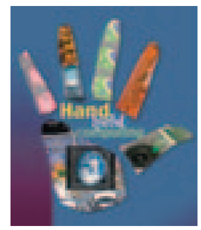
COVER FEATURE

Handhelds Go to School: Lessons Learned



Working in conjunction with teachers, researchers have developed a series of projects exploring the potential for using wireless handheld devices to enhance K-12 classroom instruction.

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The intersection of online learning and mobile computing—called *mobile learning*—holds the promise of offering frequent, integral access to applications that support learning anywhere, anytime. By and large, m-learning supports adults in the workplace—people who know what they want and why they want it. Given increased mobility in the corporate enterprise environment, m-learning has become an attractive target application area for corporate mobile devices.

But these devices can also support similar access for *classroom learning*. C-learning is oriented toward face-to-face participation. As Table 1 shows, m-learning continues and extends the learning paradigms and styles derived from a university lecture-and-seminar model, now made accessible through Web-based delivery. By comparison, c-learning builds on constructivist learning paradigms that employ hands-on projects and cooperative learning groups. Until now, educators have delivered it primarily through special computer labs or the installation of a few computers in a classroom.

However, c-learning is not merely about installing smaller, more affordable computers in the classroom. Wireless handhelds offer new opportunities for innovative user interaction, communication, and connection with sensors—both in the classroom and on field trips.[1] During the past three years, SRI International, a nonprofit research institute in California, has been exploring the potential of these capabilities through a series of projects to design prototypes and perform classroom-based research in conjunction with teachers.

FREQUENT, INTEGRAL ACCESS

Our vision for computers in the classroom is one of frequent, integral use of a tool that helps students master difficult concepts by exploring and interacting with data and ideas. For example, research has shown that sixth-grade students who use computer simulations can master Newtonian physics concepts at a level that surpasses the expectation for twelfth-graders.[2]

Work with such simulations remains rare, however, because of the gap between a school's advertised computational facilities and those that a teacher can realistically access.[3,4] Often the time frame for scheduling computer labs does not match the teacher's time frame for planning class activities. Further, getting students to the computer lab takes precious classroom minutes.

Wireless Internet connections and mobile laptop labs solve these problems in theory, but many teachers find them unreliable, confusing, and time-consuming. Difficulties that delay office workers five or 10 minutes when they arrive in the morning are prohibitive in the classroom environment.

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Because handhelds are cheap, portable, flexible, have no start-up time, and require virtually no maintenance, they offer a promising vehicle for the kind of computer access we envision. Participatory simulations such as Gridlock[5] and Geney[6] are beginning to demonstrate the educational viability of this approach. Graphing calculators, which have many of the same properties as handheld computers, offer proof of concept of its practicality. Graphing calculators have reached far more K-12 students than desktops or laptops. Approximately 40 percent of high school mathematics classrooms use graphing calculators, whereas only 11 percent use computers.[7]

Table 1. Comparative features of m-learning and c-learning.

Feature	M-learning	C-learning
Paradigm	Lecture, seminar	Hands-on projects, collaborative groups
Use of medium	Media designed to deliver information	Tools designed to support inquiry
Student input	Writing free-form text	Constructing graphs, animations, questions
Communication	Mostly online discussion with little support from shared nontextual referents	Face-to-face discussion supported by shared attention to data, drawings, graphs, and text

SRI-PALM EVALUATION PROGRAM

During 2001-2002, SRI International, in collaboration with Palm Inc., conducted a systematic large-scale evaluation of handheld technology for education.[3] The Palm Education Pioneers (PEP) program distributed handhelds through a competitive grant program and examined how the 100 selected teachers used them in the classroom.

