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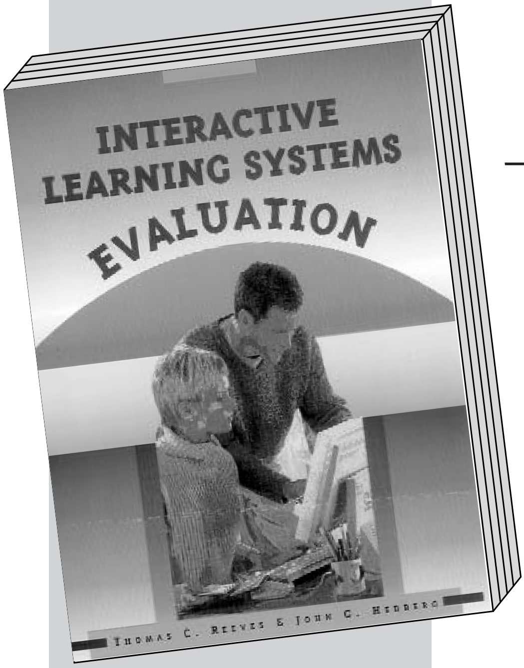

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A special issue on highly mobile computing; plus regular features

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Special Issue on Highly Mobile Computing

Regular Features

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contributing editors

Introduction to Special Issue on Highly Mobile Computing

Mark van ‘t Hooft
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Guest Editors

Highly mobile digital devices have become so inexpensive and ubiquitous that they are considered part of the fabric of society; however, they are not part of the fabric of schools. To introduce the reader to the magnitude of expected changes in teaching and learning, the authors consider four areas relevant to education that are being changed by the near ubiquity of inexpensive highly mobile devices: society, information access, learners, and schools.

“God meant us to be wireless. The last cord we were connected to was cut at birth”
–Frank Sanda, Motorola

When Gordon Moore predicted in 1965 that computers’ processing power would double every 18 months to two years, computers were large, bulky, and expensive devices that had little use outside of number crunching. While a small number of visionaries such as Vannevar Bush and Doug Engelbart could imagine a future where computers could fundamentally change the way we learned and worked, these visions seemed as much in the realm of science fiction as flying cars.

As Moore’s prediction became reality over the next 20 years, there were dramatic increases in computing power. As a result, the personal computer started becoming a mainstream appliance, and computer programs such as *Oregon Trail* began to appear in a few classrooms. However, the main use of computers remained in academia. Researchers began investigating new ways of using the computer in education through probes, simulations, and collaboration. The Internet and email were being used by a small number of academics. Creative thinkers such as Seymour Papert described a future where computing was the center of education. Even so, computers were still too big, too expensive, too slow, and too esoteric for education (or most of society) to take seriously.

In the next 20 years that all changed. With desktops, laptops, cell phones, the World Wide Web, WiFi, handhelds, game consoles, streaming video, tablets, smart boards, and smart phones, innovation after innovation came pouring out into the world. Research that had been investigating futuristic uses of technology went from science fiction to mundane seemingly overnight. Whereas twenty years ago you would have needed a computer the size of a small room to do any serious work, today a hundred dollar handheld device has the computational power to collect, represent, and analyze data in real time. Wireless access connects us to most of the world’s information. Increased storage capacity allows us to carry our entire music and video libraries in our pockets. We can connect to anyone at anytime using voice, text, video, or screen sharing. It should perhaps not surprise us that education, never the most agile of endeavors, has been left catching its collective breath, trying to make sense of the changes that are zooming by at blinding speed.

Today we are at an inflection point: electronic handheld devices have become so inexpensive and ubiquitous that they are considered part of the fabric of society. However, they are still not part of the fabric of schools: in fact, some schools even ban the use of electronic handheld devices, seeing them as a nuisance that interferes with real learning. This need not be the case, however. In this special edition we consider how highly mobile devices can have a positive impact on education. The first three articles take a look at what is currently known about effective uses of handhelds in education. Next, a series of six articles discusses what uses of mobile computers look like in and outside of the classroom. We also present the latest thinking in industry about how handheld computers can transform education. The final three articles present visions of the future, to help guide the field’s thinking on next-generation uses of handheld computers.

For the purposes of this special edition, we take a very broad definition of what is meant by a highly mobile device for learning. This category includes devices with the following characteristics:

- high mobility (that is, small enough that students can hold the device in one hand and carry it from place to place);

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- small footprint (so that they do not intrude in face-to-face interactions);
- the computational and display capabilities to view, collect, or otherwise use representations and/or large amounts of data; and
- the ability to support collaboration and/or data sharing.

Devices included in this definition are PDAs, mobile phones, some tablet computers, networked graphing calculators, UMPCs, the new generation of handheld gaming systems, iPods, motes, data loggers, etc. We do not include laptop computers in our definition.

To introduce the reader to the magnitude of the changes in teaching and learning we may expect, we briefly consider four areas relevant to education that are being changed by the near ubiquity of inexpensive highly mobile devices: society, information access, learners, and schools.

Changing Society, Changing Technology

Today's adults can remember growing up in a world that was stable, low-tech, with basic communication channels, and information that was limited. For current generations of children the world is a very different place: it's 24/7 and high tech, with an overwhelming amount of communication devices and information channels (Jukes, 2005). Thinking about the variety of activities we engage in on any particular day, most of us would be surprised at how many of these activities involve some type of digital tool. Yet, for most of these activities, we take the technology for granted and focus on the task at hand instead. Despite the fact that digital technology will continue to develop and change in ways we cannot possibly imagine, current visionaries (e.g., Abowd & Mynatt, 2000; Roush, 2005; Thornburg, 2006) agree that future tools will be predominantly:

- personal (one-to-one or one-to-many access);
- mobile (always-on-you technology);
- networked and connected to the Internet 24/7 (always-on technology);
- accessible (cheap and easy to use);
- flexible (users have choices);
- social (collaboration and allowing for creating, sharing, aggregating, and connecting knowledge);
- multi-modal (support the consumption AND creation of different media, including text, image, sound, and video); and
- contextual (context-awareness, but also context-creating).

Changing Information Access

Given the characteristics of new technologies, it is obvious that the ways in which we create and interact with knowledge and information are changing. Knowledge has moved from physical repositories such as libraries to the virtual repository of the Internet, which has been dubbed a "global virtual knowledge ecology" (Breck, 2006, p. 44), characterized by its open content and "interconnectivity within and among subjects" (p. 46). Younger generations are fluidly accessing digital, networked, information wherever and whenever the need arises. When interacting with this information, users typically "interact with other users [and] with more than one computer or device at the same time" (Roth, 2002, p. 282; see also Cole & Stanton, 2003; Danesh, Inkpen, Lau, Shu, & Booth, 2001; Mandryk, Inkpen, Bilezkjian, Klemmer, & Landay, 2001). Because digital tools are increasingly personal, mobile, and connected, they lend themselves well to both individual and collaborative learning, encourage the use of technology in everyday activities (including learning), and enable students to understand digital tools as lifelong-learning tools (Inkpen, 2001; Sharples, 2000; Thornburg, 2002), eventually leading to the type of ubiquitous and "invisible" computing that Weiser (1991) envisioned 15 years ago.

Society in general has picked up on this shift, but current educational practices have done relatively little with the ever-increasing digital connectivity, instead trying to "shape the technology around outdated notions of what schooling is about, rather than reshaping our notions to reflect new world conditions" (Warlick, 2005). Consequently, schools have created "a fundamental disconnect between the ways kids learn, think, and communicate, and the ways that [schools] interact with them" (Jukes, 2005, p. 21), leading to increasing levels of dissatisfaction, perceptions of school as being irrelevant, and increasing drop-out rates (Jukes, 2005; NCES, 2005; Thornburgh, 2006).

Changing Learners

While schools are holding on to oral traditions, textbooks, and learning that is linear, current learners live in a different world with different media that allow for different ways to access information (see, e.g., Alexander, 2004; Jukes, 2005; Roush, 2005). Today's students prefer:

- quick and open access to information that is networked/hyperlinked;
- actively networking and communicating with many others;
- current digital tools over print;
- multimedia before text;
- just-in-time learning that is relevant and useful;
- expressing their creativity.

Also, in a mobile and connected world, learners:

- are mobile (that is, mobility is a function of the learner, not just the technology (Sharples, 2005);
- are active, communicative, and resourceful as they multitask (Alexander, 2004; Jukes, 2005; Roush, 2005); and

- construct context through interaction (Sharples, 2005).

Changing Learning, Changing Schools

If schools are to re-connect with students who live in an age of mobile and connected technology, their approaches to teaching and learning need to fit with today's learners and their needs. Learning should be:

- interwoven with other activities as part of everyday life and transcend imposed boundaries of space and time (Breck, 2006; RCET, 2006; Richardson, 2006; Sharples, 2005);
- more authentic, relevant, spontaneous, creative, and learner-driven (Alexander, 2004; Fryer, 2006; Molina, 2004; RCET, 2006);
- faster and less linear (Jukes, 2005);
- personal and customizable (RCET, 2006; Swan *et al.*, 2006);
- digital and connected (Alexander, 2004; Rogers & Price, 2007; Richardson, 2006); and
- integrative of both traditional and so-called 21st century content (Jukes, 2005; RCET, 2006).

Conclusion

Considering that the children we teach in our schools today will run the societies we will live in tomorrow, it is imperative that educators connect teaching and learning with the realities of all of their students' lives. Highly mobile and connected technology is one tool that can be used to this end:

> Today, as educators, we must not only learn how to use the tools students take for granted; we must also actively employ this same gear to engage them emotionally. But first, we have to learn to fluently speak their language, an electronic conversation of infinite information delivered in multiple emerging forms over a variety of transmitters. The upcoming generation is going to amaze us in ways we're just beginning to understand—if we can just keep up. (Daly, 2005)

If technology is to be used in meaningful and effective ways for teaching and learning, any vision of the future of education should include the technologies that many youngsters are currently using as a part of their everyday lives. Hopefully, the articles in this special issue will help shape that vision. □

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Educational Technology for the Mainstream: A Call for Designing for Simplicity and Reliability

Cathleen Norris
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Namsoo Shin
Elliot Soloway
University of Michigan

This article proposes three guidelines for mobile technology design that address the needs and goals of teachers who are considered mainstream with regard to technology use. Devices should be easy to learn and use, focused on the curriculum, and instruction-friendly. Only if the three guidelines are followed by hardware and software developers will there be technology use by mainstream teachers en masse.

Introduction: From Early Adopters to the Mainstream

Following the terminology used in G. Moore's (1991) now-classic monograph on the process of technology adoption, computers have "crossed the chasm"—computers no longer are niche products, but rather, they are becoming an integral part of the consumer mass market. Computers are now products purchased by the mainstream, along with TV sets, radios, cameras, etc.

In Figure 1 we present a graph that, according to Moore, depicts the adoption of technology. During the early stages of a technology's development (e.g., hybrid automobiles, flash memory sticks), only a small number of early adopters use it. If the technology crosses the chasm, then large numbers of mainstream individuals come to use it. While hybrid automobiles have not crossed the chasm, flash memory sticks have.

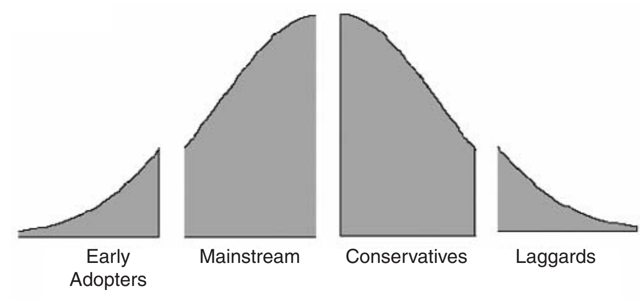

Figure 1. Crossing the chasm: Technology adoption according to G. Moore (X axis is time, Y axis is number of individuals).

Early adopters pick up on a technology because they see that this technology affords them an opportunity to make a major improvement in a practice or activity. Early adopters will put up with technology that is not particularly easy to use or breaks down occasionally because they have their eyes on a bigger goal—making a substantive change. Early adopters are risk-takers; they are willing and adept enough to develop work-arounds to cover for a technology's failings. Anyone who has a hybrid automobile now is an early adopter—though recent versions are much better than when they were first introduced.

As we mentioned earlier, flash memory sticks did cross the chasm; they have effectively replaced floppy disks as the portable storage media of choice. Why and when will a technology cross the chasm? We can answer that question by deconstructing the chasm crossing of the flash memory stick.

Mainstreamers have adopted flash memory sticks because they are easy to use and highly reliable. Mainstreamers were ***not*** looking to replace their diskettes per se; mainstreamers were ***not*** out looking for an opportunity to carry around more and bigger files. But, when flash memory sticks are included on the other end of an ink pen, sold in drug stores at the checkout counter, worn around the neck as a form of jewelry, and truly plug-and-play—easy to use and reliable—then mainstreamers have found the money to buy flash memory sticks instead of much cheaper, but less reliable and less functional, floppy diskettes.

In K–12 education, Moore's (1991) model of

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technology adoption and his notions of the early adopters and mainstreamers are also very appropriate. In many schools, computing technology has primarily been the province of a relatively small number of early adopting teachers and administrators. Early adopting educators are willing to put up with hard to use and flaky software, hardware, and networks because they see the bigger goal—that these technologies are motivating for learners and give learners access to new opportunities for learning.

However, there are clear signs that mainstream teachers, not just the early adopters, will soon be using technology in their classrooms. Districts are passing bond issues to provide funds to provide each and every child in the district with a computer. In Figure 2, we present the document provided to Alvin, Texas, voters that describes the bond proposal that was passed in November, 2005. It is particularly interesting to note that in the description of the technology that was going to be purchased, "handheld computers" were explicitly mentioned.

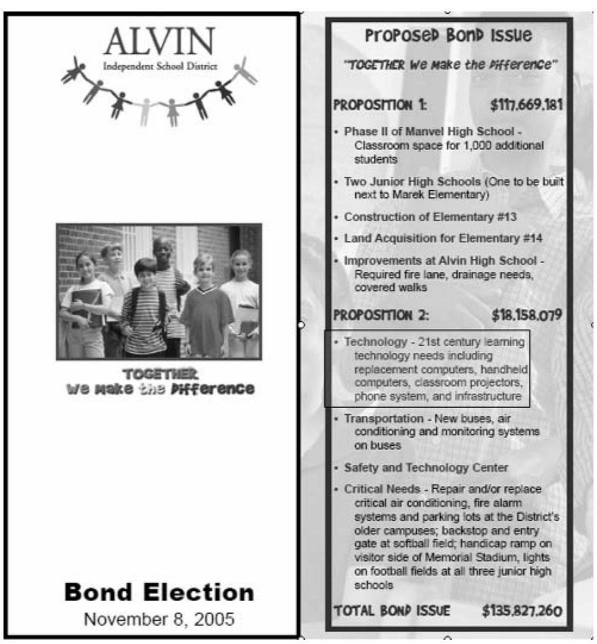

Figure 2. Alvin, TX bond issue, November, 2005.

Indeed, in the recent American Digital Schools (Hayes & Greaves, 2006) nationwide survey of over 1,000 school districts, 85% of the school leaders say they will be moving to a 1:1 computer-to-student ratio over the next few years (Figure 3).

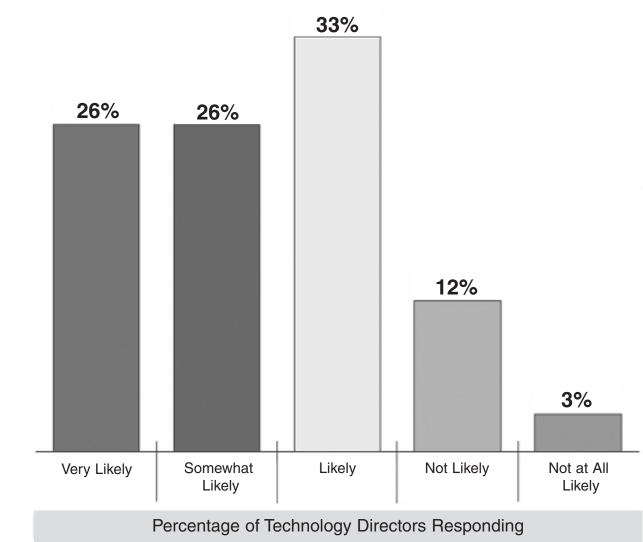

Figure 3. Likelihood of adopting student appliances.

But crossing this chasm will fail unless educational technology companies design their products for mainstream teachers and not just early adopters. Mainstream and early adopters are different sorts of people, who have different sorts of technology needs and goals:

- Early adopters find technology per se interesting, and they are capable of making use of the technology in spite of the technology's failings. In contrast, mainstream teachers worry about the curriculum and delivering the curriculum; they see technology as a means to an end, not an end in itself. We have had the experience of a mainstream teacher wanting to throw the computers out of the classroom when just one student had trouble using them.
- While early adopters see technology as new opportunities, mainstream teachers want simplicity and reliability. New opportunities that are fraught with a steep learning curve and/or flaky performance are simply not worth the bother.

In what follows, we present three guidelines that educational technology developers should adopt in order to design for the mainstream.

The Big Three Design Guidelines

The guidelines described below draw directly on the needs and goals of the mainstreamers. Following these guidelines should result in technology—hardware and software—that mainstream teachers will feel comfortable adopting:

- **Simple, Simple, Simple:** Packed into this slogan are the notions that a technology needs to be easy-to-learn, easy-to-use, and reliable in order for it to cross the chasm. In looking at the technologies that have crossed the chasm (from overhead projectors to response pads), those three properties are evident.

Why? A litany that appears throughout this section is that time and effort are in short supply in K–12. Mainstreamers feel that time and efforts are wasted if they or their students need to expend resources learning how to use the technology or troubleshooting balky technology. Thus, while early adopters do make compromises on these three properties, mainstreamers are reluctant to do so. That's not to say that compromises are impossible: the graphing calculator, which has crossed the chasm, is neither easy-to-learn nor easy-to-use—though it is rock solid reliable—but its compelling value lies in the next two design guidelines.

- **Curricular Focus (What):** Today, more than ever, there is a given curriculum that must be taught. In the USA as well as in the rest of the world, governments set standards and define goals that must be achieved. Lack of time is the teacher's constant lament, and thus off-curricular topics are a luxury that can't be indulged in. There are schools in the USA that teach only math and reading all day long; no time for science, let along music or art, since only math and reading are the subjects that "count" on tests for the No Child Left Behind program in the USA. No compromise is possible on this guideline; to cross the chasm, a technology must be focused on the given curriculum.

- **Instruction Friendly (How):** Direct instruction, with episodes of constructivist practices, is the dominant instructional framework in K–12 classrooms in the USA. Teachers and textbooks are used to tell students the content. However, projects, where children write, draw, and create spreadsheets and mind maps, while working collaboratively, are also being included as legitimate learning activities. Teachers have developed a broad range of instructional strategies that they use to enact this hybrid instructional framework. Most importantly, for the most part, teachers do not feel that their instructional practices are broken and thus they don't really see much need to fix or change them.

  However, the **raison d'être** for using technology in the classroom is precisely the new instructional opportunities that the technology affords, so some compromise, some change must occur in the teachers' practices. Yet, in contrast to the early days, when techies asked teachers to substantially change their instructional practices immediately (e.g., learn to program in Basic and then write instructional programs for students), our mantra is "evolution, not revolution." Thus, in order for a technology to cross the chasm, it must start where the teachers are, with their existing curriculum and instructional practices. Teachers will change, but slowly, as they build up confidence and, most importantly, as they are successful in having their children be successful using the technology.

Interestingly, technologies that have crossed the chasm, e.g., hardware such as graphing calculators and response pads, and software such as KidPix and Inspiration, do at least follow these latter two guidelines. But, given the dearth of technology-based products that have crossed the chasm, it is clear that the educational technology development community needs to rethink its perspective on product design, development, rollout, and maintenance. Fortunately, as we argue in the next section, a new type of technology is emerging that can give the development community just the opportunity it needs to refocus its efforts so it can develop technology-based products that do cross the chasm.

Mobile Technologies for Learning: A New Beginning

> *"It's inevitable that all computing will be mobile"*
>
> –Jeff Hawkins, Inventor of the Palm Pilot, 1991

Hawkins's amazingly prescient observation is absolutely coming true. Mobile, small-screen, handheld, lightweight, instant-on/instant-off, and low-cost devices are beginning to pour out of the technology industry. With cell phones as the leading platform in this new group, manufacturers are searching around for the next "killer device."

> *"The industry has entered the era of the handheld… devices. You can argue that the PC era isn't ending, but it is."*
>
> –Richard Templeton, CEO, Texas Instruments, *NY Times,* July 9, 2006

The emerging mobile technologies may well be the technological platform that K–12 has been waiting for all these years. With low cost as a primary property, mobile devices, when designed according to The Big Three Design Guidelines, may well match the needs, constraints, and goals of K–12 in ways that desktop or even laptop technologies have missed. Five to seven pound laptop computers are mobile in the same way that a brick is a mobile object. Indeed, our educational colleagues across the pond in the UK feel that even two-pound devices with seven-inch screens are not sufficiently mobile for students. A mobile computer is one that slips into a child's pocket; a mobile computer is one that fits comfortably in the palm of a child's hand.

In design, the mantra "less is more" means that the challenges in designing for a constrained, limited platform (e.g., a computing device with a 3.5-inch screen and the processing power of a Pentium 1) helps, if not forces, the designer to focus on what is truly important for the device to do for the end user. While desktop or laptops afford—if not encourage—bloated, ill-focused, and grandiosely designed software, a minimalist platform can well foster the development of a clearly focused, task-appropriate product that is easy-to-learn, easy-to-use, and reliable, that squarely addresses the curriculum, and enables the use of existing instructional practices.

We point to our animation program, Sketchy,* as one clear example of an educational application that was designed for a mobile computing device using The Big Three Guidelines. Sketchy is an educational application that has all the earmarks of a chasm-crossing, technology-based product.

Will designers of educational products embrace the mobile platform and follow The Big Three Guidelines? We have already seen products for a mobile platform that are attempts at copying the desktop version, e.g., Inspiration for the Palm/PocketPC is closer to its desktop cousin than not. While the desktop version has been a truly smashing success, will its mobile version enjoy the same market share? Only time will tell.

Concluding Remarks

Integrated Learning Systems (ILSs) are the most widespread technology in K–12 today. These systems are not Simple, Simple, Simple, and they aren't Instruction Friendly, but they do have Curricular Focus. Have ILSs crossed the chasm? No. Prevalent, ILSs are still not in a significant percentage of schools in the USA. Indeed, it is interesting to speculate how popular ILSs might become if they were moved to a low-cost, mobile platform. Given the emphasis on testing, perhaps Curricular Focus trumps the other design guidelines.

Schools are stepping up their demand for technology. Parents recognize that if their children don't use technology in schools, then they aren't being properly prepared for future employment. Educators recognize that technology is highly motivating for the students; paper and pencil are just boring to today's children, but ePaper and ePencil are not. In addition to the costs of technology dropping dramatically, children's personal entertainment and communications' technologies can serve as learning tools also.

