argues that classroom networks can facilitate a blend of public anonymity and individual accountability that reduces academic anxiety and fear of embarrassment but encourages all students to work hard. More generally, classroom networks encourage students to pay attention to the differences among ideas, not to who said them. This factor may encourage all students to strive for mastery. Such shifts can produce changes in students' own motivational goals and, consequently, in students' engagement in learning activities (Griswold & Urdan, 2001; Maehr & Midgley, 1991).

Looking Ahead

Classroom network technology is maturing and becoming widely available from many vendors at reasonable costs (we have counted 12 available products). eInstruction claims to have installed its classroom network product in more than 1,000 schools in all 50 U.S. states and 10 countries. Recently, Texas Instruments and Educational Testing Service have entered this market with advanced products that can be integrated with graphing calculators and networked handheld computers, respectively. This emerging technological potential must be matched by appropriate guidance from research.

Classroom networks, unlike many other technologies aimed at improving mathematics and science instruction, have followed a distinctive trajectory, starting with the work of many enthusiastic educators and only recently attracting the attention of professional researchers. If future studies confirm these early findings, teachers can expect to benefit from a technology that makes them more efficient in their classrooms, helps them align their teaching with research-proven best practices, and centers their classrooms on the things that count: the learner, knowledge, assessment, and the classroom learning community.

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