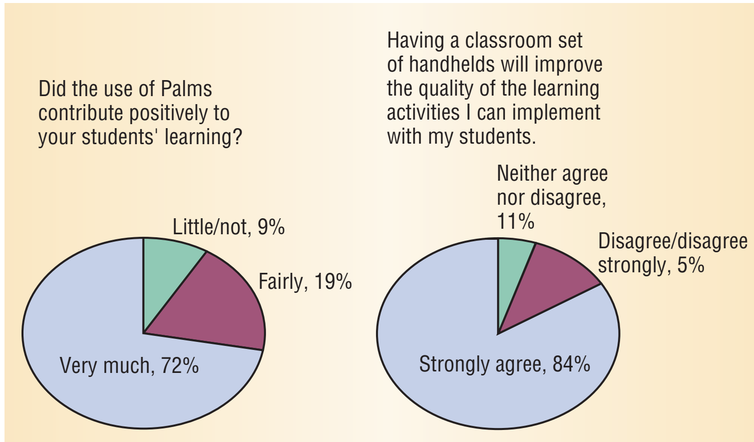

Figure 1. Teacher ratings of handheld use in classroom. Participants in the 2001-2002 Palm Education Pioneers program reported benefits including greater student engagement, more effective collaboration, and increased student autonomy.

Benefits and drawbacks of handhelds

PEP teachers adopted the handheld computers with enthusiasm and, as Figure 1 shows, later gave them mostly high marks as classroom learning tools. The teachers reported greater student engagement, more effective collaboration, and increased student autonomy on lessons that integrated handheld computer use. They also said that handhelds let them bring more and better use of technology to a wider range of students and circumstances.

Most of these teachers reported only minor drawbacks to using handheld computers in the classroom. The main problems were associated with inappropriate use, especially by beaming inappropriate content; technology management, particularly involving synchronization; usability, particularly using Palm's Graffiti software program for long text input; and equipment damage.

Although synchronization is integral to the utility of handhelds for professionals, off-the-shelf synchronization solutions created problems in classroom use. Traditional synchronization models assume that each user can synchronize with an individual computer—a situation that does not exist in the classroom. Problems often arose from asking many students to synchronize with a small number of computers. Many PEP project teachers had to administer the synchronization process themselves, but education-specific solutions are now available (http://goknow.com/Products/PAAM.html).

Need for education-specific applications

Many teachers simply used the handhelds as portable word processor or other productivity devices such as calendaring programs. They appreciated the increased access to technology brought by the handhelds, especially for writing assignments.

Teachers noted that there were too few education-specific applications. In the science classroom, however, specialized hardware helped expand the use of handhelds beyond generic, portable productivity devices. For example, handheld-based probes augmented inquiry-based investigations with real-time data and visualizations, which in turn increased the students' engagement and let them concentrate on science rather than logistics.

Teachers contrasted the investigative situation to using pH strips, in which students spend most of their effort color-matching to determine pH. With handheld devices, the students use probes to collect and analyze data in real time and compare it instantaneously with data from different locations—often by shouting out their readings to others. Teachers and the teaching literature both report that the most valuable learning opportunities occur when students can ask questions while they are actually working with scientific data.[8]

Surprisingly, many teachers said that using handhelds had little or no effect on their students' use of desktop or laptop computers. Instead, handhelds