All this momentum will hit a wall, however, if developers don't heed The Big Three Design Guidelines; mainstreamers are just not going to put up with the technology products that early adopters find acceptable. Given that there are 55,000,000 school children in the USA alone, there is real motivation for developers of educational technology products to practice good design; products that cross the chasm can bring huge financial profits.

Thus, we feel confident in making the following prediction: educational technology is finally entering its Golden Era. While there will still be missteps, well-designed technology-based products will be produced that can and will cross the chasm and be used by mainstream teachers—benefiting our children enormously and creating an exciting and motivating work environment for educators. Still further, the positive feedback loop that is being set in motion will re-kindle and re-energize all sectors of our society: business will produce great products, government will enact productive policies, and education will attract the best and the brightest. Education is the engine that drives our society, our culture, and our community. Buckle those seat belts, it's going to be a great ride! □

*At *www.goknow.com/sketchycontest* an astonishingly broad range of student-produced artifacts are on display.

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Highly Mobile Devices, Pedagogical Possibilities, and How Teaching Needs to Be Reconceptualized to Realize Them

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Highly mobile devices are not just little computers or calculators. They have unique affordances and constraints that matter in teaching and learning. In addition, kids not only like portable digital technologies but use them as integral parts of their lives. If schools do not reconsider what they teach and how and where they teach it, students will continue to feel a disconnect between school and the world.

Highly mobile devices are not just little computers or calculators. They have unique affordances and constraints that matter in teaching and learning. In addition, kids not only like portable digital technologies but use them as integrated parts of their lives. They want to use mobile networked devices for learning, in particular to personalize and connect to what they are learning. They want to be prepared for a 21st century world that is very different from the one that many schools are still preparing them for. This new world includes technology that is a "way of communication and information gathering that is central in almost every part of our lives" (Utecht, 2006). If schools do not reconsider what they teach and how and where they teach it, students will continue to feel a disconnect between school and the world.

Indeed, McClintock (1999) contends that digital technologies have changed what is pedagogically possible, but everyday classroom teaching has changed little in the quarter century since computers were first placed in schools. Highly mobile devices arguably epitomize and extend such possibilities, emphasizing learning instead of schooling. However, unless teaching is radically reconceptualized to embrace technology, and unless teaching is continuously redefined within the changing context that these new tools create, highly mobile technologies will have no more impact than the many other technologies once touted as revolutionary (Cuban, 1986). Areas to be redefined include boundaries, pedagogy, and curriculum.

Rethinking Boundaries

A crucial area that needs to be reconceptualized concerns the boundaries traditionally imposed on schooling—boundaries between school and the world (see Vavoula *et al.*, this issue), formal and informal learning (see also, Lin, this issue), and public and private cognition (see also, Vahey, Roschelle, & Tatar, this issue).

Wireless mobile devices diminish boundaries imposed by brick and mortar spaces and the school day. Teachers can bring the world and its resources into the classroom by way of the Internet, while students can take mobile, connected, and versatile tools into the world. The technology enables anytime, anywhere learning, even when teachers and students are not in the same physical or temporal location. It can also close the gap between school and the 'real' world, both literally and virtually, making teaching and learning more relevant for students.

Good examples of how the use of mobile technologies helps bridge the classroom and the world are classrooms that are digitally enhanced to simulate real-world phenomena, such as is the case with RoomQuake (Moher, Hussein, Halter, & Kilb, 2005). Participatory simulations in which objects in the world are embedded with digital information are good examples also. For example, in Ambient Wood (Rogers, & Price, 2007) students explored a woodland environment as part of a scientific inquiry, and at certain times they could access relevant sources of digital information embedded in the natural surroundings. In addition, mobile devices can provide location-aware and digital layers of information, as is the case in Frequency 1550, as described below.

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Another way to bridge formal and informal learning happens when students carry mobile devices into the world to document, record, and share information related to their formal studies. For example, a first grade class in our AT&T Classroom that was studying body structures conducted cell phone interviews with a variety of "experts," including the farmer who provided eggs the class was hatching into chickens. One first grader remembered this while at the dentist, took advantage of his mother's cell phone to record an interview with the dentist regarding teeth and bones, and shared it with his classmates the next day (Kratcoski, Swan, & Campbell, 2006). Another example is the Frequency 1550 project (Waag Society, 2005), a scavenger hunt-like game using GPS-equipped cell phones that students use to download challenges, learn about Amsterdam's history, and create their own knowledge as they travel through the city.

Finally, as Vahey *et al.* note in this issue, mobile technologies can also help bridge public and private spheres, and social and individualized learning. Because these two learning domains have long been separated in theory and practice, developing activities that take advantage of mobile devices to seamlessly support both may be conceptually taxing, but could also have very important effects on learning.

Rethinking Pedagogy

Shifting or disappearing boundaries will obviously require changes in pedagogy, which can be defined as the art and science of teaching, the activities of educating, and the strategies, techniques, and approaches that teachers use to foster learning. To fully realize the educational potential of highly mobile devices, it is important that our understanding of pedagogy shift from a focus on teaching to a focus on learning. Teaching needs to be seen less as instruction, and more as the facilitation of personal and social learning.

Highly mobile devices enable learners to easily switch between learning individually and working collaboratively (Vahey, Tatar, & Roschelle, 2007), to access a wide variety of tools and information (McClintock, 1999), and to move flexibly among learning environments both within and outside of classrooms (Dieterle & Dede, 2007; Rogers & Price, 2007). Within such contexts, pedagogy can and should be customized with materials and strategies that are appropriate for individual students and student groups. The role of the teacher becomes similar to that of the conductor of an orchestra. The conductor's job is to bring together the disparate voices of the orchestra to give life to a common musical theme. Similarly, the role of a teacher in a ubiquitous computing environment is not only to support individual learning, but to blend individual learning into a shared class experience (Roschelle & Pea, 2002; Swan, Kratcoski, Schenker, Cook, & Lin, 2007).

Rethinking pedagogy is not easy. What would it mean to conduct learning in an environment where students have ubiquitous access to highly mobile technologies? It might begin with identifying learning goals, especially those goals involving what Wiggins and McTighe (2005) call "enduring understandings," as well as state standards. Clearly, such goals can be reached in many different ways. Teachers/conductors provide multiple ways in which students can demonstrate learning that meets given goals, and are open to students' alternative proposals. Teachers/conductors also find ways to share and blend students' individualized efforts to enhance the learning of all students. The important idea here is that there are many ways to get to the top of the mountain (to meet learning goals). In one sense, it only matters that one gets to the top, and individuals should be supported in finding ways that work for them. In another sense, we can all benefit from at least reflecting on the paths of others.

Conducting learning with highly mobile devices also involves designing and implementing authentically collaborative activities, projects that entail both positive interdependence and individual accountability in a real-world context (Johnson & Johnson, 1992). Positive interdependence makes all students in a group responsible for the learning of each group member; individual accountability makes each member responsible for their own learning as well.

Rethinking Curricula

A third way teaching must be reconsidered to make full use of highly mobile devices involves the curriculum. As McClintock (1999) suggests, we must rethink what knowledge is important and what it means to be literate in a digital world. Carvin (2006) writes that, "Literacy in the 21st century is all about participation: the ability to critically consume and create knowledge for the betterment of ourselves, our families, and our communities." Similarly, the Partnership for 21st Century Skills (2003) argues that the emphasis of No Child Left Behind on core subjects is not enough, but rather that students need to learn how to "appropriately use digital technology and communication tools to access, manage, integrate, and evaluate information, construct new knowledge, and communicate with others" (p. 6). Projects like Frequency 1550, MyArtSpace (Vavoula *et al.*, this issue) or Environmental Detectives (see Klopfer, this issue) are examples of how students can use technology to learn all of these skills, using up-to-date information and tools.

Therefore, if we are going to help our students become citizens of the 21st century, we need to rethink curricula to include the knowledge, skills, and attitudes our students need to be full and active participants. It means that we need to educate students:

- with 21st century content, which includes information that is digital, networked, and fluid;
- in 21st century contexts, including communication and collaboration that transcend spatial and temporal boundaries;
- with 21st century tools, which are increasingly mobile and connected.

Conclusion

We have entered an era in which mobile technologies are fundamentally changing our culture and impacting every aspect of our life, including how we learn. Knowing how to critically and strategically use them is becoming an ever-increasing part of being literate, as digital technologies have become the "pen and paper of our time, …the lens through which we experience much of our world" (Warlick, 2006), and the communication channels of choice for many. We need to consider how we can take advantage of the unique affordances of highly mobile devices to enhance learning, and at the same time explore and discuss the constraints mobile devices might put on our students. Only then will education truly prepare its students for the world that lies beyond…. □

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Using Handhelds to Link Private Cognition and Public Interaction

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This article discusses the importance of private interactions, in which a student works alone with learning materials, and public interactions, in which a group of students engage in discourse around learning materials. While traditional technology requires that designers choose one type of interaction over another, the authors show how handheld computers can be used to support both types of interaction, leading to increased learning.

The Individual and the Community: Two Approaches to Teaching and Learning

What is the goal of education? One view is that the primary goal of education is to increase the body of knowledge of individual students, each potentially working in isolation. Another view is that the main goal of education is to increase students' abilities to participate in important communities (such as the community of mathematicians or scientists), with the corollary that the particular knowledge possessed by any individual is of less importance than the "distributed knowledge" possessed by the group.

These two perspectives run throughout the educational arena: in theoretical journals we find the cognitivist versus the situative views; in policy debates we find "back to basics" versus teaching for collaboration and innovation; in assessment we find multiple-choice tests versus portfolios; and in technology we find computer-assisted instruction (CAI) versus collaborative groupware.

While there have been attempts to bring these views together, the schism remains. In this article, the use of handheld computers is shown to be a potential middle ground in which both of these goals not only can be met, but are complementary.

The Private and the Public: Two Types of Interactions

We posit that these two camps have remained separate largely due to the types of classroom *activities* that are possible using the technologies that have thus far been available (technologies include books and blackboards as well as electronic technologies such as televisions, calculators, and computers). In particular, we differentiate between two types of interactions available in activities: *private* interactions and *public* interactions (note that this article pertains mainly to face-to-face classroom activities, and not activities designed for distance education).

Private interactions with the environment are those interactions in which students engage with materials individually. To be truly private, the interactions with the environment must take place over an extended period of time (at least several minutes), without others being able to see or directly impact the interaction. When students work privately, they can work at their own pace and style, iterate on their work, take time to reflect on feedback, and avoid any embarrassment that may occur from other students viewing incomplete or incorrect work.

Public interactions with the environment are those interactions in which students engage in discourse (typically face-to-face) while they are engaged with materials. This discourse can occur in pairs, small groups, or whole-class discussions. When students work publicly, they participate in joint sense-making, are exposed to different perspectives, can build on each other's ideas, and learn to participate in a community of practice. They can even benefit from the reflection that occurs from the knowledge that others are (or will be) looking at and thinking about their work.

The benefits of both private and public interactions are clear. In fact, the learning goals appear complementary. However, creating learning activities that incorporate both is a significant challenge, due in large part to the technology available thus far.

When students are provided with desktop computers, two modes of use are typical. One is to put each student at his or her own computer, emphasizing private interaction. While students can talk to each other

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(typically by shouting over or around the computer displays), it is not a simple matter to engage in deep discussion about a student's work. This may require a student to physically move across the room to see the other student's screen, usually leaving his or her own work behind. Coordinating this type of collaboration in a class of 20–30 students is a significant classroom management challenge, as the isolation and size of each student's display makes the switch between private and public work difficult.

The other mode is to have small groups of students (typically two or three) share a single computer, emphasizing public interactions, as there is no way to privately interact with the technology. All actions and states are visible and therefore open to debate, commentary, and discussion. There is little time for individual reflection or experimentation with the environment.

Because the overhead of switching between public and private modes is considerable, the teacher or activity designer must choose one or the other for a given activity.

Implications for Handheld Computers

As alternatives to desktops, we have handheld computers, initially designed as personal computing devices. As a result, they allow students to engage with electronic materials, including complex interactive representations, in a *private* workspace. This allows students to interact privately with the materials, experimenting and reflecting as they see fit, without fear of interruption or embarrassment. Handhelds were also initially designed to allow sharing of information, and so they support infrared beaming and other simple forms of electronic communication. They are also small enough that they can be easily handed to another student, and multiple handheld screens can be put next to each other and viewed at the same time. These features allow students to engage with representations and ideas in a *public* space, collaborating and building joint understandings.

The true benefit of handheld computers, however, comes in the ability to support activities that allow students to seamlessly move between mainly private and mainly public interactions. Such activities have the potential to support students while they engage in tasks that are optimized to build their individual knowledge, while also supporting students as they learn to collaborate and participate in a community of learners.

Examples of Handheld Technology Use

To illustrate how handhelds can support seamless movement between public and private interactions we examine two examples: the large-scale Palm Education Pioneer (PEP) program, and a handheld-based implementation of SimCalc Mathworlds that we call NetCalc.

Palm Education Pioneers (PEP)

From October 2000 to September 2002, SRI International, in collaboration with Palm, Inc., conducted the Palm Education Pioneer (PEP) program. Through PEP we distributed classroom sets of handheld computers to 102 teachers throughout the United States via a competitive grant process. No requirements were specified in terms of content areas or grade levels. Instead, teachers were encouraged to create innovative projects in areas they felt were most appropriate, and as a result a wide variety of grade levels and subject areas were represented (for more on the PEP project, see Vahey & Crawford, 2002).

The teachers adopted handheld computers with enthusiasm. Approximately 90% said that handhelds were an effective instructional tool, and over 80% stated that the use of handhelds could improve the quality of learning activities (Vahey, Tatar, & Roschelle, 2007). While these numbers tell us that teachers felt that the use of handhelds was productive, they don't tell us how teachers and students used handhelds.

The data show that teachers found two very different benefits of handheld computers. The first was that handhelds allow for more personalization and student directed learning (84% of teachers). The second was that handhelds supported increased collaboration and cooperation (94% of teachers). We found this surprising, as we expected teachers working in such a short timeframe (they were typically reporting after only one school-year of use) to concentrate on one usage model before exploring other possible uses. Instead we found that teachers were able to exploit aspects of both private and public interactions simultaneously in their first year of use.

We analyzed teachers' written comments to provide detail about what they considered important in both collaborative and individual work. The answer was twofold: mobility and the easy exchange of information (typically through beaming). Teachers said:

- I loved seeing the students work cooperatively in teams and groups....This just wouldn't have happened if they were using pencil and paper or if they were seated in a permanent position in front of a PC.
- [Handhelds facilitate] more exchange of information, more documentation of tasks by students, more teaming projects.

Teachers also stated that mobility aided in individual learning, as did the availability of a personal computing device for each student:

- I see the students being able to take their thinking and work with [the handheld] right then. I see handhelds as being essential to helping that thought process along and in the place that the student is at.
- [Using handhelds results in] greater student

autonomy and accountability toward assignments and a greater sense of partnership in learning together (teacher and student).

We found these results from PEP intriguing: teachers, in the first year of use, found that handheld computers enabled both collaboration and autonomy. We then set out to investigate how we could leverage this result in the creation of handheld-based learning activities.

NetCalc

To leverage the benefits of handheld computers, we built upon an already proven educational intervention, SimCalc (Kaput & Roschelle, 1998; Roschelle *et al.,* 2000), in the creation of NetCalc. To achieve its goal of democratizing access to the Mathematics of Change and Variation, which is the foundation of Calculus (Kaput, 1994), SimCalc builds on three lines of innovation: restructuring the subject matter; grounding mathematical experience in students' existing understandings; and providing dynamic representations.

To exploit what is unique about handheld computers, we did not build a stripped-down version of desktop SimCalc. Instead our design was based on the principles of SimCalc, while keeping in mind what we learned from the PEP project. This work took place in parallel with the creation of a graphing-calculator version of SimCalc (Hegedus, this issue; Kaput & Hegedus, 2002). NetCalc was tested as a one-month replacement unit for an advanced eighth-grade mathematics class in an affluent San Francisco suburb.

While we created several activities in our NetCalc work, due to space limitations we only discuss Match-My-Graph, an activity designed for students using NetCalc (for more detail on this and other activities, see Vahey, Tatar, & Roschelle, 2004; Vahey, Tatar, & Roschelle, 2007). Match-My-Graph is a simple game that students play in pairs. One student, called the grapher, graphs a linear function that is hidden from the other student. The other student, called the matcher, attempts to match this function by graphing his or her own linear function and beaming it to the grapher. The grapher analyzes the two functions and, if they are not the same, provides a verbal clue to the matcher, which the matcher uses to make more refined guesses. An example is shown in Figure 1.

In this activity, students struggle to create and interpret clues such as "Mine is steeper," "You're going the wrong way," and "Yours is not as fast." While at first imprecise, students soon realize the importance of using precision in language, and also begin to construct a robust understanding of slope. We used the same activity structure in three separate instances, each designed to highlight an important mathematical topic.

This simple activity is illustrative of the ways in which the combinations of private and public interactions can be harnessed using handheld computers. In this activity it is vital that each student has a private screen. This private screen affords two key aspects of functionality. One is that it keeps the information of the grapher hidden. A second is that it allows both players to privately experiment with the simulations before making their contributions public. The public sharing of the matcher's graph is also key to the success of the activity. The aggregate representation that results from easily beaming the matcher's guess to the grapher's handheld allows the game to flow smoothly, and allows the private interactions necessary for the grapher. Finally, we note that this activity took place in a face-to-face setting. Students made significant use of gesture, nonverbal hints, and intonation when participating in this activity.

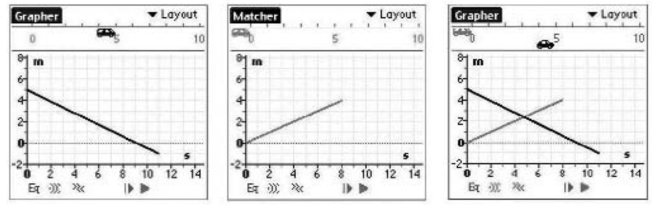

Figure 1. A sequence in Match-My-Graph. The Grapher generates a function, the Matcher generates a guess, which is beamed to the Grapher.

To analyze the effectiveness of the NetCalc activities, we turn to two data sources: classroom observations, and test results.

Classroom observations show that students playing "Match" engaged their peers and provided mathematically appropriate hints. Key indicators of engagement are the rate at which hints were provided and the content of hints. We videotaped four pairs of students in all "Match" activities, transcribed the videotapes, and coded all hints. Averaging over all three "Match" activities for all videotaped pairs, hints were delivered at a rate of one per minute (Vahey *et al.,* 2004). Students were actively engaged in this activity, as over 90% of student utterances were on topic (Tatar *et al.,* 2003). Finally, student hints were sensitive to the content of the representations, showing that the activity was successful in drawing students to collaborate about the intended mathematical ideas (Vahey *et al.,* 2004).

While an analysis of test results from the end of the unit does not allow us to make claims about the effectiveness of any given activity, such analysis is illustrative. As reported in Vahey *et al.* (2004), students did increase their proficiency in the mathematics of change and variation during the NetCalc curriculum. Furthermore, the NetCalc eighth-grade students performed better on AP Calculus items than high school students taking the AP exam, according to published test results (Vahey *et al.,* 2004).

Conclusions

Research has shown the importance of both private and public interactions with learning environments. Until now there has been little research on how to combine these two types of interactions. In this article, we showed that handheld computers can be used to support both public and private interactions, and presented examples of handheld use that combine the two and led to student learning gains in mathematics. □

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Teacher Uses of Highly Mobile Technologies: Probes and Podcasts

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This article introduces two contrasting ways of using highly mobile information technology for educational purposes. The first example uses mobile devices and scientific probes to gather information; the second uses a combination of mobile and desktop computers to disseminate it by way of podcasts. The examples also show that mobile devices complement, rather than replace, desktop computers.

Introduction

The history of computation is largely a history of miniaturization. From the four-function calculator of the seventies to the smart phone of today, mankind has consistently found ways to squeeze greater computational power into smaller and smaller containers. It was predictable that educators would take advantage of this trend, and they have. This article introduces two contrasting ways of using highly mobile information technology for educational purposes. The first example uses technology to gather information, the second to

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disseminate it. The examples also show that mobile devices complement, rather than replace, desktop computers.

Technology Enhanced Elementary and Middle School Science

Technology Enhanced Elementary and Middle School Science (TEEMSS2) is a project funded by the National Science Foundation (Grant No. IMD0352522) whose goal is to bring the power of information and communication technology to science education in grades 3–8. It does so by creating and disseminating valuable, proven, and easily implemented technology-based science learning materials and associated teacher professional development. The project is creating instructional materials that address important science content and can be easily and inexpensively integrated into any science program. It has selected age-appropriate, standards-based content for which technology offers real advantages (see Figure 1). The learning strategy is based on student investigations of real phenomena using sensors and of virtual environments based on computer models.

Standard	Grades 3-4	Grades 5-6	Grades 7-8
Inquiry	**1.** Sound Explore sound and vibrations **sensors:** microphone	**6.** Water and air temperature Mix fluids and measure temperature changes **sensors:** temperature	**11.** Air pressure Explore soda bottles, balloons and lungs **sensors:** gas pressure
Physical Science	**2.** Electricity Explore light bulbs, batteries, and wires **sensors:** voltage	**7.** Levers and machines Learn about and test your own simple machines **sensors:** force	**12.** Motion Graph, describe, and duplicate motion **sensors:** motion
Life Science	**3.** Sensing Compare electronic and human sensing of your environment **sensors:** temperature, light	**8.** Monitoring a living plant Monitor a living plant in a plastic bag **sensors:** relative humidity, light	**13.** Adaptation Explore population, selection pressure, and adaptation **sensors:** computer model
Earth and Space Science	**4.** Weather Observe and measure weather-related changes **sensors:** temperature, relative humidity	**9.** Seasons Connect planetary motion to day/night cycles and seasons **sensors:** light	**14.** Water cycle Study water phase changes and relate to terrestrial phenomena **sensors:** relative humidity, temperature
Technology and Engineering	**5.** Design a playground Study your playground and build models of several pieces of playground equipment **sensors:** force, motion	**10.** Design a greenhouse Build and monitor a working greenhouse model **sensors:** temperature, light, relative humidity	**15.** Design a measurement Choose something to measure and devise a way to do it **sensors:** temperature, light, force, motion, air pressure

Figure 1. TEEMS content by grade level.

The new materials take advantage of computers, sensors, handhelds, and electronic networking to more effectively teach students and give them deeper insights into the process of science inquiry. These educational technologies can significantly enhance science learning at elementary grades. They are particularly valuable at helping students to: investigate the natural world analytically; understand cause-and-effect relationships; visualize change; gain insights into the ways systems act; connect math, science, and technology; and explore emergent behavior.

The core of science is about investigating, exploring, asking questions, analyzing, and thinking—activities that these educational technologies are uniquely able to facilitate and deepen. They facilitate inquiry in four ways that are largely lacking in elementary science teaching:

- investigations of real events with sensors—a central activity of science;
- explorations using highly interactive models;
- electronic communication about investigations, which supports student reflection, thinking, and collaboration; and
- assessment embedded in learning activities, which gives teachers and researchers new ways to reveal student understanding.

Technology is an essential part of modern science, but it is rarely used in elementary and middle school science education. The project addresses this void and, in doing so, has the potential of improving elementary and secondary science education nationwide, particularly in under-resourced urban and rural schools, serving poor and diverse communities.

TEEMSS2 Tools

TEEMSS2 is producing 15 units keyed to the National Science Education Standards (NSES) that take full advantage of computers, sensors, and interactive models. Grade levels 3–4, 5–6, and 7–8 will have five units each, targeting the five NSES standards: Inquiry, Physical Science, Life Science, Earth and Space Science, and Technology and Design. Each unit contains two investigations, each with a discovery question, several trials, analysis, and further investigations. There is also a teacher's version of each investigation, which contains background materials and a discussion guide.

The TEEMSS2 activities are embedded in software (SensorPortfolio) that allows students to read the investigation, answer questions, collect data, analyze their results, and save their work within one application. It also allows the collection of formative and summative assessment data, which is readily available through online teacher reports in CCPortfolio. This tool is not specific to any manufacturer or platform. It is designed to work with whatever curriculum, computers, handhelds, and sensors schools may adopt.

TEEMSS Sampler

The following is a brief description of parts of two of the 15 TEEMSS units. The first is from initial experiments in a "Sensing" module in which grade 3–4 students compare temperatures and light levels they perceive with measurements using probes (see Figure 2). The second is part of a grade 7–8 motion unit. For access to these and all other activities, go to the project page at *http://teemss.concord.org/* , click on "try a sample activity," and select one of the hardware systems.

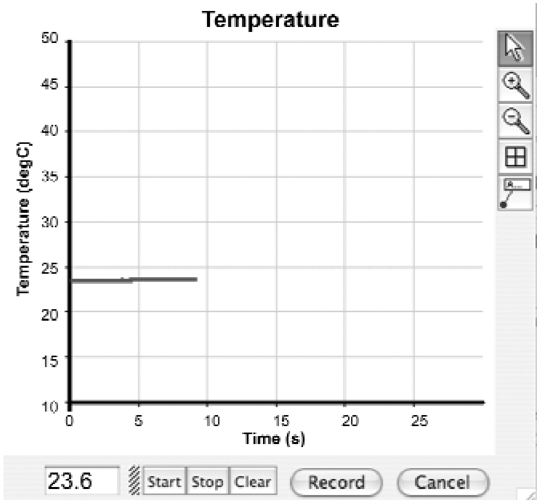


Figure 2. TEEMS2 temperature activity.

It is important to realize that TEEMSS2 works with eight different hardware systems, connected to most handhelds and full-sized computers. The technical hints built into each activity are specific to the hardware system selected. The illustrations are constrained in size so they are meaningful on the small screen of a handheld (see Figure 3).

Figure 3. Example of technical hint for temperature sensor.

The activities consist of steps in a platform called SensorPortfolio. When students launch an activity, they see a list of titles that link to steps that are specific to that activity. Some steps present material in a multimedia format. Another kind of step is the data tool that supports a sensor and graphs its output as shown at right. Yet other steps kinds include: embedded assessments that support multiple choice and open response items; a student portfolio for student products; and tools such as a notepad, sketchpad, table, and concept mapper.

The Sensing Module

The first activity in this unit asks students to measure air temperature. Clicking on a single-value data-collection icon opens a smaller popup window, allowing the students to collect temperature data and record a single value. Clicking the **Record** button closes the window and saves the last measured value.

Next, students are asked to measure their arm temperature. Once again a single-value data-collection graph is displayed and the last measured value is entered into the activity. Later in Trial 1, air temperature is measured again and the software displays the results of the earlier measurement and asks the students to do two things: first, the students have to calculate and enter the difference between the first and second measurements of air temperature; second, the students need to come up with an explanation of the difference in measurements. After finishing this section, students could see the screen, as shown in Figure 4.

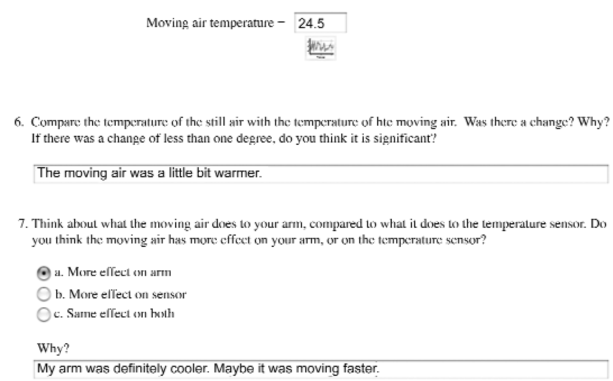


Figure 4. Measuring air temperature.

All of the data, writing, drawings, and assessments are saved in the student's portfolio. The portfolio is like a lab book that students can edit, turn into a report, and submit to the teacher. Teachers can use these reports to monitor class progress.

Later in Trial 2 (Feeling and Measuring Temperature Investigation) the authors use the Multiple Choice assessment capability. The teacher can see these data in an aggregate form.

The Motion Unit

The same graphing tool used to collect and display data from sensors can be used to record student predictions. An early activity in the Motion unit asks the student to draw their prediction of a graph of them walking away and walking back over 30 seconds as shown in Figure 5.

Figure 5. Predicting motion.

After making four predictions, students then collect data and compare the results to their predictions. A typical trial generated the bottom line in the graph in real time (see Figure 6). This provides a powerful medium where student can compare their mental models represented by the prediction to actual data.

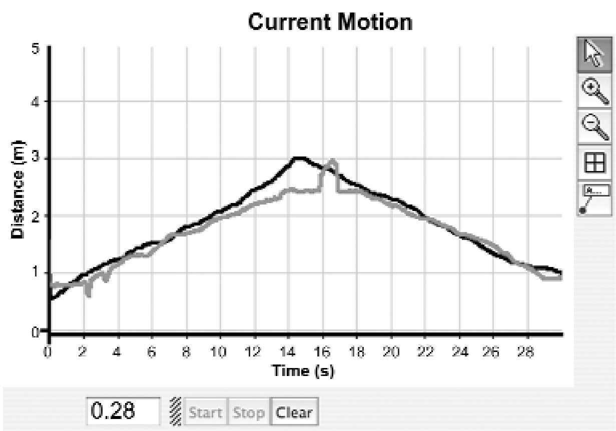
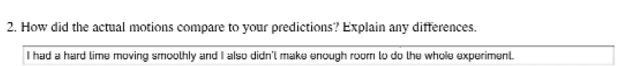


Figure 6. Motion trial.

Each prediction also includes an open-response essay question, asking students to reflect on their results and to explain the differences. A typical open-response item is shown in Figure 7.


2. How did the actual motions compare to your predictions? Explain any differences.

I had a hard time moving smoothly and I also didn't make enough room to do the whole experiment.

Figure 7. Open-response question.

Technical Hints

Throughout the activities are technical hints that jump to detailed and carefully illustrated explanations and directions. While the main activities are generic and apply to all senor systems, the technical hints are specific to the sensor system that the student is using. For instance, Figure 8 shows one of five illustrations for connecting the PASCO motion detector for the motion unit.

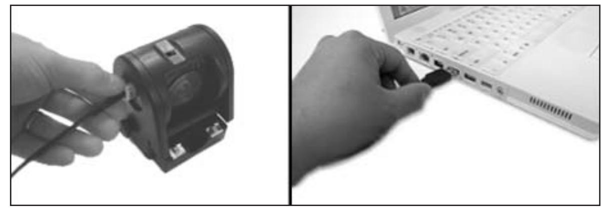


Figure 8. Connecting the PASCO motion detector.

If you have any questions concerning TEEMSS2, please contact *teemss2@concord.org* .

For Kids, By Kids: The Our City Podcast

A second example of highly mobile technologies, in combination with audio and video editing software, is podcasting. Podcasting is a powerful tool for educators to get students involved in activities that are meaningful, integrative, value-based, challenging, and active (NCSS, 1998). We all know how important it is to get students involved in their own learning. Today's Net Generation is very connected and technology-savvy, and sees technology as an essential part of their lives (Education Evolving, 2005; Lenhart, Madden, & Hitlin, 2005; NetDay, 2005). Therefore, digital tools can and should play an important role in learning (Daly, 2005; van 't Hooft & Swan, 2007). Podcasting is one such tool, and the Our City Podcast Project is a perfect example of how kids can learn from other kids. In this case, kids create podcasts about the places in which they live, using digital tools they know and use as a part of their everyday lives. Podcasting allows students to share what they've learned with a global audience.

So, what exactly is a podcast? It is an audio or video file that is posted on the Web, can easily be cataloged, and automatically downloaded to a computer or portable device. That means that once audio or video has been published online, anybody can search and browse for it. Currently, the Our City podcasts are distributed to hundreds of users who subscribe to the program. The file is stored on subscribers' computers to be listened to at their convenience.

Because students are working on something meaningful and motivating, they are engaged in every aspect of producing a podcast. They believe their work is important because they have a real audience outside of the classroom. In fact, the Omaha episode of the Our City Podcast is listed in the iTunes Music Store, just three clicks away from music by Green Day and television shows like Friends. As a result, the students have carefully edited out mistakes, and added catchy music and transitions to make the podcasts sound professional and entertaining (see Figure 9).

Figure 9. Our City Podcast.

There are several steps to producing a podcast. The required software and equipment can cost little to nothing. Many teachers probably already have the equipment they need (computer, headphones, and microphone), and the software (e.g., Audacity) is free. The process plays out as follows:

- *Preproduction:* students plan the podcast, write scripts, and practice speaking (see Figure 10). This is where learning happens. Students divide up the podcast in segments, conduct research, and explain what they know and learned in ways that listeners can understand.

Figure 10. Podcasting: Preproduction phase.

- *Recording:* If students have practiced reciting their scripts, recording takes very little time at all. What's nice about software like Audacity is that mistakes can be edited out after all the recording is done. Also, recordings can be made in short portions, and does not have to be done in the right order. See Figure 11.

Figure 11. Podcasting: Recording phase.

- *Postproduction:* Audio segments are arranged into the proper order and sound effects and music can be inserted. Volume levels are adjusted and all audio is edited. After the recording is perfected, the audio is converted into the appropriate file format.
- *Publishing*. First, the file must be placed on the Web by placing it on a Web server. Once on the server, the MP3 file has its own Web address (a URL). Next, the podcast needs a Web page or blog associated with it to post a link to the MP3 file so that Web surfers can listen to it right inside their browsers or download it to their mobile devices.
- *Creating an RSS feed (optional)*. At this point, the podcast is merely a media file posted on the Web. However, it can be catalogued and programmed for automatic download. This is done through RSS, or "Really Simple Syndication." An RSS feed is really a specialized Web page written in XML code, and can be created using wysiwyg software like FeedForAll. The RSS code includes information about the podcast, including links to audio or video files, and when the podcast was last updated. Feed aggregators like iTunes, SharpReader, or FeedReader periodically check the RSS feed to see when it was last updated. If the RSS code has been updated since the last check, the aggregator downloads the new podcast episodes.

There are currently over 30,000 podcasts available online, and that number grows daily. Podcasts can be found in directories like the Education Podcast Network, Podcast Alley, and Yahoo! Podcasts. Most directories have a category for educational podcasts, but with tens of thousands of programs, there are podcasts about almost every subject you can think of, and some searching and sorting may be required. Also, podcasts are not regulated by the FCC, so explicit adult programming could be mixed in with other content.

Conclusions

Just as the desktop overshadowed the mainframe, are handheld devices destined to replace the desktop computer? Not necessarily. While handheld technology is playing an ever more important role in educational settings, the small screen and miniature keyboards available on current handhelds pose inherent limitations. Consequently, rather than making desktops obsolete, highly mobile devices have created new and important roles for them, and the two form factors are complementary, rather than exclusive. The educational desktop computer may emulate the agora of Athens and evolve into a computational meeting place, a shared focal point where students pool their data, show off their productions, and learn together. Highly mobile technologies are creating the learning opportunities for desktops that wouldn't be possible without them. □

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Classroom Connectivity: Increasing Participation and Understanding Inside the Classroom

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This article shows how highly mobile computing, when used with new forms of network connectivity, can allow new forms of activities in the mathematics classroom. Examples are provided, such as the ability to share, harvest, and aggregate mathematical objects, and the ability for teachers and students to analyze the entire set of classroom contributions.

Working and interacting on a network are quite familiar activities for most teenagers nowadays, from browsing the Web and instant messaging, to connecting in chat rooms and playing games with friends. A common feature of such activities is that the network is a technical infrastructure that connects information or people together from remote locations. The users reach outside their local, private workspaces to a web of possible information and interaction. This is a fairly disparate activity relying on search engines and directories to find what we are looking for in a disconnected, non-ordered set of people and resources. The infrastructure of the Internet, i.e., the physical wires, servers, and engines to search information, as well as the communication mechanisms that help people connect, is what orders the whole enterprise.

Now let us turn to the classroom. Most classrooms have computers that are connected to the Internet so that students can access information outside of their classroom environment. But this is not the only use of networks. Networks can be embedded in the classroom.

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They can be instantiated into the communication and participatory infrastructures of the classroom, creating new possibilities for learning and teaching. In this article, we focus on two complementary technologies:

- **TI-Navigator** from Texas Instruments, used to connect graphing calculators to a teacher computer via a wireless network. In this case, the network is closed; it does not connect to the Internet, but it facilitates interesting forms of interaction between multiple agents inside the classroom;
- **SimCalc MathWorlds**, a dynamic, interactive visualization environment that links representations of functions to each other and to simulations. Our latest innovation allows students' work to be aggregated into parallel software on a desktop computer, allowing each class member to be part of a larger set of varying mathematical objects (see *www.simcalc.umassd.edu* for more details and dynamic visuals).

With such a network (see Figure 1 for pictures of how the network can be set up) the hardware allows a more at-hand and mobile educational experience. We describe how such a physical set-up can have a powerful impact on the educational landscape of the classroom, affecting the learning experience into one that is more personal and meaningful, and enhancing participation in ways that allow students to learn about the structure of mathematics through the examination, comparison, and contrast of their work with each other. Active participants are not only students and teachers, but also our interactive and highly visual software environment that operates on top of a highly flexible network. We describe particular features of this environment and highlight some core examples of mathematical activities that transform the educational experiences in classrooms consisting of students of mixed personalities and abilities.

Figure 1. TI Navigator set-up.

The heart of these classrooms is a distributed form of computing using curriculum activities that exploit the mobility of such networks. More importantly, however, is a focus on the natural, distributed nature of multiple learners in a classroom. A typical class might have 25 students, and it is hard to know how every student is thinking or responding to a single question or statement that a teacher might make at a particular time. How a teachers interacts, and how a student responds, can be dictated by classroom beliefs and norms, including social norms that students or society create outside the classroom. Using our networked materials, we have begun to observe interesting shifts in the way students fundamentally interact. As their work becomes digital and projected into a public workspace, forms of participation can cut across existing norms. For example, the loudest, most confident, or brightest child is suddenly not necessarily the most frequent speaker.

Traditionally, the locus of knowledge and the domain experts are located outside the classroom—even with textbooks—so knowledge is not personalized for the classroom environment, and the participants, including the teacher and the technology, are foreign to the classroom where external artifacts of knowledge are used. We now describe how this historic form of teaching and learning can be transformed into something that is more personal and social *inside* the classroom, and where the knowledge authority can become a distributed agency.

The SimCalc Research Project

Since early 1999, when prototypes from Texas Instruments became initially available, the SimCalc Research Project at the University of Massachusetts Dartmouth has been studying the profound potential of combining the representational innovations made possible by the computational medium (Kaput & Roschelle, 1998; Roschelle *et al.*, 1998), with the new connectivity affordances of increasingly robust and inexpensive hand-held devices in wireless networks linked to larger computers (Kaput, 2002; Kaput & Hegedus, 2002; Roschelle & Pea, 2002). We developed software that works on several platforms called SimCalc MathWorlds. With such software, students can contribute mathematical functions created on their own personal TI-graphing calculator to a teacher computer via a wireless network that is operating parallel software to publicly display and analyze, in concert, the work of students.

We have addressed the Mathematics of Change and Variation, a core school mathematics strand (NCTM, 2000) that is representationally demanding, that is studied at many levels by all students from Pre-Algebra through Calculus (Kaput, 1994), and that can serve to energize and contextualize the core ideas of algebra in ways that lay a conceptual base for Calculus (Kaput & Roschelle, 1998).

We soon realized that we were not just dealing with networks but new forms of connectivity that we called Classroom Connectivity (CC) as it tapped into the social, cognitive, and physical set-up of the classroom. CC has earlier roots in classroom response systems, most notably **ClassTalk** (Abrahamson, 1998), which enabled instructors to collect, aggregate, and display (often as histograms) student responses to questions, and, in so doing, create new levels of interaction in large classes in various domains (Burnstein & Lederman, 2001; Crouch & Mazur, 2001) and levels (Hartline, 1997). Roschelle *et al*. (2006) show remarkably consistent, positive impacts across multiple domains and levels. However, major new CC affordances beyond classroom response systems that we studied are as follows:

(1) The mobility of multiple representations of mathematical objects such as functions is reflected in the ability to pass them bi-directionally and flexibly between teacher and students and among students, using multiple device-types.
(2) The ability exists to flexibly harvest, aggregate, manipulate, and display to the whole classroom representationally-rich student constructions, and to broadcast mathematical objects to the class (provided appropriately designed software is available).
(3) Thanks to the at-handedness of handhelds, we are able to do (2) in ways that build upon naturally occurring social and participation structures.
(4) The opportunity is present to engineer entirely novel classroom activity structures, in concert with the mathematics to be taught and learned that engage students in new and powerful ways.
(5) Teachers can arrange, organize, and analyze sets of whole-class contributions at once, and students can make sense of their work in a social context, reasoning and generalizing about their contribution with respect to their peers' work.

We will use the work of our research and development project to demonstrate and exemplify the educational perspective for in-classroom education for establishing "networked" environments. We highlight how these can allow students to develop intuition, generalize and reason from collaborative private-to-public work.

Highly mobile environments need some stability. We think of a desktop computer that has more computational power but less mobility than handheld devices to provide a root to the distribution and management of digital activities in a classroom, as is the case with larger, scaled-up Internet services.

Hence, we built two versions of SimCalc MathWorlds; one of them runs on the TI-83/84+ graphing calculators as a Flash ROM application, the other runs as a cross-platform Java Application. Adding Flash ROM to graphing calculators resulted in a device that allowed third-party development of executable applications, so a calculator has become a handheld computer! Adding a serial port made it a communication device. Originally, this allowed one to download objects and files from a desktop computer, or simply to back up programs. Now, the TI-Navigator system allows one to plug into hubs that wirelessly communicate via a closed LAN within a classroom. In essence, this is a server-terminal model where the teacher computer as server becomes a central processing unit to distribute files and collect work from students' calculators. Hence, highly volatile and mobile forms of data transfer can occur as a student's function (for example) gets projected from a low-resolution, black-and-white screen to a high-resolution, full-digital image, displayed through a computer projector onto a whiteboard for public viewing and analysis, with all the mathematical representations and software attributes preserved.

Activities based on this type of networked technology can unleash multiple forms of expressivity linked to the nature of the activity teachers ask their students to perform. The activities we have created are highly stylized, to using the network from a personal or small-group activity to a public, whole-class event. We outline one activity structure below to illustrate how core algebra ideas can be introduced in a way that lays the foundation for access to Calculus ideas, particularly the Mathematics of Change and Variation. Our activity structures are at the core of our innovation that are designed to increase understanding of functions and variation by allowing students to be intimately involved with the mathematical objects that *they* create.

Example: The Case of a Function

SimCalc MathWorlds creates an environment in which students can be part of a *family of functions*, and their work contributes to the mathematical variation across this mathematical object. Consider this simple activity, which exemplifies a wider set of activity structures: Students are in numbered groups. Students must create a motion (algebraically or graphically) that goes at a speed equal to their group number for 6 seconds. So, Group 1 creates the same function, $Y = (1)X$, Group 2, $Y = (2)X$, etc. When the functions are aggregated across the network via our software, students' work becomes contextualized into a family of functions described algebraically by $Y = MX$ (see Figure 2). Students are creating a variation of slope and in doing so this can help each student focus on their own personal contribution within a set of functions.

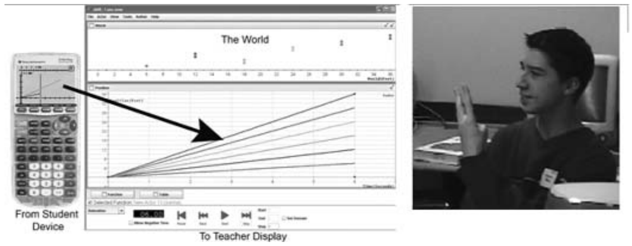

Figure 2. Sample function in SimCalc MathWorlds.

At the heart of SimCalc MathWorlds is a pedagogical tool to manage classroom flow. This tool has been developed based upon classroom research and experimentation and observing teachers' use of the system over several years. The classroom management tool allows teachers to control who is connected to the teacher computer using a simple user interface, and choose when to "freeze" the network and aggregate students' work or allow students to send a number of tries via the TI Navigator (see Figure 3).

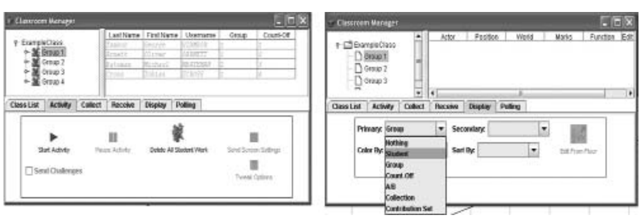

Figure 3. The SimCalc MathWorlds classroom management tool.

In addition, teachers have control over which set of contributions (e.g., Group 1's functions) and which representational perspectives (e.g., tables, graphs, motions) to show or hide. Thus, the management tool encapsulates a significant set of pedagogical strategies supported by question types in existing curriculum materials to satisfy a variety of pedagogical needs, focus students' attention depending on their progress, and promote discussion, reasoning, and generalization in a progressive way at the public level. For example, teachers can ask the question: What do you expect to see in the World when everyone's function is aggregated? The World is an aggregation of the simulations of actors which move corresponding to the position-time graphs students have created. They can continue to ask questions that focus attention on the Mathematics of Change and Variation in the aggregation: What will the motions look like for Group 1? What will the graphs look like for Group 2? What will the graphs look like for the whole class? Teachers can progressively show each set of work, following conjectures made by the class, developing reasoning and generalization based upon students' personal or group-based contributions.