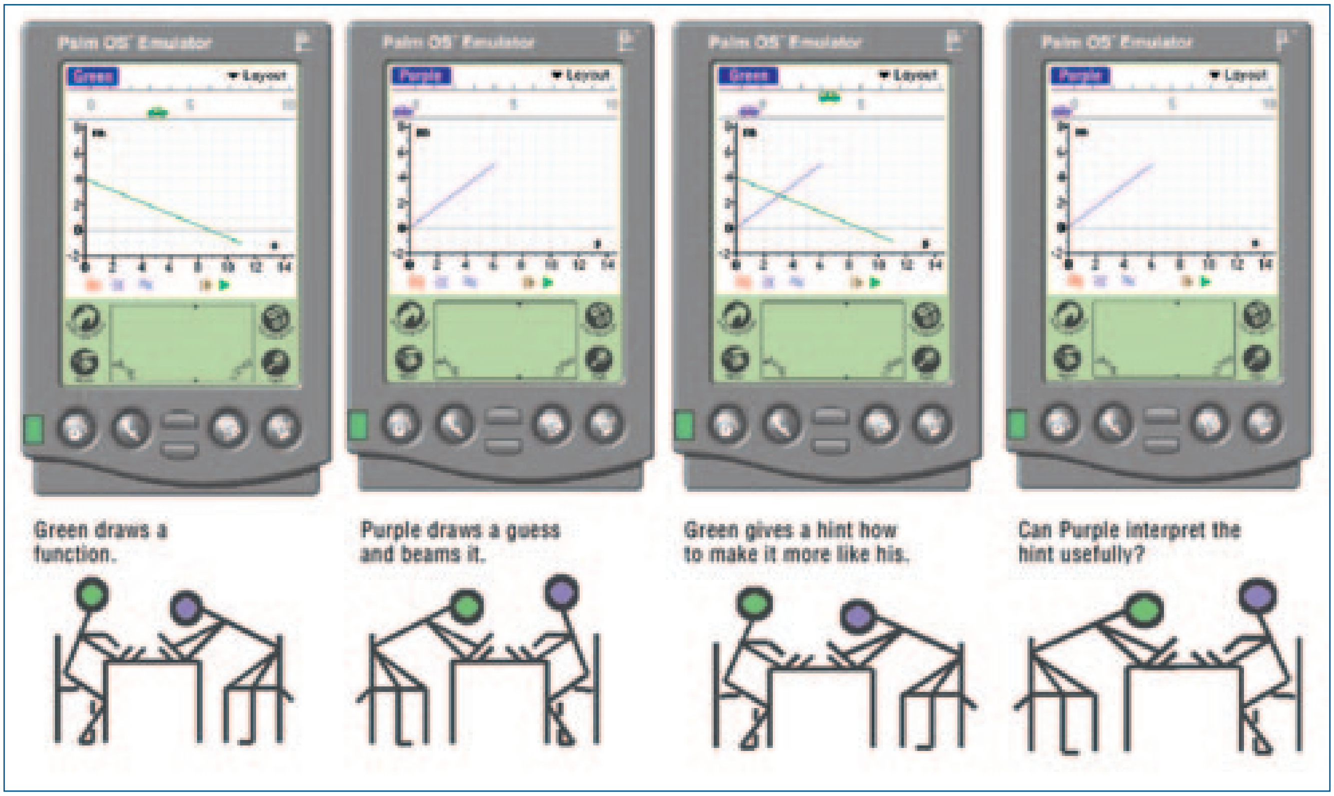

Figure 2. Activity sequence in Match-My-Graph. Taking turns, one student describes a function in terms of its graph, while the second student tries to duplicate the graph from the description.

found their own niche and often complemented existing technology uses.

CODESIGN WITH TEACHERS

Our experience with the PEP program, together with prior literature in educational computing,[2] suggests that the future of handheld computers in education lies in designing tailored technologies for learning: identifying educational tasks and using the unique properties of handheld systems to address them.

To this end, both active and retired teachers are integral members of our design teams. Active teachers influence the technology targets and help us limit system complexity. They are the first users of our handheld devices, and we study their classrooms to learn more about how to apply the systems effectively.

Mastering math and science representations

Offering students rich representations that they cannot easily reproduce with pencil and paper is an area of primary application interest. Match-My-Graph and Slot Machine are two applications that create focused learning environments in which students are asked to think about the meaning of the relationship between animated simulations and graphical representations of mathematical functions.

Language games for math learning. Middle school math students typically have difficulty remembering the meaning that a graph represents. Indeed, students may interpret a position graph that shows a line with a downward slope—like the one in Figure 2—as a representation of a car going down a hill.

Match-My-Graph targets the graph's meaning by asking students to put it into words. Students work in pairs. One student, the grapher, uses the stylus to draw a function over a domain. The other student, the matcher, creates the same function over the same domain by making successive guesses and interpreting hints. The matcher must use math language with sufficient care to convey precise meaning to the grapher. Over multiple rounds, the students take turns in the grapher and matcher roles. Students involved in this activity are focused by several metrics of engagement, including their resistance to attempts to distract them from the task at hand.

An important part of Match-My-Graph is animating the simulation and graph to understand whether a steeper graph represents a faster or slower car. What does an increase in the line's slope mean for the simulation? Four variations of this task stress the student's ability to create and interpret mathematical language. In the most complex version, a grapher looking at two velocity graphs must give hints to a matcher looking at a position graph.

Practice and puzzlement. In Match-My-Graph, the differences between the two students' screen states motivate them to confront underlying confusions. Slot Machine also focuses on middle school mathematics and confusion about the underlying meaning of graphs, but the emphasis is on whether a simulation, position graph, and velocity graph describe the same situation.

Figure 3. A Sketchy animation of the food cycle near a pond. Student animations demonstrate their understanding of relationships among animals in the environment.

Slot Machine's social structure is also quite different. In this application, one student solves a problem and another student "grades" the work. The students are rewarded with extra points if they both do well.

The technology's benefits include both the quick-fire practice and the discussion that occurs when the matcher and grader disagree.

Minds on the data

Two projects address students' concepts of scientific processes and how the concepts relate to hands-on activities. In both cases, the goal is for students to be "minds-on when they are hands-on." Students can use these tools when working alone or in small groups, preparing material they may eventually share in a discussion.

Visualizing scientific processes. Sketchy is a system created at Elliot Soloway's Highly Interactive Computing in Education laboratory (http://hice.org/). Students use Sketchy to make frames with drawings and textual annotations in them, which they can then use to produce animations.

In collaboration with HICE, we have augmented Sketchy to support science learning in the classroom. The software now has color, icon stamping, and background images. Teachers can store student animations on their desktops and project them on a screen for class discussion.

Students use Sketchy to animate processes that otherwise remain static in their textbooks. Designing an animation requires deciding how to represent physical phenomena, causal processes, space, and time—all integral to understanding science. By designing and drawing their own animations, beaming their sketches to one another and the teacher, and discussing what is represented, students discover what is important to illustrate.

Teachers gain insights into student misunderstandings by seeing what they draw. For example, the sequence in Figure 3 shows how some elementary school students represented food webs as a linear path from large predators to small prey, rather than as the complex multiplex relationships the teacher thought they understood.

Minds on the prize. Students engaged in hands-on work can become distracted or confused about the task at hand and its relationship to the larger point of the experience: What were those numbers? What was I supposed to do with them? What are we doing anyway? Their confusion may last only a few minutes, yet in a fast-paced classroom, a few minutes can put them at a disadvantage.

Because teachers cannot be everywhere in the classroom at once, the Data Doers application lets them create handheld-based worksheets for labs or demonstrations to help students with data collection activities.

Data Doers reminds students to think about what they are doing in two *direct* ways:

- Based on teacher-set upper and lower measurement bounds, the application gives students feedback when they need to reconsider and possibly remeasure a result that is not plausible.
- Students can beam their data to one another to compare and contrast their results more quickly.

It also provides more occasions for student thought in three *indirect* ways:

- Teachers can collect student values and respond in a more timely fashion than with paper-based systems.
- Students do not need to copy data tables during class discussion.
- Teachers can use the Data Doers spreadsheet to create a classroom discussion about the lab and its goals before it starts.

We have created participation structures in which opportunities to learn are contextualized in learning sequences.

Supporting questions and feedback

Handhelds can also improve class discussion by promoting feedback and display.

Image map assessment. Teachers can use the image map assessment tool to evaluate the range of student comprehension in a classroom and to frame questions accordingly. For example, suppose the teacher asks the class which states fought for the North during the US Civil War. Students might respond by marking one or more states on a map of the US, which the system then broadcasts to a monitor that displays a map with the distribution for the whole class. A display showing that 15 students included New York but only three included Kansas could spawn a discussion of why Kansas' status might be confusing. This activity orients students and teachers toward the body of knowledge for which the student is accountable.

Capturing student-generated questions. Students use the Boomerang tool to submit questions privately that the teacher posts for discussion by the group as a whole.

When students ask questions in their own words, they reveal gaps in their understanding that the teacher's use of standard terminology and phrases might not elicit. By asking questions, students not only fill gaps in their knowledge base but also open the space for speculation. Standard classroom practice may permit only a small number of student questions. Students are often discouraged from asking good questions if others ask questions that are very different from theirs.