In our present research, students build meaning about the overall shape of the graphs and have demonstrated gestures and metaphorical responses in front of the class when working on this activity. For example, in two entirely different schools, students have raised their hand with fingers stretched out, and said it would look like a "fan." In this socially-rich context, students appear to develop meaning through verbal and physical expressions, which we observe as a highly powerful way of students engaging and developing mathematical understanding at a whole group level. We have studied forms of participation both in terms of how each student is part of a collective mathematical object, examinable by a teacher, as well as the interaction cycles between students and their peers and the teacher. Such examination has enabled us to begin to develop pedagogical strategies and accompanying instructional materials to support the teacher in implementing and facilitating mathematically-rich discussion that such a connected environments provides. This is at the heart of our existing materials and pedagogical approach that make them significantly different from traditional curriculum.

Conclusions: Implications for Future Educational Software and Curriculum Design

We conclude with some statements about the design of such systems and the educational opportunities for deep, sustained mathematical learning in the future.

It is evident in our present work that across moderate periods of use (8–10 weeks) students who use our CC software and curriculum perform significantly better on sets of standardized test items (from high stakes state examinations that we compiled) versus groups of students without the intervention. We also noted significant shifts in certain types of attitude from pre to post, such as a preference to work alone versus working in groups. We have begun to see new forms of participation in these types of classrooms. Participation has often been analyzed with respect to how and in what ways students talk, but we are also examining how students use metaphors and gestures to express their ideas, and how these forms of expression are tightly linked to the nature of the mathematical activity and the visual feedback through the public display.

The SimCalc software team took a grounded, iterative design approach over several years, where classroom observation and empirical data helped inform future design and software revisions. A core philosophy was to focus on curriculum and ask what types of mathematics can be discovered in new and innovative ways using classroom connectivity that can have a deep and sustained impact on students' mathematical ability, impacting not only their attitudes towards the role of mathematics in their education but also their ability to see a longitudinal, connected perspective of mathematical ideas develop across the grades—hence, our focus on the Mathematics of Change and Variation.

Our activity structures not only exploit the infrastructure provided by the classroom network, but also provide collaborative learning experiences in mathematically meaningful ways. They are highly stylized and constrained to a particular set of curriculum and pedagogical objectives per activity, with activity variations available to the teacher as allowed by a curriculum developer. In this sense the teacher is assisted in a supportive way to focus on only what is necessary, as opposed to what potentially could be a combinatorial nightmare of data objects, student contributions, and representations.

The role of technology here is not in the form of a prosthetic device where the software or hardware supports the existing practices of the teacher. Technology instead transforms the communicative heart of the mathematics classroom. Allowing students to build and see the structure of mathematical objects, i.e., a family of functions versus a static single function, enables students to make deeper links with the mathematics. In addition, the technology has a more fundamentally participatory role, as one that offers feedback through dynamic, executable procedures. Teachers can hide and progressively show groups of student work to expose the underlying structure. The technology becomes a partner with the teacher at a public level to support emergence of ideas, support or refute conjectures made by students at the whole class level, and guide, as well as be guided by, the software at a local, personal level, as students interact and explore dynamic links between graphs, simulations, and each other's thoughts.

Finally, mobility now transcends the physical at-handedness of "small" devices to a model that also includes wireless and "invisible" connections of ideas in meaningful ways; a true sign of how learners, educators, and digital technologies of different forms can co-exist and collaborate in the future. □

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What Happens to "Writing Across the Curriculum" with Handheld Devices?

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This article presents findings from research in a school district using handhelds to support writing across the curriculum. The authors report that handheld devices can be useful to foster classroom note-taking activities, assist students who have handwriting difficulties, and provide inspiration to teachers who want to create collaborative and creative writing activities for students. Guidance for educators and technology designers is also given.

In 2003, as district administrators in one Oklahoma City suburb reviewed their slumping test scores, they decided to try a bold experiment: Use mobile computing to kick-start an educational reform program of "writing across the curriculum." The curriculum team put the experiment into action with a $1-million federal grant through the Oklahoma State Department of Education. They distributed Palm OS handheld devices and keyboards to teachers in multiple core subjects in two middle schools and one high school in Putnam City, OK. They purchased a license for a suite of educational software tools through the Michigan-based GoKnow mobile computing software company (*http://www.goknow.com/*) that supports a variety of instructional activities—writing, reading, visualizing scientific phenomena, collecting data in science labs, and tracking student homework and grades.

After the grant ran out three years later, district curriculum leaders saw that a rudimentary handheld word processing program called FreeWrite was fairly regularly used by teachers in two subject areas—science and language arts. These teachers had students use the software by attaching keyboards to the handheld devices. The district asked SRI to find out how the teachers were using the tools for writing.

The theoretical and empirical research supporting the use of word processing tools for "writing across the curriculum" was promising. Computers can provide a motivating context for engaging students in writing (Warschauer, 1996). A meta-analysis of 32 word processing and writing studies indicated such tools simplify editing and allow teachers to use more collaborative forms of instruction (Bangert-Drowns, 1993). Students gain a new way of conceptualizing written text, as "a fluid and easily transformed communication," similar to thinking and speaking (Bangert-Drowns, 1993, p. 72). Another extensive review indicated that word processing tools seem particularly well-suited to what is called "process writing," which engages students in various stages of planning, rewriting, and recopying drafts (Cochran-Smith, 1991).

The recent introduction of handheld computational devices into classrooms presented a new opportunity for innovative writing instruction (Tatar, Roschelle, Vahey, & Penuel, 2003), potentially providing classrooms with a broader range of writing tools and activities. Further, using handheld devices to support "writing across the curriculum" was consistent with constructivist theories, noting that when students write, they may actively make sense of what they learn, when properly supported (Scardamalia, Bereiter, & Goleman, 1982). Some researchers have argued that giving students different types of writing tools in science class provides them with more opportunities to learn (Prain & Hand, 1999). Writing in science class, for example, makes student thinking visible and may help students "connect, organize, reflect, and extend" new information (Miller & Calfee, 2004) or reflect on their science labs (Davis, 2003; Gertzman & Kolodner, 1996). Empirical studies of teachers using handhelds for word processing have shown that such devices can improve student motivation by increasing student

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choice and control over the writing tools they use (Teacher Training Agency, 2001), especially when provided keyboards to assist with text input (Vahey & Crawford, 2002).

In this article, we review what district leaders in Putnam City learned about how mobile computing may be used to support writing in language arts and science classes. We briefly discuss four key findings:

- Handheld screens were too small for complex process or product writing and editing, but sufficient for simple note taking. Even so, storage and retrieval of notes was sometimes challenging.
- Handheld-using teachers reported creating more collaborative lessons compared to teachers not using handhelds. They were observed engaging students in more collaborative writing and focused note taking than the non-handheld teachers, who relied more in individual tasks and worksheets.
- Handhelds remained compelling to use when teachers and students framed them as a way to make note taking easier and render notes more legible.
- Handheld use did not affect the quality of student writing.

Finding 1: Handheld screens supported note taking, but not extended process or product writing. The Putnam schools were using a variety of PalmOS devices (M105, M130, M505, and Zire 31), which have screens slightly smaller than a Post-It note. The square screen can accommodate a dozen or so lines of text, each containing about 30 characters. Given such a tiny space, teachers observed that students tended to write less on the handhelds than they did on paper. The primary difficulty was in scrolling to edit and backtrack through their written work: the small screen did not provide enough space for students to do this effectively.

The word processor FreeWrite included some advanced software features to alleviate some of the disadvantages of the small screen. For instance, FreeWrite gives students and teachers the capability to review and edit text by sharing edited documents through infrared beaming or by uploading text to a desktop computer. Putnam City teachers and students rarely used these features. In our study, we gathered weekly log data from teachers in both handheld classes and non-handheld classes to find out how—and how many minutes per week—their students engaged in writing activities, including note taking, process writing, and product writing. We chose these writing categories because the research literature suggested word processing tools support process writing, so we expected to see higher levels of process writing in handheld classes. However, we also felt that the small screen size might limit the tool's utility for real process writing, so we added a "note-taking" category to capture another use more focused on recording information than editing it. Our data showed less process writing and much more note taking in the handheld language arts class than the non-handheld class. We found Putnam City's one handheld-using language arts teacher quickly limited the use of the tools to note taking only. This teacher devoted six times as much classroom time to note taking than her non-handheld-using colleagues, who were spending much of that time on individualized short writing activities. This focus on note taking was not unique to this one teacher: three science teachers who used handhelds reported devoting 33% more time on note taking than their non-handheld-using colleagues.

While teachers found advantages to using the handhelds for note taking, students often had trouble finding their notes because they had to scroll down through many small-screen pages, and printouts were not formatted for easy reading.

Finding 2: Handhelds supported teachers' interest in collaborative lessons. In our study, we also asked teachers to keep a record of the amount of time per week that students worked on individual or collaborative writing activities for a period of 14 weeks. We found that teachers who integrated the handhelds into their classes reported engaging their students more in collaborative writing lessons than non-handheld teachers. The participating handheld language arts teacher reported collaborative writing lessons during eight of the 14 weeks of classes compared to only three weeks for the three non-handheld language arts teachers. The three handheld science teachers reported collaborative writing lessons during five weeks of classes compared to only one week for the two non-handheld science teachers. Overall, there was more collaboration in handheld classes in note-taking, process writing, and product writing.

In observations, we also saw differences in the nature of the writing assignments in handheld and non-handheld classes. Teachers who did not use handhelds typically had students writing on worksheets. In contrast, handheld teachers engaged students in focused note-taking in English class and a couple of creative writing exercises in science. For example, the handheld language arts teacher involved her students in a whole-class reading comprehension activity during which she encouraged students to note questions and vocabulary terms on their devices or on paper while she read aloud. One handheld science teacher involved students in a writing activity to assess how well they could apply the terminology of the physics of motion to a story they wrote about a roller coaster ride. Another handheld science teacher prepared students for an upcoming chapter on soil by asking them to write briefly on their devices about their recent readings of a poem about Oklahoma's Dust Bowl era.

Finding 3: Student engagement with the handhelds remained high if the tools were framed as assistive note taking devices. Teachers gave mixed reports on how much the handheld devices improved student engagement, but consistently endorsed the tools as a way to involve students with penmanship difficulties while note taking. With respect to student engagement, two of the science teachers reported that their students continued to see the handhelds as inherently interesting after 14 weeks of use, but two other handheld-using teachers reported that the novelty wore off and the devices became just another school supply. When the novelty declined, handheld teachers who let their students bring the devices home reported problems with students forgetting to bring them to school. In contrast, even after 14 weeks of use, all teachers reported the devices continued to be relevant to students with handwriting difficulties. Teachers reported some students preferred using the devices, which helped make their work more legible. These results suggest that the way teachers framed the usefulness of the handheld devices affected students' engagement around them.

Finding 4: Handhelds did not support student writing quality more than typical classroom activities. SRI International developed a study to measure improvement in student writing and the quality of teachers' writing assignments. Student writing samples were gathered from up to nine teacher-nominated students per class in December and late April. Teachers selected three trios of students representing writers—three who were performing above grade level, three at grade level, and three below grade level. The writing samples were scored by an expert according to a rubric that rates how much student writing reflects—and teacher assignments require—higher level thinking. We used this rubric because literature suggested that students might be using the word processing tools for "process writing" in language arts and "laboratory report writing" in science, which, in theory, are activities involving high level thinking. The expert scored 226 valid writing samples (70% response rate) blind to time of collection (December, April).

The expert also rated the quality of teachers' writing assignments, focusing on the demands they made on students for higher-order synthesis, evaluation, and analysis. Further, to validate teachers' ratings of students' writing ability, we engaged the students in a 10-minute writing benchmark at the end of the year that was also scored by raters using an established rubric. As mentioned before, most handheld teachers were not using the tools for process writing but note taking, so one of the preconditions that informed our use of this scoring rubric was not met in practice. We also found that teachers' assignments for both language arts and science made only weak demands on students, focusing primarily on reproduction of knowledge with minimal interpretation, analysis, synthesis, or evaluation. For example, we found no assignments that asked students to construct a solid argument or compose an extended piece of creative writing. Most of the assignments asked students to report information from another source or respond to a few short questions. As a result, we saw no statistically significant improvement in samples of student writing from December 2005 and April 2006 in either the handheld or non-handheld classes.

Conclusions

Our work in Putnam City shows that handheld devices can be useful to foster classroom note-taking activities, assist students who have handwriting difficulties, and provide inspiration to teachers who enjoy experimenting with lesson design that involves more collaborative and creative writing activities for students. Our study also indicates that handhelds appear to be associated with greater use of collaborative writing activities in note taking, process writing, and product writing, but some of our data suggest that preferences for collaborative writing reside largely with the teacher, not the device.

Our work also suggests some ways to guide teachers to get the most value from handheld-based writing devices. Before using handhelds in their classes, teachers should test the word processing software to ensure it offers an easy way for students to navigate, edit, and share multiple versions of text. When teachers do not feel the software permits ease with these features, our study indicates they will use handheld devices primarily for basic note taking, rather than process or product writing of long papers. Also, to ensure lasting student engagement, it may be helpful for the teacher to frame the tools as an easier way to write legibly.

In the future, educational technology developers and educators may want to examine further how to improve the tools for purposes of note taking, handwriting assistance, and collaborative lesson design. The area of student note taking has been studied little, but holds much promise for formative assessment about what students already know when they come to a class and how they make sense of what they learn. Further, note taking often includes diagrams and sketches, and seeing how to integrate multiple forms of representation in the handheld note-taking context would also be worthwhile. Second, some students found the tools to be a good way to produce legible notes.

Future research might explore how to improve handheld word processing software to offer such students and their teachers more choice in writing templates and print layouts.

Finally, teachers who enjoy experimenting with new materials and tools may find such tools a particularly rich source for reflection on their own practices and student learning. These tools could be developed further to help teachers integrate them into lessons and use the data collected in them more powerfully for instruction and assessment. □

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Can Handhelds Make a Difference? Lessons Learned from Large and Small Scale Implementations

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The emergence of mobile technologies has afforded educators new ways of thinking about teaching and learning. When mobile technologies target specific instructional initiatives, they become lifelong learning tools for students and an integral part of the learning process. The key to success is creating logical and meaningful connections between students, teachers, technologies, and professional development.

"I have never seen a technology initiative create student-centered classrooms like these handhelds," proclaims Danielle Gustafson, an administrator for Joliet 86 School District in Illinois. With notable increases in student scores on local and state assessments, this district, with 69% of its students from low-income families, is in the fifth year of funding handheld classrooms. Increases in student achievement were not only touted by this elementary district; 36 other elementary and high school districts in northern in Illinois involved in the No Child Left Behind (NCLB) grant, *Bridging the Disconnects,* achieved statistically significant increases in reading, social studies, and science scores during a multi-year handheld project.

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Why Were These Projects Successful?

It all starts with asking the right questions for guiding and sustaining a mobile technology initiative. There are common questions that educators ask about mobile tools as they seek and acquire funding. Which device should be purchased? Palm or Pocket PC? Is a keyboard needed? What software should be used? What about wireless? What staff development is needed? Are handhelds really cost-effective? Should students share devices? A results-driven project generates additional questions, worth visiting first in planning. Examples are: How will mobile tools support learning? How will handhelds help reading and math scores? The design and implementation of successful mobile technology initiatives focus on instructional initiatives and research-based strategies for increasing student achievement.

Any implementation of mobile technology must stage itself from the learning platform, and have learning goals. To get results it is best to specifically link large or small scale mobile initiatives to a specific learning target. Some examples include supporting reading strategies in science or social science to extend reading instruction; utilizing handhelds in the math classroom to focus on number representations and relationships; or applying them in the language arts classroom to help students with process writing skills. Defining specific learning targets will increase the chances that a handheld initiative will be successful.

For example, our expertise and experience with designing and implementing mobile tool initiatives includes over 3,000 students with handhelds and hundreds of teachers, administrators, and technology support personnel in 40 school districts over the past five years. When administrators representing many school districts organized to develop an implementation plan for an NCLB grant, they identified a common learning target for extending the teaching of reading as the first step in planning. They determined that science and social science teachers would focus on embedding reading strategies in instruction using handhelds to increase reading comprehension and content understanding. Another district looking to increase student writing scores mobilized for the use of handhelds in a 6 + 1 *Trait Writing* (NWREL, 2001) initiative, while a school improvement goal for another school aligned their handheld use to support strategies for *Classroom Instruction That Works* (Marzano, Pickering, & Pollock, 2001).

What Tools Can Be Used to Measure Impact?

Once the learning focus is defined, the second consideration must be about measuring the project's impact on student learning. No matter the funding source for your initiative (a $3 million dollar NCLB grant, a local school or district source, or a private grant), determining the impact of the implementation should be clearly defined for student learning. In many cases student scores are used to measure the impact of a project involving technology, yet professional development and student use are loosely centered around "students using the technology," "technology use in a subject area," or "designing some subject activities with technology." This is exactly why a discussion is needed about what tools will be used for gathering data to gauge impact. Clear learning targets should match assessment tools whose evidence will provide a useful snapshot of progress toward meeting project goals. Consider going beyond using student scores on local or state assessments to gauge the success of an initiative. It may be beneficial to look at tools to measure student engagement, technology literacy, and instructional practices. Sometimes the impact on student learning may be the changes in learning activities with handhelds, promoting higher-level thinking, collaboration, and reflection in learning. In other instances, the portability of mobile device can extend learning with digital tools beyond the classroom and the school day.

With the project goals and assessments clearly defined, school districts can make detailed decisions about professional development, teachers and students involved, and appropriate mobile devices. Here, we attempt to highlight some notable tips extracted from the knowledge, experience, and best practices gained from many large and small scale mobile tool implementations. These should help bring about more informed decisions in planning efforts.

What Should Professional Development Look Like?

It is easy to underestimate the amount of professional development needed to fully integrate handhelds in learning, and sometimes the learning target gets lost because of time constraints. Small device does not translate into little professional development. In the Gower School District (Burr Ridge, Illinois) Superintendent Steve Griesback decided to use Pocket PCs to support writing in the middle school. Professional development was limited and focused on handheld basics. "I would say that we underestimated the amount of professional development needed to use them effectively in the classroom. Teachers tried to fit the handhelds into their traditional conception of instruction rather than using them as a tool to facilitate new ways for students to learn." In order for teachers to do something different and transform their teaching, they need time and guidance to move from activities they used to do on paper to technology-based learning to make a difference (NCREL, 2004).

Using a professional development model such as one based on the National Staff Development Council (NSDC) Standards that takes place over two or three years is more effective. In addition, professional development should always focus on the learning target and include blended learning opportunities for teachers with workshops, classroom support, and virtual communities. Training materials should be easily accessible online as a "shared desktop" for anywhere, anytime learning. Another successful strategy is utilizing a curriculum team made up of exemplar teachers to create quality student learning activities for other teachers to use. In short, introducing a pervasive technology like handheld computers means that teachers need to learn new ways of teaching. They need more time to work with colleagues, critically examine the new standards being proposed, revise curriculum, and reflect on their own teaching philosophies (Corcoran, 1995).

For example, teachers in the eFriendly Learning Project in the Joliet 86 School District *(http://www.efriendlylearning.com/jolietweb/ehome.htm)* use a team-teaching approach with teachers and experts jointly designing classroom activities. Experts work in classrooms to observe, team teach, and assist teachers. Nothing guides professional development sessions and teacher growth more than bringing experts into classrooms where tools are used. This strategy guides the teacher as a learner, as opposed to just delivering best practices in a workshop. As an added bonus, this in-classroom experience helps shape future professional development sessions for blending pedagogy, practice, and theory, and provides for effective modeling of instructional management techniques for using handhelds with students in a realistic context.

The most successful implementation efforts involve a team approach where school-level administrators and technical experts also participate in training. Administrators must have an understanding of how handhelds support instructional initiatives in order to provide appropriate support to classroom teachers. Through professional dialogue, they can identify effective classroom and school-wide practices that positively impact teaching and learning. Technical staff must understand their role in effectively supporting one-to-one computing. Consider training technical experts to set up the handhelds at the beginning of the year and providing year-round support so that the teachers can focus their efforts on technology use for learning instead of troubleshooting.

What About Teachers?

While many teachers are enthusiastic about digital technologies for learning, we know it is a reality that other teachers are sometimes "assigned" to an initiative, maybe because they complement a grade level team, or because they are the only ones at a targeted grade level. Consequently, a targeted training group will have varying skills and levels of enthusiasm. Some teachers are phobic about technology and exhibit the "you go first" philosophy, some are very savvy with technology but have limited instructional expertise, and others are just plain skeptical about making any changes. No matter the readiness level, when teachers repeatedly experience the benefits for students and the effects on individual learners, many become part of a "professional transformation." Jim, a fifth grade teacher, didn't see his students doing much writing in science as he began his grant experience, but after three years of professional development and classroom implementation, he designed many science lessons that included writing and reflection. LuAnn, a teacher just five years away from retirement, said during a training session, "This has inspired me so much! I am now ready to go back to get my graduate degree."

It is amazing to see how teachers can develop varying technology skills when professional development focuses on instructional strategies within context and not technology literacy. For Pat and Linda, two veteran teachers involved in handheld initiatives, the first year of training for using handhelds in science and social science found them wondering if they would ever get it. During the second year, both affirmed that a "light bulb went on and it all made sense and was so easy." A high school teacher noted, "When our professional development focused on using reading strategies first, and then how you can do this with the handheld, it really helped my lesson design be driven by content instead of technology." Shifting the focus from textbooks and technology to instructional practices resulted in teachers creating richer lessons, leading to higher-level thinking activities with the handhelds.

What Can Students Tell Us?

Common feedback from students with access to one-to-one tools is that using the devices makes learning more personal, flexible, and engaging, and assists in organizing and accessing information. Perhaps this positive impact can be attributed to the many learning styles that handhelds support. Students can collect information in a variety of ways, including text, graphics, images, video, and raw data. They can write, draw, and sketch in order to process information, and share easily using a variety of wireless communication channels. The creativity of students is stunning, as noted in classroom observations and samples of student work; for example, they illustrate personal connections to vocabulary words, manipulate webs to demonstrate cycles in science, and create animations to explain abstract concepts.

From day one of implementation, students should use handhelds for daily learning activities, such as note taking, writing journal entries, working with vocabulary, or building basic skills. With the focus on personal and anytime/anywhere access, handhelds become important learning tools, as necessary as pen and paper. Teachers describe increased student engagement, time on task, and willingness to discuss ideas through meaningful dialogue when these tools are in the hands of students first thing in the morning and not in a cart in the back of the classroom. "For the first time in 26 years of teaching, this has empowered my students to take effective notes on their own," says one elementary teacher.

Finally, handheld implementations should span across grade levels. Offering students a powerful learning tool one year and then living without the technology the next has a negative impact on students. "They were so used to collaborating and reflecting during learning with the handheld, and then they get to sixth grade and they don't have it. They have just become so good with this tool," said Pat.

What Is an Appropriate Mobile Tool?

There are many considerations for selecting suitable mobile tools to support learning. New mobile devices and peripherals for seamless integration in the classroom constantly emerge. Whether the budget is large or small, many discussions are needed to select the "right" tools for successful implementation. As discussed above, some of the discussions should focus on the best fit for teachers, students, and the targeted learning goals. Additional conversations may center on technical aspects such as screen size, memory, keyboards, charging solutions, and software.

A promising feature with some of the newer models of handhelds is non-volatile memory. When a handheld battery loses its charge, all the data on a handheld is lost if it is stored in RAM, or volatile memory. Since teachers' comfort with technology varies and not all classrooms have students backing up handheld data, not losing applications and student work when a battery goes dead is priceless! Non-volatile memory devices keep that from happening. Using memory cards not only extends storage capacity for applications and files, but also acts as an alternative to backing up files and applications to a desktop or laptop.

As an added expense, many schools question the need to purchase external keyboards. Some handhelds come with a built-in or thumb-sized keyboard, but others rely on handwriting recognition, tap-keyboard input or external keyboards. Students tend to adapt very easily without standard keyboards, especially for writing sentences, summarizing, posing questions, or taking notes. On the other hand, if the focus is process writing, full-size keyboards might be a better option.

While there are many free applications that can round out your essential software toolkit, budgets should allow for the purchasing of commercial software where needed. Visual mapping software such as *Inspiration* helps students construct understanding by creating concept maps, attribute charts, and graphic organizers. A word processor with the capability of creating tables, like DataViz's *Word to Go*, is suitable for structured note taking. A drawing program (commercial or free) for non-linguistic representations allows learners to create personal connections to new concepts and vocabulary. The rest of the toolkit can be a blend of software that promotes discussion, personal reflections, and content and skill development.

Many technology initiatives attempt to get the most from limited funding and have students share devices, but handheld implementation needs to be different. Traditionally, schools have focused on training more teachers and involving more students, creating a "shared" device approach. This limits the effectiveness of the device becoming a personal learning tool. To take full advantage of the affordances of mobile technologies, a one-to-one approach is by far the best solution.

Conclusion

The emergence of mobile technologies has afforded educators new ways of thinking about teaching and learning. They are powerful learning tools, and there are numerous benefits beyond the "lower cost" as compared to laptops or desktops. Mobile technologies are beginning to transform learning environments by creating new dimensions for collaborating, accessing and managing information, fostering discussion, sharing ideas, and personalizing learning. When mobile technologies target specific instructional initiatives, they become lifelong learning tools for students and an integral part of the learning process. The key to success is creating logical and meaningful connections between students, teachers, technologies, and professional development. Only then will portable digital tools have the potential to fundamentally change teaching and learning. □

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Learning Bridges: A Role for Mobile Technologies in Education

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MyArtSpace is a service for children to spread their learning between schools and museums using mobile phones linked to a personal Web space. Using MyArtSpace as an example, the authors discuss the possibilities for mobile technology to form bridges between formal and informal learning. They also offer guidelines for designing such bridges.

In 1963 the science fiction writer Brian Aldiss wrote a short story for a children's science annual[1] about a world, thirty years in the future, where children learn through guided project work rather than formal schooling. The fictional London Educational Authority funds a trip for Jed, a 13-year-old boy, and his father to Antarctica to survey the melting glaciers: "The sad masses of rock were heavily scarred where the ice flow had once rubbed them, for in this year of 1994, the glacier was smaller than it had been even a century ago."

Looking out over the ice floes, Jed adjusts a little apparatus behind his right ear that offers him immediately-relevant information about the world as he explores:

> …It was a simple thing to do. Many of the parts of the miniputer were synthetic bio-chemical units, their 'controls' built into Jed's aural cavity; he 'switched on' by simple neural impulse. At once the mighty resources of the machine, equal to the libraries of the world, billowed like a curtain on the fringes of his brain…Its 'voice' came into his mind, filling it with relevant words, figures, and pictures.
> … 'Of all continents, the Antarctic has been hardest hit by ice.' As it spoke, it flashed one of its staggeringly vivid pictures into Jed's mind. Howling through great forests, slicing through grasslands, came cold winds. The landscape grew darker, more barren; snow fell.

Although the story is fanciful, its basic premise is sound. Children learn more effectively when they are in a more challenging environment than a school classroom, when they are investigating an open question of real interest (for Jed, the consequences of global warming[2]), when they are accompanied by an adult guide, where mobile technology gives them rich and relevant information in context, and where they can make connections between formal knowledge and personal experience.

Mobile computers are not yet controlled by neural impulse (though labs are working on it[3]) and the funds of UK education authorities can only stretch to school trips to the local museum, not Antarctica. However, a project called MyArtSpace *(www.myartspace.org.uk)*, funded by the UK Department for Culture, Media, and Sport, is today exploring how children can engage in similar inquiry-led learning supported by mobile technology and how this can link to school and home learning. Using MyArtSpace as an example, we discuss the possibilities for mobile technology to form bridges between formal and informal learning. We also offer guidelines, drawn from our experience with MyArt Space, for designing such bridges.

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[1]Aldiss, B. (1963) The thing under the glacier. C. Pincher (Ed.) *Daily Express Science Annual No. 2*. Norwich: Beaverbrook Newspapers Ltd.

[2]In this story, Aldiss not only predicts the concern about global warming, but also personal computing in the 1970s ("it wasn't until the great developments in microtechnology in the seventies that portable computers were made") and mobile computing in the 1990s.

[3]See, *e.g., http://en.wikipedia.org/wiki/Brain-computer_inter face* .

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MyArtSpace

MyArtSpace is a service for children to spread their learning between schools and museums using mobile phones linked to a personal Web space. It currently runs in three UK museums: the Urbis museum of urban life in Manchester *(www.urbis.org.uk)*, the D-Day museum in Portsmouth *(www.ddaymuseum.co.uk)*, and the Study Gallery in Poole *(www.thestudygallery.org)*. It can be used for informal learning, but is best suited to school field trips. The aim is to make a day out at the museum part of a sequence that includes setting a big question in the classroom, exploring it through a museum visit, reflecting on the visit back in the classroom or at home, and lastly presenting the results. The technology provides the essential link across the different settings.

The teacher starts by planning a class visit to the museum, consulting the MyArtSpace Teacher's Pack to prepare the trip. Typically, the teacher sets an open-ended question that the students can answer by gathering and selecting evidence during the museum visit. For example, Key Stage 3 (US Grade 6–8) students from a history class visited the D-Day Museum, which interprets the Allied landings during World War II. Their task was to collect evidence on whether D-Day was a triumph or a disaster for Britain.

At the museum, the students are given multimedia mobile phones, and each student keys in a personal identifier. Then, they can explore the museum in any way they choose. They can 'collect' an exhibit by typing a two-letter code (shown on a printed label beside it) into the handset. This then shows a multimedia presentation on the phone and also automatically sends an image and description of that exhibit back to the online "store"[4] on their personal Web space (see Figures 1a and 1b). The students are prompted to type in their reasons for collecting the multimedia representations of the exhibits, encouraging them to reflect on what they see in the museum in relation to the big question they are trying to answer. After collecting an exhibit, the students are shown a list of who else has collected it and prompted to find and talk with them face-to-face. In addition, they can use the mobile phones to create their own interpretation of the visit by taking photos, recording sounds, or writing text comments (see Figures 1c and 1d). After each action the phone sends the picture, sound, or note to their online "store."

Back at school or at home, the students can view their personal collections. Each student's Web space shows a record of the visit, including the exhibits they collected, the pictures they took, sounds they recorded,

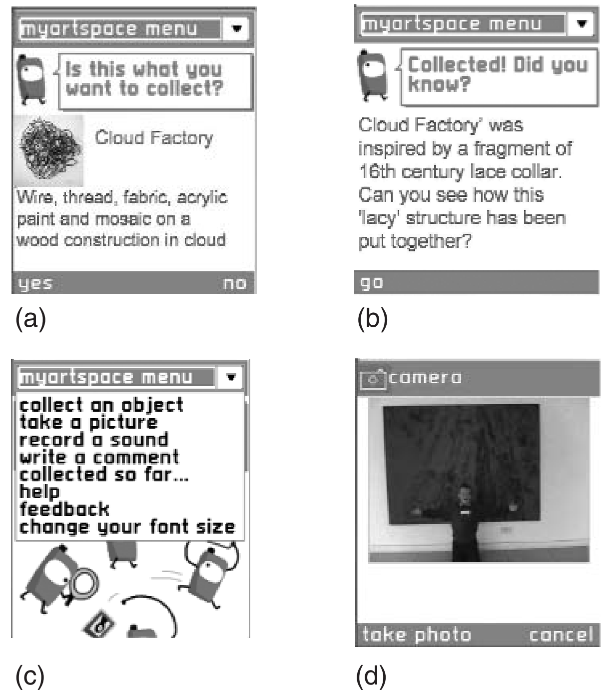

Figure 1. MyArtSpace mobile phone interface: (a) collecting an object, (b) multimedia presentation about a collected object, (c) main menu options, (d) taking photos.

and notes they wrote. They can also see the collections of other students in the class, and can add their items to their own collections as well as items from an online "store" provided by the museum.

The students can organize their collections into personal galleries (like simple Web-based presentations) to present in the classroom or to share with their family (see Figure 2). Access to the Web space is password protected, and the content published by the students is moderated to ensure privacy protection and appropriate use.

Figure 2. An example student gallery.

[4]The term "store" is used in MyArtSpace in the sense of online storage space.

MyArtSpace is now a fully working service that has been used by over 1,500 students on visits to the three museums. It is also being tested in other museums and outdoor sites. Our early evaluations of the service have collected positive feedback from students, teachers, Local Education Authority representatives, and museum educators. This indicates the value of the service as a way to provide children with meaningful, engaging, and enjoyable experiences of museum visits, complete with tangible outcomes that they can take away with them and work with after the visit:

> The day was of tremendous benefit to the pupils and their history studies. The mobile phones were easy to use and the children were quickly off exploring the museum and making their own collections. I have not seen pupils so engaged or enthusiastic on a museum visit before. (teacher, D-Day museum)

The way the 'collection' of museum items takes place encourages students to stop and think about each exhibit: what is the exhibit about, and how does it relate to their learning task?

> Made me look at artwork more...Most people think going to galleries is boring, but when you put ideas on a Web site and use the phones it's much more fun. (student, The Study Gallery)

By following up the visit online, the students' interest in the museum topic is increased as is their motivation for related learning. This is what makes MyArtSpace different from other multimedia museum guides: It connects the museum visit to the classroom and to the children's homes, so that the visit becomes part of a sequence of planning, engagement, and reflection, rather than just a fun day out.

In this way, the mobile technology of MyArtSpace is used to bridge the children's experiences of different contexts, media, and content, leading to an integrated learning experience across formal and informal settings. The various bridging roles of mobile learning—at least as important as the delivery of teaching content onto small screens—will be examined in the following paragraphs along with suggestions about how to design for them.

Designing Technology Bridges: Divide and Conquer

A successful learning activity should be integrated with other learning events, building on them and contributing to their outcomes. Likewise, successful mobile learning activities should be seamlessly integrated with other types of learning activities. Systems like MyArtSpace do not confine the learning experience just to interactions with a mobile device. Rather, they make use of highly mobile devices for the part of the experience where they bring the most value (e.g., for data collection in the museum, where the use of fixed technologies is impracticable and the use of traditional media such as pen and paper is cumbersome). The mobile device is then used as a bridge to technologies used in other parts of the learning experience (e.g., the exhibits, installations, and printed media available in the museum that trigger reflection and inform data collection, or the Web-enabled ICT suite at school used for data analysis).

This is a wiser use of mobile technology than an indiscriminate digitization and 'mobilization' of all learning activities. For example, it would in principle be possible for students to use a Web browser on a mobile phone to organize their personal MyArtSpace collections. However, a desktop PC is a better medium for students to manage their large collections of multimedia objects, collected with the mobile phone in the museum. Moreover, most schools in the UK are already equipped with desktop PCs in ICT suites, so taking advantage of existing technology and infrastructure is more cost-effective.

Deciding which type of technology to use should be done by 'divide and conquer.' The learning experience needs to be broken down into a sequence of activities and the following questions answered for each activity:

1. *What will be the location of the activity?* Will it be taking place in the field, in the classroom, or in the lab? Will it be indoors or outdoors?
2. *What are the human factors of the learning activity?* Does it involve physical movement and interaction? Will the learner's hands be otherwise occupied? Will the learner be standing, sitting, moving?
3. *What technology is already available?* Are there PCs, laptops, PDAs or tablet PCs available? Do the learners bring their own devices that they are willing to use? Is there a network infrastructure already in place?
4. *What are the technical requirements for the user interface?* Will the user need to manage complex collections of data that require a large amount of display real estate to be represented properly? Are there specific requirements for input/output form?
5. *What is the cost of transition from this activity to the next one?* Will the learner do another activity immediately after that will require them to switch to another device? How smooth can the switch between the two be?

Designing Technology-Activity Bridges: Mobility in the Learning Experience and the Technology. The design of educational technology of any kind needs a good balance between the technology and the education, and the same is true for the design of mobile learning systems. Although it is relatively straightforward to design a piece of technology that is usable, robust, and delivers impressive functionality, the experience should go beyond the technology, with clear purpose for the teaching and learning.

In the case of MyArtSpace, the design of the mobile phone service and the Web portal that hosts the students' collections went hand in hand with the design of the three-stage learning experience (in the classroom, in the museum, and back in the classroom). Teachers, educational consultants, museum educators, and Local Education Authority representatives were involved throughout the design of the system, providing expert advice on the kind of functionality that would be useful and shaping the template for the learning experience that would make use of that functionality.

Moreover, it is important that teachers are given the chance not only to adopt the designed system, but also to customise it for their classrooms. MyArtSpace implemented this through Teacher's Packs, a set of materials that describe the potential of the technology and make suggestions for activities. The teacher can then use these as a starting point to plan in detail a learning experience for their class that matches its teaching style, objectives, and background.

Designing Learning Space Bridges: Acknowledge and Respect All Learning Spaces. MyArtSpace allows visitors to interact in three spaces: the physical space of the museum which they explore; the personal space on the mobile technologies that they use to collect and create items of personal interest; and the virtual space provided by a Web portal that stores their collected items and additional resources for them to organize, share and present.

In designing the system, debates over how much of the experience should take place in each of the spaces had to be resolved. For example, when collecting an item in the museum, the student receives a list of other students who have also collected that item. Although it would be possible for the system to also display the other students' reasons for collecting that item, it was decided instead that it would only display a suggestion that the user might want to talk to them face-to-face—the rationale being that if face-to-face interaction is possible, it should be encouraged rather than replaced.

Decisions need to be made about when and where to make interactions in each space possible. For example, should the students be able to access their online collections while in the museum? What would be the price for an additional interaction space? As trials of mobile museum guides often show, there is a danger that the visitor's attention is completely drawn to the mobile device at the expense of the rich museum environment. MyArtSpace therefore limits interactions in the virtual space outside the physical context of the museum.

Such design decisions discourage immersion in one learning space at the expense of the others. The technology that enables interactions in the personal and virtual spaces should be there to augment the experience in the physical space of the museum, not to 'swallow' or replace it without good reason. A good reason for technology to replace the physical experience might be when the student involved has particular special needs.

Designing Context Bridges: Fill in the Gaps between Museum, Classroom, and Home. Many visits to museums and other similar school trips involve giving out numerous pieces of paper to children who will inevitably deface, tear, and possibly lose them before bringing the tattered remains into the classroom. MyArtSpace provides the means for children to end up with something less fragile and more engaging than a sheet of scribbled notes. Everything they collect in the museum automatically ends up being part of a meaningful artifact that they take away from the museum and then put to good use in later classroom sessions. The best thing is that neither the children nor the teachers need to put in any effort to make sure that this happens; the system just does it by default. One of the teachers at the D-Day museum in Portsmouth enthused about how MyArtSpace meant that the children's work wouldn't be lost on the bus on the way back to school—a real tangible benefit over visits without MyArtSpace. In this way, mobile learning technologies can help us build much needed bridges between different contexts and different learning spaces. It's hard to move museum experiences back into the classroom, but MyArtSpace shows us one way to do just that. The children ended up with something real to work with back at school. More than that, they then worked to produce something lasting that could be shown to their friends and family. The benefits go beyond simple mobility of artifacts—learners are able to continue their learning experiences across different locations and contexts.

From Bridge Designs to Steady Bridges: The Importance of Evaluation. Mobile learning can form bridges between different technologies, contexts, experiences, and learning spaces. However, bridges that are designed to aid the learning practice will also change and affect that practice. The way a system like MyArtSpace is used cannot be determined until it is actually used by real people in real settings. Often the way learners adopt a piece of new educational technology is not the same way that the designers and educators expected. New tools that enable learners to perform new activities may change the way they perceive and carry out old activities. We therefore need to stress the importance of continuous evaluation and re-design.

As an example, we will mention the phenomenon of "aggressive" collecting that we have observed in some cases with MyArtSpace, where students enthusiastically create their own content, taking dozens of pictures and recording lots of audio notes in the museum. This results in huge personal collections, which are later hard to manipulate and even recognize ("what is this picture?"); let alone interpret and use constructively. This overuse (misuse?) of the mobile technology could be dealt with, for example, by putting constraints on the number of items a student can collect during a visit, or by increasing the time students spend on post-museum lessons. MyArtSpace was designed with the potential to form a useful bridge between the museum and the classroom contexts. However, it is only through continuous evaluation and fine-tuning of the new technology with the learning practice (including adjustment of peripheral and contextual support, like lesson planning, IT support, and activity planning), that we will arrive at a steady bridge.

Conclusions

In conclusion, the image of mobile learning in education is slowly crystallizing into a picture of a learner enabled to not only use new technologies, but also to perform new activities with them; and of an educator who can not only put lots of learning 'stuff' in a mobile gadget and hand it to their students, but also to plan new learning experiences for them. Mobile devices can form steady bridges between technologies, contexts, experiences, and learning spaces.

As Brian Aldiss might have written:

> It took just a moment. The mobiphone seemed made for him. Jeff tapped in the two-letter code written beside the exhibit and waited just a moment. Somewhere, far away, a massive electric-library sprang into life, fetching just those pictures and words that would give meaning and context to the battered soldiers' boots in the museum display.
>
> ...The machine let him explore on his own, or with his friends. It never disapproved or got cross, but was always ready with the most helpful facts and pictures at that moment for his age group. When he needed to ask questions, the teacher was there to help. Best of all, when he got home he could show everyone what he'd seen—he was curator for a day! ☐

In and Beyond the Classroom: Making Informal Learning Truly Ubiquitous with Highly Mobile Devices

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In a world that is increasingly mobile and connected, the nature of information resources is changing, and wireless mobile technologies provide access to a wide range of resources and tools, anywhere and anytime. Consequently, learning is shifting increasingly from formal to informal environments. This article provides some thoughts about this shift, the role of highly mobile technology, and how it may be able to bridge the gap between informal and formal learning.

In a world that is increasingly mobile and connected, the nature of information resources is changing. The new information is networked, unlimited, fluid, multimodal, and overwhelming in quantity. Digital technologies such as cell phones, wireless handheld devices, and the Internet provide access to a wide range of resources and tools, anywhere and anytime, and therefore greatly increase opportunities to learn outside institutionalized school systems. Clearly, learning is shifting more and more from formal to informal environments. This article provides some thoughts about this shift, the role of highly mobile technology, and how it may be able to bridge the gap between informal and formal learning.

What Is Informal Learning?

Sefton-Green (2004) points out that learning is not

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usually valued until it can be recognized as knowledge within the frameworks of formal academic disciplines. However, it is well-known that learning takes place within and outside schools, and cannot be easily separated from our everyday activities such as work, watching TV, playing, reading, and shopping. These activities can be resources and contexts for learning as well (Sharples, Taylor, & Vavoula, 2005). Accordingly, informal learning can be defined as learning in which both goals and processes of learning are defined by the learner, and where the learning is situated rather than pre-established. It should be seen as a lifelong process whereby individuals acquire information, values, skills, and knowledge from social interactions, work, play, exercise, and media (Lave & Wenger, 1991; McGivney, 1999; Sefton-Green, 2004; Vavoula, 2004). When people engage with their surroundings, an impromptu site of learning is created. In other words, informal learning is to formal learning as riding a bike is to riding the bus. While a cyclist chooses his/her path and destination, a passenger on a bus is just along for the ride (Cross, 2006).

Informal learning can be intentional or unintentional (Vavoula, 2004), and technology can provide support for both types. Informal learning that is intentional could consist of accessing digital information that is part of a museum exhibit, or downloading podcasts on a mobile media player for future playback. Unintentional informal learning could involve Googling a topic or problem as it arises, for example, while watching a TV program or playing a computer game, or retrieving restaurant information on a GPS-enabled mobile phone when looking for a place to eat. The Internet has become a great repository of information and knowledge and is seen by many as a core element of the future of learning (Breck, 2006; see also this issue), but some type of hardware device is needed to gain access to the wealth of resources in cyberspace. Desktops and even laptops constrain users in that they tend to leave users tethered to a fixed location. While this works well for learning in formal environments like schools, it prohibits the more spontaneous and 'just-in-time' access to information that informal learning requires. In contrast, small mobile devices such as wireless handheld computers and GPS-enabled mobile phones encourage the use of technology in everyday activities and enable users to understand digital technology as a lifelong-learning tool anywhere, anytime (Inkpen, 2001; Sharples, 2000).

The Role of Mobile Technology in Informal Learning

Many segments of the global market for mobiles are reaching points of saturation. Over 75% of the general population and 90% of young adults own mobile phones in the UK (Crabtree, Nathan, & Roberts, 2003). Approximately 75% of South Koreans and 99% of Taiwanese have a mobile phone (Forsberg, 2005; Wu, 2006), and over 432 million people (33.2%) are mobile users in China (Nystedt, 2006). Further, in many developing countries, particularly in rural areas in sub-Saharan Africa, the growth of mobile cellphone networks is even more rapid than the infrastructure for fixed network telephony (Brown, 2005; Shapshak, 2002; Sharples, Taylor, & Vavoula, 2005). These figures clearly indicate a trend towards ownership of mobile technology on a global scale. As a result, mobile digital technology has merely opened up more opportunities for informal learning.

Because learners are continually on the move, the mobile aspect of informal learning cannot be overlooked. Educational thinkers often use terms like 'mobile learning' or 'M-learning' to signify this context-free learning. Sharples, Taylor, and Vavoula (2005) have developed a theory of M-learning that states that "we learn across space as we take ideas and learning resources gained in one location and apply or develop them in another. We learn across time, by revisiting knowledge that was gained earlier in a different context, and more broadly, through ideas and strategies gained in early years providing a framework for a lifetime of learning" (p. 2). While M-learning as defined here can take place with or without digital tools, information and communication technologies (ICT) have transformed M-learning. Today, M-learning is much more dependent on ubiquitous accessibility of ICT, especially mobile and wireless technology in all kinds of environments, and can be seen as one form of informal learning.