Aggregation. SimCalc/NetCalc structures activities to help students perceive function families.[9] For example, the tool assigns each table a group number for b in $y = mx + b$. Then it assigns each person in the group a number that is their personal m. The students then graph their unique function and send their results to the whole-class display at the front of the room. Aggregating individual student functions helps them see the pattern for the whole group.

DESIGNING FOR LEARNING AND TEACHING

In all these projects, we sought to maximize four kinds of opportunities that promote learning:

- focused encounters with the representational capabilities of the system;
- planned activities that induce conversations about those representations;
- serendipitous conversations and discoveries about the representations; and
- more meaningful encounters with the teacher in relationship to the material.

We have created participation structures in which opportunities to learn are contextualized in learning sequences. At the same time, we sought to minimize impositions on the teacher so that the projects do not add to the work of managing a classroom. For example, we avoided designs that required the teacher to be in a certain place at a certain time to press the right button.

Last, we tried to maximize technology-based opportunities such as the use of powerful computational representations to aid learning and maximize the capture of data about what the student is doing.

NETWORKING

Developing and deploying these and other handheld-based technologies in the classroom have taught us some lessons and raised additional concerns.

Infrastructure and topology

First, decisions about the network infrastructure and topology are basic to the ease and effectiveness of using mobile wireless devices in classrooms. Our primary work has been with machines that use infrared beaming, affording spatially directed, point-to-point communication. While IR communication may superficially seem like a poor cousin to radio frequency (RF)-based networking, it has some strong advantages in a classroom:

- IR requires no fixed infrastructure and no configuration, which lets teachers adopt the technology without becoming or employing network administrators. It avoids dependencies on the uptime of other network components.
- IR simplifies the designation of communication targets. Instead of picking target names from a list, users point to the person they are beaming. They negotiate the appropriateness and timing of a particular beam in the social realm with little technical overhead.
- IR fits the ad hoc student ensembles that frequently occur in classrooms. Teachers may design tasks for pairs, but if the number of students is uneven, they expect to assign the tasks to trios. When they say, "Everyone who is done, come to the front of the class and bring your handhelds," they want to create pairs from the students who are ready for the next task.

- IR retains its communication functionality when students need to use their handheld devices on field trips.

Coordinated full-classroom action is, however, more difficult under IR. For example, there is no simple way for a teacher to get everyone's device to a particular state or to collect work from all students simultaneously. More importantly, it is difficult to support aggregation activities like the image map assessment. Finally, without an infrastructure, students do not have Internet access.

Even if RF ultimately prevails over point-to-point beaming, retaining IR and peer-to-peer topology characteristics such as minimal configuration, natural integration with social control, and easy sharing of information among ad hoc social groups would be beneficial.

Network functionality

We have found it useful to think about the network as accomplishing pedagogically useful transformations of the data available throughout the classroom, instead of merely as a vehicle for sending and receiving data. The most useful network operations in this regard were

- distribution—sending the same starting document to every student;
- differentiation—sending different parameter settings to each student in a systematic pattern;
- contribution—transmitting a mathematical function or data point constructed by a student to a peer or the teacher;
- harvesting—forming a group of related but distinct functions or data constructed by multiple students and viewed side by side for contrasts; and
- aggregation—combining related functions or data into a single overall construction, often then displayed publicly, with or without anonymity.

Two additional network operations would be useful, but implementing them with currently available technology is difficult:

- looking—allowing people to capture views from other screens without disruption, for example, while walking around the classroom; and
- exchanging—swapping information to continue to the next step of a symmetrical process, for example, by grading each other's work.

No single network protocol or application readily supports all these operations. Achieving them with existing Web protocols is particularly difficult, although they have been available in proprietary workplace groupware for some time. Designing new network services and applications for classrooms will be an important area for future work.

Teachers report decreased disruptions compared to classes without handheld tools.

Teacher control

Teachers want and need control over their classrooms. Users of existing school installations of computer networks often report problems with students using them to cheat, download illicit content, or engage in disruptive behavior.

Centralized network control is possible, but such functionality requires significant teacher administration. This is especially true with handhelds, precisely because they allow a fluid change between activity structures. For example, within a few minutes, students may go from participating in group work that requires beaming to taking a quiz individually, where beaming would constitute cheating. Centralizing control over student communication requires teachers to manage responsibilities that they cannot address moment to moment.