Examples of Informal Learning with Mobile ICT

One example of informal learning with mobile technology is the context-aware guiding service in the National Museum of Natural Science (NMNS;*http://www.nmns.edu. tw/index_eng.html)* in Taiwan, launched in July 2005 and developed around a knowledge-based mobile learning model proposed by Hsu, Ke, and Yang (2006). Before visiting the NMNS, a visitor can login to its Website, personalize a learning plan that fits individual needs and interests, and save his/her preferences in the museum's database. When the visitor arrives at the NMNS, he/she is equipped with an Internet-ready wireless handheld device. The visitor then has three choices of learning modes: following the individual's plan, accepting a recommended learning tour, or freely exploring exhibits. The context-aware system can automatically determine the visitor's location and deliver corresponding content and relevant information to his/her handheld device. After the visit, the system provides additional learning content and recommends further resources according to the record of the individual's on-site learning behavior and preferences. The visitor can obtain this information from the museum's Website.

A second example of informal learning can be seen in the Outdoor Location-Aware Learning System

(OLALS) project in Taiwan. The communication infrastructure system of OLALS includes Global Positioning System (GPS) technology and a wireless LAN network. When users enter a location that provides the OLALS service, they can access information related to the particular location (history, culture, geographical characteristics, and tour information) via a wireless mobile device. In addition, users can take notes and record information while interacting with the environment through the OLALS e-diary tool. Following the learning experience, users can upload their data files to the OLALS server to share information with others or do further research (Chang, Sheu, & Chan, 2003).

Using Mobile ICT to Connect Informal and Formal Learning

Mobile ICT makes it increasingly difficult to separate formal and informal learning processes. As learning becomes more social, interactive, and context-based, and mobile ICT provides just-in-time access to a variety of tools and resources, Sharples, Taylor, and Vavoula (2005) firmly assert that "we need to recognize the essential role of mobility and communication in the process of learning, and also indicate the importance of context in establishing meaning, and the transformative effect of digital networks in supporting virtual communities that transcend barriers of age and culture" (p. 1).

As a result, new forms of learning are emerging, many of them having both formal and informal characteristics. For example, De Crom and Jager (2006) initiated a project in South Africa that uses PDAs as an alternative to conventional paper-based workbooks for learners in Ecotourism Management at Tshwane University of Technology during field trips. Before departure to the field station, information about animals, locations, maps, workbook questions, discussion questions, and surveys are prepared by the instructor and transferred to the PDAs. At the observation site, students use the handhelds to access information, such as a digital multimedia version of Roberts's Birds of Southern Africa, an image-based database of African birds. Students take notes and digital pictures of observations. Furthermore, the PDAs provide opportunities for authentic, 'just-in-time' learning because students can work collaboratively to create and share information based on what they are observing in the field and not necessarily what they are asked to do for their assignments. Back on campus, students synchronize their files to a Web-based course delivery system, add analysis and information to the data collected, and multimedia presentations or reports.

Rethinking Teaching and Learning in the Mobile Age

Traditionally, teaching and learning have focused on the learner's mastery of knowledge and skills. Teachers were the primary source of knowledge, and their role was to transfer knowledge to learners. In contrast, contemporary educational paradigms have shifted the emphasis of learning to the production of new knowledge, and the effective application of information and knowledge. Within this context, teachers are seen as but one source of information and their role is becoming that of a facilitator rather than an authority.

Even so, both types of learning are still assumed to take place in a classroom environment and mediated by teachers, and this fails to capture the distinctiveness of anywhere, anytime learning in an era in which digital technology is ubiquitous. Therefore, a new paradigm for teaching and learning is needed (Brown, 1999; Sharples, Taylor, & Vavoula, 2005; van 't Hooft & Swan, 2007; see also Swan, Kratcoski, & van 't Hooft, this issue). This paradigm should be based on the premises that learning:

- takes place anytime and anywhere, and transcends the spatial and temporal boundaries of educational institutions;
- involves mobile ICT that provides access to tools and resources on an as-needed basis;
- curricula should focus less on 'things to know' and more on 'strategies for information navigation' (Resnick, 2002).

All in all, we have an environment in which digital technology and information are paramount, and learning to become a better learner (know-how) becomes far more important than memorizing explicit knowledge (know-what). It is undeniable that to today's learners, the Internet is beginning to turn into the key infotainment medium, and ICT is seldom used in isolation to support their learning. John Seely Brown thus argues that "the real literacy of tomorrow will have more to do with being able to be your own private, personal reference librarian, one that knows how to navigate through the incredible, confusing, complex information spaces and feel comfortable and located in doing that" (Brown, 1999, p. 8).

Finally, in his literature review on informal learning with technology, Sefton-Green (2004) calls upon urgent needs to find ways to synthesize learning across formal and informal domains. He suggests that teachers need to know a lot more about student experiences in general and how youngsters use technology for creating, sharing, and communicating. Teachers also need to work in various contexts to develop links with out-of-school learning experiences. In this respect, highly mobile technologies may become the bridge that spans the divide between foral and informal learning. □

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Handheld Computers in Education: An Industry Perspective

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Five representatives from the mobile computing industry provide their perspectives on handhelds in education. While some of their ideas differ, they all agree on the importance of staff development, appropriate curriculum development, and teacher support to create the kinds of personalized learning environments that mobile devices make possible.

Introduction

Recently, we spoke with five industry luminaries about their perspectives on handhelds in education. They discussed their views on the effects of technology on education, the possible impact of mobile devices, and what schools need in order to make the most of currently available technology. Here is what they had to say:

Eric Johnson, Palm Inc. *(www.palm.com)*

It is difficult to say what impact technology has had on education. We know it has, but the biggest issue is finding ways to measure that. Technology's impact on business productivity is not readily noticeable because it becomes invisible (email, for example). You cannot really measure its impact, but you can't do without it either. A similar thing may be happening in schools. It's difficult to say how the Internet changes education, but kids can't be educated without it anymore.

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Technology literacy should be included in any education. Sometimes technology doesn't have as much of an impact in schools because there's not enough of it. There is a real difference here between home and schools.

Nevertheless, there are many handhelds in use in education. Some are having remarkable impact, others less so. Change is not as advanced as I thought, due to difficulty of acquisition; schools are slower to adopt, and there are often funding issues. When teachers have to bring in their own paper, it is difficult to be innovative sometimes. What do we need for innovation to happen? Certainly training and staff development. Palm provides the PETC program, because it strongly believes staff development is essential. What teachers need the most is time to make changes to their curriculum. One-to-one technology will eventually happen. It will take time and hardware and software solutions that are better adapted to the market. I expect this to be the case in twenty to fifty years. The current loanership model will be replaced by an ownership model. This is where you will start to see real learning and productivity gains. You have a much deeper interaction with things you can count on all the time. This is not terribly mysterious. Productivity will go up; in schools this is called learning.

Mike Lorion, LeapFrog
(www.leapfrog.com)

In some ways, technology has had a lot of impact on schools, but it depends on what you are trying to measure. This is similar to what happened in business. In the early 2000s, Alan Greenspan said that it took 10 years to get gains from technology. We are around that 10-year timeframe for education. Teachers have switched to email and the Internet as their information source for all types of things and this has had a large impact.

In student achievement there are still some issues. The USA is at a 4:1 student-to-technology ratio, so at most 25% of the classroom day a student may have access to technology. If it is only available that amount of time, it won't have a large impact, so we need to figure out how to get the other 75% covered. More personalized, mobile, and individualized technologies should play a bigger role, because they give students more individual access to and time with technology.

Technology applied to the right process can make a huge difference. Digital whiteboards are starting to do so. The TI calculator has had a huge impact. Applied personal learning tools can be used more and are more cost-effective than the traditional computer platform, so the issue becomes: do I need a specialized tool for each subject area or a generic, ubiquitous tool?

Besides technology, content is a key area. The $100 laptop project at MIT is interesting, but we need to look at this from a classroom and not a technology perspective. Students change content publishers many times in a day. They may have Addison Wesley math textbooks, Open Court for reading, and Harcourt for social studies. How can we get a ubiquitous platform that can be used with all?

Leapfrog focuses on the learning tool, and providing the bridge between home and school. We apply technology to good curriculum practice, versus writing curriculum that fits on technology. Leapfrog enhances curriculum by adding low-cost technology, not rebuilding everything on an expensive platform. This lower cost approach can reach more kids.

Finally, we need staff development. New teachers can't imagine teaching without computers, and current students fully expect it. We have to make sure that teachers are able to use technology effectively.

Dave Santucci, Texas Instruments
(education.ti.com)

While technology in general may not have had a strong impact on education, this may be because the focus has been more on the technology itself rather than on the uses of technology for educational purposes. The attitude has been one of, "If we get this wonderful technology into the students' hands of course good things will happen educationally." In ontrast, graphing calculators, which were designed for a particular educational purpose, have had a proven impact on education, as shown by many research studies.

Handhelds in general won't necessarily resolve this issue, but graphing calculators become part of a set of changes in curriculum, pedagogy, and assessment practices. Also, graphing calculators are actually an integrated combination of hardware and software. Other educational technologies seem to be thought of primarily as hardware with the promise of the potential of the software. In addition, many devices such as laptops and even PDA-type devices seem very costly, and given the lack of a sound educational model for the technology, the cost-benefit is not there yet.

We need a combination of pedagogy, curriculum, and professional development around a model of effective technology use. With graphing calculators and associated software there is the potential for greater engagement and exploration by students of the topics in a class. With a wireless classroom network (like TI-Navigator) there is more immediate assessment feedback and active participation by the students (see also Hegedus, this issue).

TI's focus is on solutions for simple implementation in the math and science classroom. This includes handhelds, integrated computer software, and a wireless classroom network, to enable teaching of important topics. We put a huge focus in our product development on making the product work well in a classroom environment. We focus on working with publishers to assure that teachers have strong options for curricular materials that integrate the TI handhelds and software. We also provide strong professional development programs through the Teachers Teaching with Technology and other organizations.

Bill Hagen, Microsoft Mobile *(www.windowsmobile.com)*

Mobile technology can have an impact, but it hasn't as much in the USA because there are many different organizations trying to create their own environments. In other countries (e.g., the UK) innovations are shared with the entire country. Schools and districts in the USA are setting their own standards. Instead, we need a nationwide, baseline standard, centrally managed, and updated every three years. This is a very controversial issue in the USA, but with money being cut, less time can be spent by school districts to create their own technology standards. Overall, we need better processes, more than better technologies. This is important, as other countries are gaining on us, and we have to get better and more efficient.

The PDA can be seen as a transition to smartphones. Smartphones will help out teachers, administrators, and students by converging many devices into one and providing mobile connectivity. For example, distance learning with podcasting is already happening. People are creating media servers, streaming relevant information to handhelds or smartphones. We'll see a big increase in this over the next 12–18 months.

Handhelds can be a low-cost, effective way for students to have anywhere, anytime access to tools and data. Comfort levels and learning increase when students own a product, e.g., calculators, science probes, and reading helpers. Handhelds are more immediate, social, and allow for creativity; students take to them immediately. Thus, handhelds provide an improved way for students to access to more information and tools in a form factor they find extremely personal and very useful in and out of the classroom.

Handhelds and the $400 PC are close in price, but handhelds are probably easier to manage than laptops. They are less conspicuous and easier to replace. The biggest issue is knowing how to deploy and maintain large numbers of handhelds. We need at minimum statewide standards for a limited number of configurations for successful implementation. The only way to make this work is with state and federal support for handheld initiatives; we are currently too fragmented in K–12, to the detriment of students.

We owe it to our students to continually examine the role PDAs and smartphones can play in the classroom to enhance the education experience. The improvement of professional training, curriculum development, and local technical support for mobile devices will help adoption, enhance the mobile ecosystem of partners who integrate and support these devices for schools, and lastly, which device program the district can financially and politically embrace, whether it be a student ownership option, district-based option, or shared-device program.

Graham Brown-Martin, Handheld Learning *(www.handheldlearning.co.uk)*

In the twenty years that I've been involved with ICT and education, digital technology hasn't had the impact on teaching and learning that we hoped for because:

- We've got our timescale wrong. Just because we haven't seen the impact yet doesn't mean there won't be one.
- Technology/computer use has changed tremendously over time, so the impact has changed; think, for example, about developments like wireless mobile devices and video/image sharing online.
- We've spent too much time on learning how to use technology, not what to do with it.
- There are issues of access. Technology use in schools should be seamless, like we use pencils. Labs and scheduling don't work because they prohibit seamlessness.
- True embedding = invisible technology. We shouldn't draw attention to it.

Educational transformation needs a serious reconsideration of what school means to us. Is it a building or a community where learners with mobile tools can access information in different locations? In my view, school has been a state-provided nanny. Is that really what we want educational systems to be in the future?

Mobile devices can be helpful in rethinking schooling. They are ubiquitous and allow for personalized learning, rather than one size fits all. The devices have already impacted the learners' world while education lags behind. If schools don't change, they are going to be digitized out.

With mobile technologies, we are seeing a change. Students can assemble their own learning materials. Teachers will still be around, and not be replaced by technology. There will actually be a need for more teachers creating materials for learners. Inevitably, the role of teacher is going to change from caretaker to real teacher.

The key is to embrace what young learners already have; 97% of children over 12 in Europe have a mobile phone. Symbian's new version allows phones to go in the mid-market, which is huge. Nintendo DS sells 140,000 units a week in Europe. Sony PSP sold 20 million units worldwide last year. Ultimately, it's about recognizing that technology now belongs to the user and is no longer controlled from above. Learning should be viewed in the same way, with mobile technology providing access to information and communication supported by learning coaches. In addition, we need wireless, mobile systems to collect and assess evidence of learning, e-portfolio types of systems using mobile devices that will enable learners to record what they do using rich multimedia. This will help reward creative thinkers, which the current system doesn't do.

In sum, transformation of education requires a real change in the mindset of teachers, learners, parents, and government of what learning is all about. Learning is something we do from the cradle to the grave. I don't think we've come to terms with that yet.

We're headed for an interesting transition period in education. There's a lot of technology out there and not all of it works yet. Anyone who gets involved now is an early adopter. Without them, we won't get to the next stage. □

Author Guidelines for Magazine Articles

In preparing an article for *Educational Technology* Magazine the primary fact to keep in mind is that this magazine is not a formal research journal. It is, as the name implies, a magazine. The Editors are looking generally for articles which interpret research and/or practical applications of scientific knowledge in education and training environments.

Thus, your article should not be cast in the form of a traditional research report. The facts of your research, or that of others, should be stated succinctly. Then you should go on to explain the implications of this research, how it can be applied in actual practice, and what suggestions can be made to school administrators, trainers, designers, and others.

The style of writing should be on the informal side—an essay—since once again this is a magazine and not a formal academic journal. Authors are free to state their opinions, as long as the opinions are clearly identified as such. The use of specialized jargon should be kept to a minimum, since this magazine has a very wide interdisciplinary audience.

There are no minimum and maximum length restrictions. Make your article as short as possible to do the job you intend. As a general rule, most articles are about 3,000 words. Include graphics as appropriate.

Note too that this magazine is read in more than 100 countries, by persons holding prominent and influential positions. They expect a very high level of discourse, and it is our goal to provide major articles of excellence and lasting significance.

Blurring Lines with Mobile Learning Games

Eric Klopfer
Massachusetts Institute of Technology

This article explores how the future of mobile learning games lies in the blurring of the line between fun and learning, between in-school and out-of-school. Accomplishing this requires new paradigms as well as new technologies. Mobile learning games can be the conduits between the world of school and the world of life, and make them both more fun and productive.

The scene is a shopping mall. A group of friends arranged to meet at the mall on Saturday afternoon to do some shopping, hang out, and maybe catch a movie. They all arrive at different entrances, not having specified an exact meeting location. A quick phone call is made, "Hey, meet me at the food court."

Within minutes other similar calls are made and the group has gathered. A few of the friends want to pick up a just-released CD, others want the new video game, and they all want to go see the new action flick.

There is a race to find the starting time of the movie. One person uses the Web browser on her cell phone, another tries a text message, and just for kicks one tries calling the theater. The race is won by the boy who just dropped off his sister outside the movie theater. The sister quickly texts back "20 min."

There are many stores in which to shop. To find the best price on CDs and games, the group decides to divide and conquer. Text messages are flying. "cd sale 12.99," with a response "gr8 brt [Great. Be right there]."

The next scene is a school. It is now Monday and the same group of kids is back in science class. As the bell sounds, they take their seats in the orderly rows of desks and face the front of the room. It is day two of photosynthesis. The lecture begins and the students begin writing notes on their paper. The lecture moves too quickly to understand and too slowly to pay attention, so many of the students are lost. One of them turns to her neighbor and passes a note, "i m so lost. r u

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2?" [I am so lost. Are you too?]. The note comes back, "4S. WTH is ATP?" [For sure. What the heck is ATP?]. That note is intercepted by the teacher and discarded.

Another pair of students is wrestling with the same issue, but has slightly greater success. One of those students quickly looked up ATP in Wikipedia using his Web-enabled phone and whispers to his neighbor, "Adenosine triphosphate." Unfortunately, as he tries to look up NADP using the same technique, his phone is confiscated and the teacher cites the "no cell phones in school" rule. The teacher follows up by saying, "The next person I find trying to cheat using their cell phone, Palm Pilot, or Blackberry is going straight to the principal." The lecture continues, only to be punctuated by an opportunity to work alone on some computer-graded worksheets.

Let's compare these two environments. The teenagers at the mall are engaged in collaborative problem solving, appropriating mobile technologies to help them communicate, gather data, and analyze information. They define parameters around poorly defined problems that they need to solve or optimize. They do it because they want to and because it needs to be done, and they have fun doing it.

In school they are just trying to keep pace with the information that is being provided to them for transcription. Disruptive technologies are banned rather than incorporated into the school. Opportunities for collaboration are few and far between. Problems with well-defined parameters and answers are doled out and marked right or wrong.

From the students' viewpoint, it seems clear that they would expect these skills that they are acquiring and applying out of school to be more relevant and applicable than the ones that they are learning in school. The question then is how to make the practice of school more like the practice of life.

This isn't to suggest that we should have students solving "trivial" problems like how to get things done at the mall, nor is it to suggest that the current model of school and everything that goes with it should be thrown away. There are opportunities to apply similar methodologies to more important and more academic topics, and to do so within the schools that we have now.

We can start by embracing mobile technologies and the communication, collaboration, analysis, and even game playing that they support to create classroom experiences that better reflect the practices and omplexities of 21st century work and citizenship (Bereiter, 2002; Dede *et al.*, 2005). These capabilities can be harnessed to promote deep learning about content, methodology, process, and problem solving using the knowledge and skills that students need.

The synthesis of these technologies, their capabilities, and the skills that are needed for the 21st century has been leading to the development of an array of mobile learning simulation games. In the Teacher Education Program @ MIT, our goal is to take scenarios, like the one described in the mall, connect them to academic content and processes, and bring them to or connect them with the classroom. Our first attempt at this connection was by way of the Participatory Simulations (PSims). The first generation of PSims at MIT made use of small wearable computers (Colella, 2000) and put people inside of a virtual epidemic in which participants had to balance the rewards of meeting people with the risks of getting infected by those same people.

The rules of this simulation were simple—one person started with the virus in incubation, the virus got passed along with some probability, and some people were "genetically immune" from ever getting the virus. Importantly, there was the ability to run the simulation again, and there were an infinite number of behavioral modifications one could make to the game. Some groups implemented quarantine, others designed sophisticated experimental designs to measure probability of transmission, and others tried to devise ways to quickly minimize the number of people who got sick (Klopfer, Yoon, & Rivas, 2004).

In the end, what everyone wanted to do was to understand the system and what caused the patterns that they saw. The class needed to work together to iteratively gather data, construct, test, and revise hypotheses, and ultimately come to a collective understanding of the system.

These simulations were run in regular classrooms and could be easily chunked to match the short periods in many schools. Observing one of these classes one would see groups spontaneously forming and breaking apart as they shared information and conducted experiments. You would also see teachers occasionally leading discussions to help the students better understand the problem at hand. You would not see restrictions on how the students could work or what information they could access. This was a problem that students wanted to solve.

As mobile devices grew cheaper and more common, the PSims were brought to the Palm platform. Other groups have done similar work (e.g., Cooties, see Soloway *et al.*, 2001; and Geney, see Mandryk *et al.*, 2001) seizing on the features of this platform to create immersive, flexible, and totally decentralized simulation games. The set of simulations at MIT *(http://education.mit.edu/pda)* has grown to include a number of simulations in the life sciences, addressing topics such as genetics, ecology, animal behavior, and resource use, as well as topics in the social sciences like social networks and economics (see Figure 1). In order to understand networks, for example, students construct links in a network through which they must route email messages to each other. They then analyze the efficiency of their networks through data collection, analysis, and visualization.

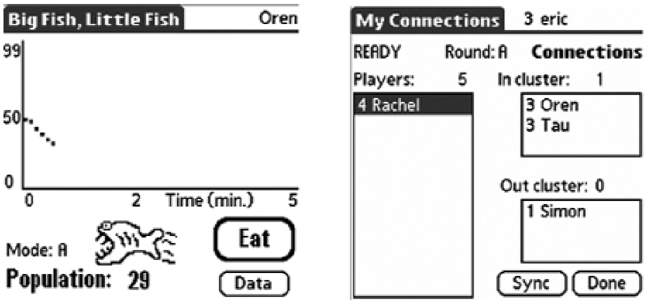

Figure 1. Screen shots of participatory simulations. The game at the left (Big Fish Little Fish) is an ecology game in which big fish need to manage a population of little fish. The game at the right (Netswork) is a game about social and computational networks in which players need to route messages to each other through nodes of a network.

A new generation of PSims that takes advantage of more recent advances in mobile devices is about to enter the classroom. These new PSims will facilitate classroom management and data collection through wireless technologies, addressing two of the critiques about the currently available generation of simulations. The first of these simulations, Palmagotchi, challenges students to care for virtual birds and flowers in a system modeled on Darwin's finches in the Galapagos. To succeed in caring for their virtual pets and gardens, they must master underlying content in ecology, evolution, and genetics. There are two unique aspects to this game that foretell the future of such simulations. First, the games provide for a variety of wireless interactions. You can interact with other players face to face via infrared, within a short range via *ad hoc* wireless, or anywhere in the world using a server on the Internet. This wireless connectivity allows for communication and for real-time data collection. Second, the games are designed to be played in and out of school. One of the challenges of introducing games into the classroom is balancing the time for game play with the time for other classroom activities. By designing games around the idea that most of the game play will take place outside of class, the in-class time can be used for activities such as reviewing data collected from the games, trying to find patterns, planning strategies, and learning the content that will support future play.

It is this same increase in capabilities of mobile devices that brought about another line of handheld simulation games, also designed for play outside of the classroom. Augmented Reality Games for Handhelds (ARGHs) are a kind of "mixed reality." They combine elements of the real world and real problems, with a thin layer of fiction/simulation via location-aware mobile devices. While the players of ARGHs move about in the real world (across spaces ranging from a few rooms in a building to hundreds of acres across a nature preserve) the simulation running on their mobile devices provides them with interactive information based on a programmed scenario and their current location. That digital information includes interviews with virtual characters (via text or video), virtual documents, and sampling equipment that can provide them with quantitative data. Together, this information, combined with the real, copious, and analog information provided by the real world, offers a rich and authentic experience in which students can learn and explore complex problems that they couldn't ordinarily engage in so deeply.

The first ARGH that we developed is Environmental Detectives (Klopfer & Squire, in press; Squire & Klopfer, under review), which placed students in the role of environmental engineers trying to uncover the source of a toxin that had leaked into the groundwater (see Figure 2). The students (upper high school and university) played this game in the actual geographic location that they were investigating (i.e., if the scenario took place on a high school campus, students needed to walk around that actual campus as a part of the game). Information, including interviews with witnesses and experts, samples of the groundwater, and historical documents, was provided to them in context via mobile devices with GPS. While the generic scenario was ported from place to place, the game was customized for the local geography, history, and usage of each place. The students, therefore, needed to take into account many of the real constraints of that particular location—use of the land and water, nearby water sources, topology, attitudes of the local community, visibility of potential remediation, and use of chemicals in the vicinity. The problem space (as well as the geographic space) was enormous. In order to define and solve the problem, the students needed to work together as teams, and use whatever they could to plan and communicate—including face to face interactions, cell phone calls, and walkie-talkies.

As ARGHs have increased in popularity they have spanned a great diversity of topics, from simulations of forensics and environmental science to history and economics. This has been facilitated by the creation of authoring toolkits that allow designers and teachers to create their own ARGHs based on locations near them. Similar work on ARGHs has been conducted by NESTA Futurelab (Facer *et al.*, 2004).

The most recent ARGHs now use wireless networked mobile devices that connect students not only to the simulation in real time, but to each other as

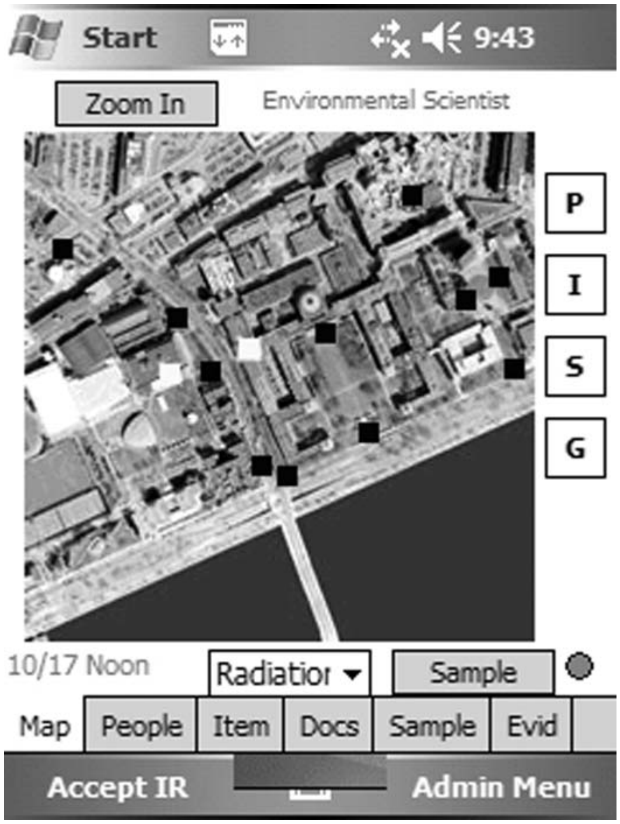

Figure 2. Screen shot of the Augmented Reality game *Mystery @ MIT*, in which players must contain an potentially disastrous environmental threat. The screen shows an aerial view of the playing area. Icons indicate the player's current position, and the positions of virtual characters, virtual data, and items that they can use to help solve the problem.

well (Rosenbaum, Klopfer, & Perry, under review). Thus students are discretely and constantly connected to a simulated world layered on top of the real world that they must physically navigate. Through this simulated world, real and virtual people and events are monitored, processed, observed, and manipulated. The technology creates a complex interactive scenario that challenges students to learn and to have fun. These new advances also lend themselves to the mixture of in-school and out-of-school learning mentioned previously for Palmagotchi. Imagine students playing a game for days or weeks, trying to track down an escaped bio-engineered organism within their community. Students need to rely on each other to tend to virtual hospital patients in their neighborhoods, pick up virtual supplies, and pour over copious amounts of data. They may communicate through IM and bulletin boards built into the game, or use their cell phones, email, or messaging clients that they normally have access to. Everything is "fair game" in these scenarios, and the students come to class wanting to gain the relevant skills and knowledge that will help them succeed.

The future of mobile learning games lies in the blurring of the line between fun and learning, between in-school and out-of-school. Accomplishing this requires new paradigms as well as new technologies. We must explore how to encourage students to learn through play outside of school. Some critics claim that once students find out that they are learning, it will cease to be fun, but we have not found that to be the case. Students can enjoy learning if it matches their interests, their skills, and their view of what is important. At the same time, it must also match the important content and set of skills that we teach in schools. Mobile learning games can literally be the conduits between the world of school and the world of life, and make them both more fun and productive. □

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Creating a Powerful Learning Environment with Networked Mobile Learning Devices

Valerie M. Crawford
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Highly mobile devices can make important information available to teachers in real-time, anywhere in the classroom, and in the form of easy-to-read graphical displays that support classroom decision making. By supporting such important teaching activities, we can create a high-performance classroom that supports teachers and the art of teaching, and makes it easier for teachers to do hard things well.

The last five years have witnessed a tremendous proliferation of mobile computing devices in both the consumer and education markets. The education community is still in the process of discovering which mobile technologies, use models, and implementation configurations will confer the greatest learning return on investment. Many studies of one-to-one computing have been undertaken as researchers and practitioners investigate the benefits and impacts of personal and mobile computing for learning. Such research is more important than ever, as increasingly the education community requires that educational technology investments be targeted to uses shown to have a real impact on learning.

In this article I argue that one way to ensure that mobile technology in schools has real impact on learning is to design mobile technologies to support instructional practices that have been demonstrated through prior research to improve learning. This should be done in a way that leverages the specific affordances of networked mobile devices to make it easier for teachers to implement high-value instructional practices. This will make it much more likely that learning will be enhanced through teachers' and students' uses of the technology.

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I present a rationale for mobile technology integration to support formative assessment and to enhance feedback during classroom activity. I also present a vision of a near-future classroom in which networked mobile computing devices enable teachers and learners to create a powerful classroom learning environment that is personalized and rich in information, feedback, and interaction. Finally, I argue that the classroom technology infrastructure of tomorrow should be designed not just for learners but also for teachers—supporting teachers as high-performance professionals who perform cognitively demanding work in the context of a classroom learning *system*.

Technology Supports for High-Performance Teaching and Learning

Designs for the next-generation classroom technology infrastructure should support instructional practices and learning experiences that have been shown to improve learning. A robust body of research in the Learning Sciences has demonstrated that two related instructional practices, formative assessment and providing feedback during learning activities, are highly effective instructional strategies—indeed, the most effective strategies yet studied (Wiliam, 2007; Wiliam & Leahy, 2006).

Formative assessment involves teachers' use of information about students' current understandings and skills to guide students' learning toward the mastery of target understandings and skills. It is highly effective in improving student learning across a wide range of topics and student populations (Black & Wiliam, 1998a, 1998b; Shepard, 1995, 2000). Both automated feedback provided by software programs and teacher-provided feedback have been shown to be highly successful in improving student learning (Anderson, Reder, & Simon, 2000; Bangert-Drowns *et al.*, 1991; Fuchs & Fuchs, 1986; Kluger & DeNisi, 1996). Research on the impact of feedback on learning has also shown that the more closely feedback is integrated into the learning process the greater the benefits of the feedback (Anderson, Reder, & Simon, 2000; Kulik & Kulik, 1988).

While both of these instructional practices work, research has also demonstrated that they are rare (Black & Wiliam, 1998a, 1998b). It's not hard to understand why. First, few teachers are trained in formative assessment strategies. Second, making accurate inferential judgments about student thinking and understanding in real-time to provide feedback during classroom activity generally requires a great deal of skill and knowledge (Ball, 1997; Berliner, 1986; Shulman, 2005).

Finally, teachers' incredibly large workloads and their work conditions can be barriers to the implementation of formative assessment and providing feedback. One study of teachers' time (Swaim & Swaim, 1999) produced a simple calculation that illustrates the challenge of providing individual feedback to students: A secondary school teacher with a typical workload and 50-hour work week will have approximately 10 minutes to prepare for each class and five minutes per week for reviewing each student's work on a *weekly* basis, assuming that the teacher teaches five classes and 125 students a day. When feedback is provided, such as scored homework or quizzes, it is available too late to impact learning, because it comes after the conclusion of the learning episode from which it is derived and in the midst of a new learning activity (Black & Wiliam, 1998a, 1998b; Coffey *et al.*, 2005). This misalignment of learning processes and related feedback is represented in Figure 1. In short, in classroom learning, feedback to students is typically too little, too late. Clearly, investment in technology to create a learning environment rich in information and feedback is warranted by the research and has strong potential to improve student learning.

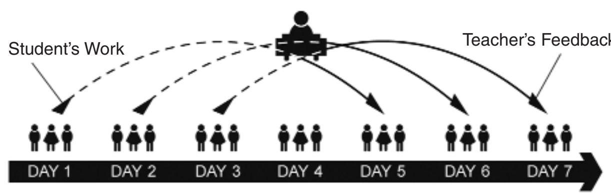

Figure 1. Misaligned feedback cycles in the traditional classroom.

Networked mobile devices in the classroom enable the *instrumentation* of teaching and learning processes in the classroom. With such technology supports, information and feedback can be available *during* classroom learning activities, greatly enhancing the effectiveness of the teacher and the productivity of students' learning time.

Imagine students interacting with digital content using their personal, mobile computing devices, for example, in completing an individual reading comprehension activity or completing a group laboratory activity. Students' responses and other information about their interactions with learning content can be captured and processed automatically. Easy-to-use information can be presented to the teacher in real-time for use in making decisions about how to target and individualize instruction during class or to help a learner or a group of learners make course corrections during their learning activity. In addition, automated feedback can be provided to the learner in real-time. For example, as a learner progresses through a set of algebra problems, he can receive feedback on his work and answers in real-time, rather than completing a set of problems and finding out a day or a week later that the solution procedure he used was wrong. Figure 2 represents a classroom with networked mobile learning devices in which real-time feedback information informs learning and instruction.

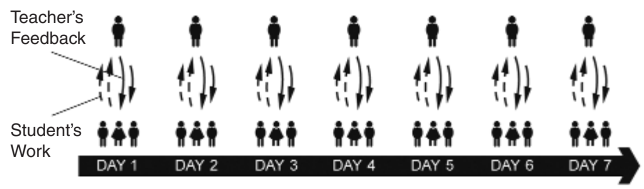

Figure 2. Real-time feedback cycles in the instrumented classroom.

What Would It Look Like in Use?

Here's a description of what teaching and learning tools in this kind of technology infrastructure could look like in use. In a high school algebra classroom, each student has a thin client, wireless, Tablet-PC-type of device, which can potentially be used in all classes. The students and teacher interact with digital content in the form of Internet-based software services with automated, real-time scoring and feedback.

Camila has completed homework the previous evening on her personal, mobile computing device. As she walks into the classroom, her device transmits her ID and homework set to an Internet-connected classroom server. Her attendance is registered and her homework scored automatically. Almost instantly, all students' homework is scored, and they receive feedback on it. The class's homework results are automatically aggregated and graphically displayed on the teacher's tablet computing device. Ms. Jensen, the teacher, glances at the results and sees that problem numbers 7, 10, and 13 posed difficulties for her students. She reviews these problems at the front of the classroom.

Based on the homework results, Ms. Jensen decides to give students an opportunity to check whether they now understand the concept embedded in these problems. She selects six new problems from her digital bank of problems and sends them to students. Learners work in pairs to solve the problems using pen input on their mobile devices, and enter their solutions in a Web form. Their answers are scored in real-time, and the teacher receives continuously updated information about students' progress and results.

Camila sends an instant message to Ms. Jensen, asking the teacher to check her solution procedures. The teacher brings up Camila's screen on her own device, examines Camila's work, and clicks on a pre-set message to send to Camila: "That's exactly right!" Glancing at her screen, Ms. Jensen sees that another student pair, Pat and Jesse, are still on problem 3 and have entered two incorrect solutions so far. She goes to their table to help them.

Soon, most results are in. Ms. Jensen sees that most students have mastered the concept and are ready to move on. Some students, though, need more time with the problem set. Ms. Jensen asks Camila and her partner, who finished all problems correctly, to work with Pat and Jesse to finish the problem set. Standing in the back of the room with her tablet computer, Ms. Jensen selects and sends out the next activity to the student pairs—the students will do an activity using dynamic-linked graphical representations of velocity and position to explore these concepts.

Supporting the Teacher as a Learning System Engineer

One of the main benefits of mobile technologies is personalization. Individualized content can be accessed and used on personal devices, at any time and in any place. Students can easily and seamlessly continue learning activities outside of class. However, the need for individualization in the context of facilitated *group* processes has received less attention in discussions of mobile technology integration into education. Classrooms are learning *systems*, and systems have emergent properties that are not reducible to individual elements within them (Checkland, 1981). During group learning processes, individual learning trajectories are varied, and each needs to be guided and coordinated with other learning trajectories. Recognizing the needs of individual students and coordinating multiple learning processes in real-time is a distinguishing skill of master teachers (Berliner, 1994; Carter *et al.*, 1987). The complexity and cognitive demands of this task are often under-recognized. Effective design for mobile computing in classrooms needs to take into account and optimize real-time *social* processes in the classroom (Hamilton, Lee, DiGiano, & Labine, 2005). Information about the interaction of individuals with each other and with content can enable the teacher to optimize these processes to improve the overall system and thereby individuals' learning outcomes.

Integrating personal mobile technology into a classroom technology infrastructure can drastically increase a teacher's ability to create a powerful learning system in which all learners can learn better. Design of the classroom technology infrastructure should take into account the full range of a teacher's work flow and instructional activities

A networked technology infrastructure can:

- Automate classroom procedures such as taking attendance, checking homework completion, and creating more time for learning activities.
- Improve teachers' workflow by automatically scoring homework, quizzes, and essays, making information available almost immediately to inform teaching and learning.
- Generate information about student learning *in real-time* by capturing and presenting information about learners' interactions with instructional materials.
- Provide performance support for teachers with the complex, cognitively demanding tasks of teaching, such as diagnosing students' errors and individualizing learning activity for 30 learners simultaneously.

With a mobile computing device such as a thin, tablet-type computing unit, information can be available to the teacher in real-time, anywhere in the classroom, and in the form of easy-to-read graphical displays that support decision making. The teacher can circulate in the classroom and check information about learners' progress at any time. This information informs how she groups students, whose desks she visits, and what kind of guidance she provides to students. It enables her to more effectively diagnose what students know and can do, provide feedback to students, and individualize instruction.

Reliable real-time information about students' learning processes and states enhances teachers' abilities to determine what students know and what kind of guidance they need to reach learning objectives. It enhances teachers' abilities to individualize instruction, and to engineer and optimize learning processes in a way that optimizes the learning processes for learners who are interacting. Another way of personalizing learning is having the right learners interact with each other at the right time. Pairing a learner who needs an extra challenge beyond the assigned task with a learner who needs some tutoring on the assigned task enhances both students' learning experiences. With real-time information about students' learning processes, a teacher can effectively orchestrate these kinds of rich learning interactions. Doing this for 30 students simultaneously optimizes the learning environment for all students and enhances the *cognitive density* of the learning system (Crawford *et al.*, 2004).

Supporting teachers' abilities to engineer a powerful learning environment thus requires work flow support through automation of administrative chores during class (attendance, checking homework) and outside of class (scoring homework and quizzes); data capture; and decision-making support to enhance formative assessment and feedback to students. In the classroom narrative above, even though students have personal computing devices and individualized content, the teacher plays the critical role orchestrating students' interactions with content and providing carefully adjusted instruction during class time. *Teachers*, not technology, engineer classroom learning environments and mediate and orchestrate student engagement with learning materials. Therefore, creating a high-performance classroom requires designing a technology infrastructure that supports teachers and the art of teaching, and makes it easier for teachers to do hard things well. □

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Education's Intertwingled Future

Judy Breck
Author/Blogger

The author provides a look at the transformation the open Internet venue causes for knowledge resources from which students are expected to learn in their education. Knowledge content richly interacts within itself in the Internet venue. Mobiles will amplify this interconnectivity of cognitive content in powerful new ways. Changes are coming, and education should prepare for them.

In the July–August 2006 issue of this magazine, I wrote about the odd online absence that education has maintained compared to other major sectors of 21st century affairs. In this quotation from a recent book about mobile phones, again education is not in the mix:

> Digital convergence brings four (previously) distinct industry sectors in collaboration/competition with each other. Thus, we have Media/Entertainment, PC/Computing, consumer electronics, and telecommunications industries all interacting more closely with each other than ever before. This version of digital convergence is happening all around us.[1]

Although some educator-selected resources are brought in from the Internet through education's walls of ivy, and some learning/teaching is conducted beyond those walls at a distance, the digital universe and education have not converged.

In my summer 2006 article, I said that educators may believe education does not belong in the open chaos of the emerging Internet and I wrote: "What is a

[1]Ajit Jaokar & Tony Fish, *Mobile Web 2.0*. Futuretext, 2006, pp. 91-0-91.

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serious educator to make of subject content created by non-pedagogues bouncing around Google instead of coming up through the channels of vetting, publication, and pre-selected Internet links that have been the tradition?"[2]

The bouncing around on Google is tame compared to what is coming: What will a serious educator be able to make of an open mobile widget that kids learn from being shared virally by hundreds of thousands of students and other people? Think of the sort of sharing that happened when Diet Coke/Mentos videos were viewed by hundreds of thousands of people on YouTube and beyond.

Todd Richmond, who is a Fellow at the USC Annenberg Center, thinks big change for education is in the virtual winds. At a DIY (Do-It-Yourself) Media seminar at the Annenberg Center on October 19, 2006, Richmond predicted that education institutions will be transformed by a "perfect storm" like the one that hit the music industry. Seminar leader Howard Rheingold wrote in a description of Richmond's presentation on the DIY Media Weblog:

> The precipitating phenomenon that could turn open educational resources into a detonator of change would be the advent of digital learning objects that go viral, the "holy grail" of DIY media production; Richmond cited the Chinese Backstreet Boys video, viewed one and a quarter million times on YouTube, as an example of "going viral."…
>
> "Resistance is futile," believes Richmond: although existing educational institutions are not generally embracing a digitally transformed future, "the educational sector will be dragged into the future kicking and screaming by the next perfect storm."[3]

Others have foretold that education would be changed by the coming of the digital age. As far back as 1992, in his best-selling book *School's Out: Hyperlearning, the New Technology, and the End of Education,*[4] Lewis J. Perelman said that education would implode. Perelman was correct in his prediction—he saw from a distance of many years the same inevitability that Richmond sees. It is too bad that over that past fourteen years since Perelman wrote his book the education establishment has not engaged the digital world to work with it in forming 21st century learning. During those years the Internet arrived along with a generation born into the Web world. Richmond uses the phrase "perfect storm" to imply a powerful convergence of factors happening now. In the face of that, can education dig its heels in again? I think the rampant dismissal among today's kids of education as irrelevant is the critical factor in the mix that will bring the storm soon and with force.

A good deal is said and written about how the perfect storm Richmond sees on the horizon will affect the social aspects of learning. The mobile phone is recognized as an important new tool of student social interaction. What follows here is not about social factors, but a look at the transformation the open Internet venue causes for knowledge resources from which students are expected to learn in their education. Knowledge content richly interacts within itself in the Internet venue. Mobiles will amplify this interconnectivity of cognitive content in powerful new ways.

One Mind Learning from One Web

The fact that computers carried in pockets made their way into the global communications picture in the first place as phones with tiny display screens must not confuse what these devices will soon do to make them fundamental to learning. That crucial feature is to browse the Internet. Although first attempts to browse with mobile phones have been very rough, there is no reason to suppose there will be an Internet out there specifically for PCs and some other combination of content sources for mobiles. Instead, mobiles are being modified to support browsing the Internet that PCs browse and efforts are underway to modify Web pages to interface effectively on mobiles.

As the language continues to develop for what happens online, the words Internet and Web are increasingly used interchangeably, as I have done in this article. A related term, "One Web," is a key to realizing that mobiles, PCs, mainframes, kiosks, and other devices will all connect into the same online virtual universe.

The principle of the One Web, as supported by the World Wide Web Consortium ("W3C") is to have "One Web…where Web technologies provide the means of accessing and interacting with content via and between all devices (computing, communications, PIM, entertainment, embedded, transportation, industrial, health care, etc.)…worldwide."[5] The education world needs to get on board here to engage the One Web for learning content, by encouraging their students to do so on their mobile devices.

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[2]Judy Breck, Why is education not in the ubiquitous Web world picture? *Educational Technology, 46*(4), p. 43.

[3]*http://Weblogs.annenberg.edu/diy/2006/10/todd_richmond_on_open_educatio.html* .

[4]Lewis J. Perelman, *School's out: Hyperlearning, the new technology, and the end of education.* New York: William Morrow & Co.

[5]Vision: Web on everything; *http://www.w3.org/2006/Talks/1106-sb-OneWeb-Mobile2/#(5)* .

As the mobile computer-in-the-pocket becomes the main channel by which students access and use the Internet, each of them will have a powerful new individuality in his or her connection to the online universe. Coming from the PC direction, as PCs have become mobile laptops, they too have made the individual's connection to the Internet more individual. In education this is a big change because the practice has not been for students to have individual computers. They have shared PCs, moving from machine to machine during the class day.

In order for the mobile device to become the primary method for browsing, the principle of One Web content is pivotal to the future of global learning. To the extent that educational resources are deliverable by mobiles, they will be accessible to the more than half of the world that is likely to have a mobile but not have access to a PC. As the individual mobile devices carried by students worldwide increase in their ability to bring the content of the Internet into their owners' hands, the content that has been maturing online over the past decade will be at the service of their minds.

DIY by Subject Experts

As the Internet developed and expanded, the primary and freshest sources of most knowledge that education is expected to teach moved to the Internet. While the education industry continued to supply mostly printed materials to schools, experts in knowledge subjects enthusiastically interpreted what they knew digitally and put their DIY (Do-It-Yourself) Web creations online. Some of the Websites created in this way were digitally a bit rough, but the vast majority are superb. Importantly, most of them are open content, free for anyone to use.