This is an area in which we found considerable individual differences and expect attitudes to change with experience. Initially, teachers may be more optimistic about their ability and willingness to preside over functions like distributing blank labs to students who arrive late. But over time, we have found that teachers generally want students to initiate network activities and correct their own problems.

Furthermore, none of the teachers have complained about disruptive behavior in classes where students use handheld tools. Indeed, perhaps because students can participate in classroom activities more effectively, teachers report decreased disruptions compared to classes without these tools. In the classrooms where we have the most prolonged experiences, we have even noted a decrease in natural behaviors such as going to the bathroom or getting a drink of water.

It is not clear yet how to give teachers the control they need without also imposing an administrative burden for network operations.

USER EXPERIENCE

While the underlying network arrangements are fundamental to the user interface of these applications, the user experience itself offers additional lessons.

Classroom use of mobile devices introduces a range of challenges beyond the established Internet and Web paradigm.

Shared attention

Attention is a sine qua non of learning. The material to be learned can itself generate this attention; so can conversations about the material, points the teacher makes about it, or unexpected discoveries the students make.

Creating shared attention is a key issue in the design of any group information system.[10] Yet introducing handhelds into the learning environment changes the classroom's *attentional affordances*—that is, the real and perceived means of commanding attention—in a way that threatens the current structure. If students are absorbed in the machine when the teacher expects them to be listening to instructions, confusion follows. If the teacher is absorbed in the machine when students need help understanding material, confusion follows. If users believe they have the same screen states when in fact they have different ones, confusion follows. If a teacher diagnoses problems from incorrect verbalizations about screen states, confusion follows.

One way to avoid creating confusion is to incorporate activities that have marked moments for sharing and discussion, as when the Data Doers application collects data from the entire class. The "foible-to-feature transform" technique that Match-My-Graph uses to emphasize screen differences is another way to encourage sharing and discussion.

Minimal, focused design

Restraint is also an important lesson, as the minimalist school of technical communication has shown.[11] Rather than trying to create an all-encompassing system, we use specific, targeted technology and rely on existing practices for other classroom activities. Talking and passing out papers remain integral parts of handheld-based activities. Students should not struggle to read instructions on a tiny screen when paper-based instructions work very well. Furthermore, our teachers prefer to have students hand in their work on paper, for later grading from an easy chair.

A related lesson is that ephemera in student work are not necessarily a bad thing. Technology developers are tempted to focus on keeping permanent records and developing databases of student work. Indeed, good political reasons exist for doing so, as portfolios of student work can be an important part of showing parents and administrators the kind of learning experience that is occurring in the classroom.

However, these goals are mostly extraneous to the fundamental learning experience, and they entail a very high cost. Specifically, someone must manage the data. Among our tools, only Sketchy preserves data in computational form after the local learning experience is over (because it isn't possible to show animations without a computer). Long-term centralized storage requires more justification than we have yet found for it in most cases.

Activity flows

A third lesson is that classrooms work when activity flows easily from individuals to small groups to the entire class. Handhelds can easily support individual and small-group activities; and with a large public display, they can also support whole-class activity.

In a provocative article,[12] economist Arnold Kling wrote that the existing infrastructure is sufficient for word processing, spreadsheets, e-mail, and Web browsing, but he asked,

> Where is the next generation of "killer applications" that will drive mainstream adoption of technologies that are tantalizingly close to realization, such as wireless Internet access, pervasive computing, and radio on a chip?

Kling argues that a likely area for such applications to emerge is social software—that is, software that allows informal groups to collaborate effectively toward shared goals. Kling suggests that classroom networking will be a key driver in developing these efforts.

We agree. In addition to meeting important educational needs, classroom use of mobile devices introduces a range of challenges beyond the established Internet and Web paradigm. Innovations addressing the challenges related to network infrastructure, functionality, control, and the classroom user experience can spread to other social, informal uses of networked handhelds. We believe these efforts will spur the development of new applications that support the localized use of handheld devices in informal groups. ■

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