There are thousands of examples of DIY subject expert online pages. Almost every museum has open Web pages where curators describe treasures from their collections. NASA offers a spirited Web section for every project it undertakes. Archaeologists post their discoveries on their Websites often before they publish in print. Literature is broadly available online with commentary from poets and scholars. Frequently professors maintain Web pages and/or blogs in which they explain the areas of their field about which they know the most.

Up to now, finding these materials has been left pretty much to bouncing around in Google. As the Internet has matured, finding and linking DIY learning assets through searching techniques has becoming easier and more refined.

Many DIY assets are all already in place—tended by experts for the knowledge they explain—and ready to be browsed on mobiles as they are now on PCs. Like everything online, the DIY subject expert materials are made up of smaller modules assembled into Web pages. The smaller modules could become mobile widgets. Think: Leonardo's sketches, videos from the Mars Rovers, a new skull from a China dig, a Browning poem with commentary.

These digital things are all out there waiting for the perfect storm to lift them into the education venue. The smaller nuggets of digital knowledge will be useable early, as the browsing by mobiles becomes more robust. As soon as a DIY method to modify content for mobile catches on, the subject experts who tend their content could spontaneously launch a tsunami of mobile learning content against the beaches of established education.

Viral: Infectious Knowledge

As knowledge moved online, it nestled into the Internet network structure. It patterned itself cognitively because knowledge naturally connects to other knowledge in an open network environment. Instead of being cubicled by grade, standard, and textbook type, when placed online subject material has been able to interconnect by its meaning. A Website about the pyramids of Egypt links to other Websites about history, engineering, mummification, and writing systems. A Website about DNA links to other Websites about genetics, molecular science, forensics, and biographies of Francis Crick and James Watson. Online, the DNA Website or forensic information Webpage effortlessly links to the mummification Webpage linked to the Egypt Website. Interlinking like that is unimaginable among the usual grade quarantined printed education materials.

Instead of being divided by school subject and grade level (unless these are imposed by Website makers) when knowledge is embedded in the open Internet it becomes viral, infecting related resources by linking to them. It is viral linking when the expert on the content at the Egyptian pyramids Website lists a link to DNA forensics on his mummification page. This idea-to-idea viral linking marvelously enriches knowledge for learning through academic subjects online. As sending nodes of ideas among mobiles intensifies, this rich resource will feed and intensify the perfect storm that is about to hit education.

Viral: Infecting People

Viral also means the activity of one person infecting another person, which has become very big in the online world. On October 8, 2006, the *Financial Times* published an interview[6] with Chad Hurley, CEO of YouTube.com. Here is how the article begins:

[6]*Financial Times*. October 8, 2006; *http://www.ft.com/cms/s/a1628800-578-11db-9110-0000779e2340.html* .

FT: What type of content on YouTube is proving most popular?

Chad Hurley: What we're finding is that since everyone has a chance to participate, you're sometimes surprised at what's entertaining people. So science experiments—people launching Coke cans or whatever with Mentos—now have an opportunity to entertain people.

If you have never seen a video of soda pop exploding upward from a bottle into which Mentos candies have been dropped, you owe it to yourself to watch one. Go to YouTube.com and search for "Mentos Diet Coke." You will be given a selection of videos to watch to observe one of the most popular viral video phenomenon of 2005, and you will observe a little science.

The well-respected science Website *stevespangler science.com* has a full page devoted to explaining how to set off a Mentos geyser from a pop bottle and what makes the often self-soaking experiment work. The explanation begins: "You should know that there is considerable debate over how and why this works. While we offer the most probable explanations below, we also understand and admit that other explanation could be possible...and we welcome your thoughts."[7] Reading on, you will learn some mechanics, some chemistry, and a bit about food science.

The Mentos/Diet Coke and Chinese Backstreet Boys videos demonstrated Web objects gone viral, spreading through interconnected people into the Internet. Small viral items like the videos have a huge potential for migrating into thousands (or millions) of mobiles, moving between them as messages. Educators should be learning how to use this new means of spreading content to distribute the stuff of learning.

Mobiles

Japan, South Korea, Finland, Hong Kong, Norway, and the UK are among the mobile markets approaching saturation, where everyone has at least one mobile, including kids. The enormous markets of China and India are absorbing mobiles at quickening paces. Even though saturation is greatest in developed countries, the majority of mobile phones are owned by people in developing countries, where a high percentage of those mobile owners are youngsters and the stage of first using desktop computers is being largely skipped. As I write this, at least one billion people have access to the Internet by desktops and laptops and over 2.5 billion have mobiles. Enhancing the mobiles so they can browse the Internet is doable and being done. It seems increasingly less likely that everyone on the planet will ever have a stationary computer.

[7]*http://www.stevespanglerscience.com/experiment/00000109* .

So far, the warp speed expansion of mobile networks within the world's youngest generations has been pretty much ignored and abhorred by education. The education establishment has watched—and grumbled a lot—as students have honed their mobile skills by primarily social networking. Meanwhile, the devices the young people use are becoming increasingly effective in browsing the Internet. It will not be long before mobile student networks and online knowledge networks mesh. Things will then become cognitively viral.

In their book *Mobile Web 2.0,* Joakar and Fish describe: "…an open Web driven application capable of aggregating (mainly non-text) content from any phone anywhere in the world. The exchange of information takes place mainly via the Web."[8] What we would think of in these circumstances for education would be the nodes on the network being both students and knowledge—all open to interaction among all the nodes.

It is marvelous to envision the interplay between the network of DNA and mummy information—which would also be part of the network with Web pages as nodes—and the linking into the pattern to students. The students, using their mobile phones, would be connected through the Web to the other students and to the knowledge about DNA and about mummies. The viral interlinking of knowledge itself online is converged with students. A new kind of learning has emerged.

Interwingularity

In the 1960s, Ted Nelson foresaw the coming digital era with rare clarity. He coined words that became basic to its vocabulary: hypermedia, and virtuality. Recently, as the Internet's inherent networked environment is being increasingly understood and utilized, another one of Nelson's words has been popping up in the discourse. In 1976, Nelson wrote:

> Intertwingularity is not generally acknowledged, people keep pretending they can make things deeply hierarchical, categorizable and sequential when they can't. Everything is deeply intertwingled.[9]

The definition of intertwingle derived from Nelson's observation is, clearly, that intertwingled things are not hierarchical, categorizable, or sequential. For our purposes, the word also implies that things infect each

[8]Ajit Joakar & Tony Fish, p. 85.

[9]*Computer Lib: You can and must understand computers now/Dream Machines: New freedoms through computer screens—a minority report (1974), Microsoft Press, rev. edition, 1987.*

other. As adventures in the virtual world move into the future, we will understand intertwingularity more fully.

For now, it is plainly obvious that traditional education is deeply hierarchical, categorizable, and sequential. Those characteristics conflict with the fact that online knowledge, viral objects, mobile networking, and students are increasingly—and increasingly more deeply—intertwingled. For education to continue to respond to the Internet and students with mobiles by pretending it can keep on with lockstep learning hierarchies, categories, and students in set sequences creates painful costs for the dragging that must be done to pull learning into the future.

Why not intertwingle? Why does education not converge enthusiastically with the digital world? Shouldn't educators call on the technical sector to enhance mobile devices into the primary digital tool of personal learning? Why don't educators demand the core enhancement in optimizing mobiles be the facility to browse the Internet and exchange digital learning objects virally? Wouldn't many woes about learning today be solved by education's digital convergence that would harness full intertwingularity of students and online knowledge?

That convergence would include embracing the DIY learning resources already placed and maintained online by experts. Embracing means no longer spending billions of education dollars to duplicate in print the knowledge available at no cost online. Education can walk away from its obstructionist role of walling resources by publisher, grade, and standard. Education's digital convergence will be real when intertwingularity is fully operational for learning.

These changes are coming, whatever education does. The forces of the storm that is roaring toward the education establishment are gathered and moving. The upgrading of the mobiles is underway and happening fast. The spread of mobile computers is also a foregone conclusion, with at least half of the world's population expected to have them in a matter of months, and virtually all within the decade. Already, the majority of people who have the mobiles are in developing countries, where the handheld digital device is leapfrogging the need to build wired connectivity.

Education intertwingularity is coming in the form of the perfect storm. In its wake, the global golden age of learning will dawn. □

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Educational Technology Classics

Education's Age of Flexibility

Francis Keppel

At the start of the 20th century, the world of science was in what used to be called an interesting condition—that is, pregnant, about to give birth.

Today I think education is in a similarly interesting condition. We seem to be at the threshold of some major new discoveries about learning and the processes of education. We would do well to be prepared for them.

There was a time, not too long ago, when education was thought of, more often than not, as its own little universe, as a thing apart from the rest of society.

That is no longer nearly so true. Education has become more and more involved with the rest of society, with government, with industry, with all manner of agencies and institutions. The problems that beset all of us—urbanization, the population explosion, automation, communications, etc.—are also education's problems, both in the sense that they affect education and in the sense that education is helping to tackle and solve them.

There is still another new aspect to education that is even more indicative of major changes to come. Education in the past consisted largely of fixed amounts of knowledge to be absorbed in fixed periods of time, of known concepts and known blocks of factual matter. In such a framework, the various aspects of education—instruction, materials, architecture, testing—had fairly explicit and well-determined roles.

Francis Keppel was chief executive officer of the General Learning Corporation when this *Educational Technology* article was published in January of 1967. Previously, he served as U.S. Commissioner of Education and had been dean of the Harvard Graduate School of Education. This is the sixth in a continuing series of articles from early issues of this magazine.

Now that is less the case. Education daily becomes more fluid and dynamic, in terms not only of its own processes, but also of its objectives and its end-products. What is most significant, however, is that this is not just a symptom of its present interesting condition. It is rather a characteristic of its new role in society, and continuing change may well be the rule rather than the exception, just as it is for an increasing number of institutions in our society. All the forces within education will have to adapt to changes that will continue to come from a number of different directions. There are at least four areas in which the need for such adaptation is fairly obvious:

1. First, of course, there is new knowledge of all kinds, proliferating in almost every direction. It not only will be taught to the young, but also will move into the content of the necessary continuing education that most of us will be constrained to undergo.
2. Next come new approaches to the content of education, new curricula, and hosts of new interdisciplinary approaches to the humanities and sciences.
3. The third thing to which we need to adapt are the new and improved tools for teaching and for learning. New kinds of hardware, as well as such new techniques as linear and branched programmed instruction, will federally give us greater accessibility to the mind of the learner.
4. Finally, we have reason to hope that we may be approaching a new appreciation of the mind and how it appears to work. The growing knowledge and familiarity with cognition, memory, transfer, and conceptual understanding will surely give us insights into all mental processes, including the learning process.

I called these the “obvious” areas of adaptation. What is less obvious, to me at least, are some of the ways we need to adapt to these changes—in short, the kind of ***flexibility*** that is required.

Should we, for example, build elements of flexibility into our teaching and learning environment, at least to the extent that the requirements of architecture and basic creature comfort permit? This is far more difficult than it may appear to be at first blush. To a certain extent, all environments are learning environments. Since the home and its surroundings make up the dominant environment of the young, we can observe that this becomes an extremely flexible learning environment for some, and a fairly rigid learning environment for others. What is unfortunate is that the least flexible environment engulfs those who are already disadvantaged in other ways.

Another area of flexibility, it seems to me, is in testing, and I know that we are well started on this road. By becoming increasingly sensitive to the consequences of education, testing can bring greater flexibility to the whole learning process. Such electronic memory and logic devices as the computer show great new promise with their capacity for making minute measurements of the pupil’s progress, and for integrating the instruction and testing processes.

Yet, flexibility comes no more easily to education than it comes to other institutions in society, and no more easily than it comes to you and me, when we take great pains to shake off old habits and routines. Education, as a matter of fact, has had a long heritage of rigidity throughout most of the world.

There are many heartening signs of a willingness to innovate in American education, to try a wide assortment of curricular experiments, and to accept or reject them on their merits.

Yet it is clear that educational institutions need to demonstrate still more willingness to innovate and to experiment in more new directions. One new tool, for example, is systems analysis, which has already been used successfully in both industry and government. There is every reason to believe that, with the application of sufficient brainpower, it could work equally well for education.

The resource now available to education that is by far the most flexible is the teacher. To take advantage of that fact, systems analysis may help to make better use of the strengths of the teacher. Few today could argue that the present administrative arrangements provide full use of teacher flexibility. The case can be made that present arrangements, by and large, do not encourage teachers to become more adaptable to change situations. Rather than seek to have the teacher reach out for new techniques, new methods, and new subject matter, they may tend to switch the teacher onto fairly narrow-gauge tracks that help simplify the problems of administration itself.

A good job of systems analysis and planning would not only seek, therefore, to achieve maximum effectiveness from all kinds of teaching materials and equipment, but would build a high degree of teacher flexibility right into the system.

As far as education is concerned, of course, the major stumbling block to reaching such a goal is reaching agreement on goals and objectives. We need to know what we want to be flexible for, and there is no more difficult task.

In education we have been called technologically backward. Many of our tools and techniques have not changed for decades, even centuries. This either means that the best ways to teach and learn were discovered hundreds of years ago, or it betokens resistance to change and a lack of flexibility. There is something of the truth in both inferences.

I think, though, we can look with hope to the future, to changes that are already under way, to other changes that lend promise to the future, and to a mounting spirit of willingness to accept change in education. □

Point of View:

Learning from Serious Games?

Arguments, Evidence, and Research Suggestions

Richard E. Clark

My goal in this column is to offer a brief view of the current state of the evidence for the educational benefit of games, discuss a few problems with existing studies, make some suggestions for the design of game studies, and suggest a possible application of games in order to invite a discussion about the design of future serious game research, evaluation, and implementation.

Evidence for the Learning Benefits of Serious Games

The widespread interest in the learning and motivation benefits of serious* video games has not been balanced by a robust discussion about evidence for their pedagogical effectiveness. The argument in favor of their educational use is very appealing. Games are enormously popular among adolescents and young adults—the age group who have arguably posed the greatest challenge to educators. In 2005, the sale of approximately 248 million computer video games was a 10 billion dollar market. No reliable figures are available for the serious games sales, but Sawyer (2005), who has authored books on game development, provides estimates permitting a guess that their gross revenue is about 500 million dollars. Games appear to offer a very appealing environment in which to provide individual problem-solving practice and competitive, team-based challenges. Advocates for games suggest that they are highly motivating vehicles that could support learning, problem solving, and collaborative skills.

Yet the use of games for education is apparently not widespread at this point. People who support the use of games in education have noted that the large audience for the more complex, interactive video games tends not to include the older adults who make educational decisions. The implication is that educational decision-makers may, out of bias and/or a lack of understanding, discount or discourage an investment in serious games and so ignore an innovative way to motivate, teach, and train.

On the other hand, the development cost of serious video games is considerable (*eSchool News online* in 2006 estimated a development cost of between 1 and 10 million dollars for commercially viable serious games) and the state and federal funds available to support education and training are limited, so it seems reasonable to ask for evidence to support increased investment in games. Sawyer (2005) in an essay directed at entrepreneurs who invest in serious games offers an analysis of serious games research titled "Research gap exists but isn't hurting things yet," where he goes on to write:

> We still are dealing with a huge research gap in serious games, but so far it hasn't hurt things because people are still getting new projects online. At some point, however, the justification and design issues related to determining the return on investment and outcomes from game-based approaches may become too hard to overcome without more and better research. There is, at this time, not nearly the same fervor for research as there is with building, and it will continue to be this way for a while. We can only hope to pick up some important pieces with the amount of research that is taking place.

The "important pieces" will come from research that asks some very direct questions about the motivation and learning benefits of serious games, such as: Do people who play serious games learn enough from them to justify the investment when games are tested against viable and less expensive alternative ways to teach the same knowledge and skills? Do games

*The "serious" qualifier indicates a game that is intended to support learning and/or motivation to learn. The Wikipedia definition suggests that serious games are "games used for training, advertising, simulation, or education that are designed to run on personal computers…or video game consoles (such as the Xbox or PlayStation 2)."

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motivate players to learn more than other, less expensive alternatives? Are some skills or knowledge most effectively and/or efficiently taught via serious games?

Empirical Research on Learning and Motivation from Serious Games

A number of individual studies, reviews, and meta-analytic studies of the benefits of games have been conducted, and a few of them have been published recently in peer-reviewed journals (for example, Chen & O'Neil, 2005; Gredler, 1996; Mayer, Mautone, & Prothero, 2002; Moreno & Mayer, 2005; O'Neil, Wainess, & Baker, 2005). All of the different reviews currently available have reached almost identical conclusions. One way to state the common conclusion in the reviews of serious games research is that people who play serious games often learn how to play the game and some factual knowledge related to the game—but there is no evidence in the existing studies that games teach anyone anything that could not be learned some other, less expensive, and more effective way. More surprising is that there is no compelling evidence that serious games lead to greater motivation to learn than other instructional programs.

One of the most comprehensive and helpful reviews of serious games was conducted by Chen and O'Neil (2005) and O'Neil, Wainess, and Baker (2005), who located over 4,000 articles published in peer-reviewed journals, yet found only 19 studies where either qualitative and/or quantitative data about learning or motivation from games had been assessed. They provide a detailed analysis of the learning and transfer measures used in all 19 studies and concluded that "…positive findings regarding the educational benefits of games…can be attributed to instructional design and not to games per se. Also…many studies claiming positive outcomes appear to be making unsupported claims for the media" (O'Neil *et al.,* pp. 461–462). Their use of the term "instructional design" was intended to highlight the occasional use of instructional methods such as providing examples, classification practice, and problem-solving routines. They make the point that all of the methods used in games could (and have) been used effectively in non-game instructional programs and are not unique to games. A similar result was reported in an earlier review by Gredler (1996). None of the peer reviewed studies reported compelling evidence that games produced significantly more learning or motivation than other instructional platforms.

Industry, Government, and Military Evaluation Studies

One might expect a less conservative and more optimistic view from industry, government, or military sponsored surveys of gaming research because of the high level of investment in those sectors, most especially the military. Military trainers in many countries have invested in serious games for training. Yet an excellent technical report by Hayes (2005) for the Air Force training command provides a very thorough review of the past 40 years of research and reviews of research on instructional games and "simulation games." He concludes that "…the research shows no instructional advantages of games over the other instructional approaches (such as lectures)…. The research does not allow us to conclude that games are more effective than other well designed instructional activities" (Hayes, 2005, p. 43). He makes the point that only poorly designed studies find learning benefits from games. In most cases, poor design implies that the learning benefit of a game is compared with not receiving any game instruction or engaging in a non-educational exercise. What, he asks, can you conclude about the "relative" benefit of games when you do not compare them with any other way to teach or learn?

Problems with Existing Serious Games Research

Readers may be able to point to other publications where reviewers have presented evidence that serious games result in increased learning or motivation. This includes early attempts at meta-analysis of studies (see, for example, the studies referenced by O'Neil, Wainess, & Baker, 2005). Yet when the specific studies or meta-analytic reviews supporting these more optimistic claims are examined, they tend to ignore most of the issues listed below:

(1) *Prior Knowledge Differences Are Important:* Chen and O'Neil (2005) note that most empirical studies of games avoid giving pretests of knowledge so that we are in the dark about whether people whose game-inspired learning was actually known before the experiment began or whether people in the game knew more at the start than people in a control group.

(2) *Comparing Games with Nothing Is Useless:* As Hayes (2005) concludes, most studies claiming learning benefits from games tend to compare a group learning from a game with another group who receive no instruction or engage in an activity unrelated to the learning that is being measured. Nothing is learned about the

relative benefits of games as instructional tools from this approach.

(3) *Serious Games Are Often Confused with Simulations:* Nearly all reviewers mention this problem and remark that it makes the interpretation of studies nearly impossible. Gredler (1996) provides a very useful set of operational definitions for serious games, simulations, and related constructs that are often confused by researchers. We can't compare the results of serious game studies where different definitions of games are employed.

(4) *Opinions About Learning and Motivation Are not Reliable:* Chen and O'Neil (2005); O'Neil, Wainess, and Baker (2005); and Hayes (2005) all suggest that most studies that report learning or motivation benefits from games only ask students whether they learned or were motivated—they do not provide any direct measures of learning (such as recall of facts or the application of problem-solving strategies) or motivation (such as increased persistence or mental effort). Student opinions about learning and motivation have been found to be highly unreliable and often in conflict with direct measures when both are gathered.

(5) *Pedagogy Decisions Are Critical:* Chen and O'Neil (2005) note that many games appear to employ unguided, discovery, constructivist, or problem-based learning pedagogy (as opposed to more structured, fully guided, direct instruction). This practice leads many reviewers to wonder if people who design serious games have an adequate grounding in pedagogical methods. Reviews of research on these unguided, discovery methods for the past half century have concluded that they are less than half as effective and efficient as guided, direct instructional methods (see, for example, Mayer, 2004; Kirschner, Sweller, & Clark, 2006).

Four Suggestions for the Design of Future Serious Game Studies

All rational suggestions for improving learning and/or motivation deserve our consideration. We also have to be open to the possibility that intractable problems might be solved by novel and surprising methods. Innovative programs are often developed before solid evidence is available to determine their impact. Serious games are not new, and we do have well-designed studies to help us make a decision about the future. At this point and in my view, that evidence clearly indicates that games do not teach anyone anything that cannot be learned more quickly and less expensively some other way. Thus, I personally doubt that a "research gap" exists. When a number of well-designed studies (such as Mayer, Mautone, & Prothero, 2002; Moreno & Mayer, 2005), and reviews of other studies (Chen & O'Neil, 2005; Hayes, 2005) all reach similar, negative conclusions, the only gap remaining is the one that separates enthusiastic expectations and negative empirical results. Yet if readers disagree, the next generation of research on this topic must be designed so that new studies reflect intelligent design criteria that will result in wide acceptance of results. Those criteria include:

(1) *Measurement:* Use reliable and valid tests of learning and motivation before, during and after games. O'Neil, Wainess, and Baker (2005) provide an excellent discussion of different approaches to measuring learning and offer suggestions.

(2) *Game Pedagogy:* Build in robust and evidence-based pedagogical and motivational strategies specific to games and design and studied to get evidence about their learning and motivation impact. If an instructional method can be used in a game or outside of a game with the same benefit, explain why we need the game.

(3) *Comparison Treatments:* Offer a viable, robust non-game alternative way to teach the same knowledge that, if possible, uses the same or similar pedagogical strategy. Avoid comparing games to weak, "straw man" alternatives.

(4) *Cost-Benefit Ratios:* Provide estimates of the cost of developing and delivering the game and the alternative treatment. Since much of the research in this area yields "no significant difference" results, treatments with the same or similar learning and motivation impact may have very different costs.

A Potential Educational Benefit from Games

As of now, the evidence is solidly against the proposition that games will replace direct instruction. If we can accept that evidence, we might be able to consider other potentially valuable applications. For example, games could provide a critical and currently missing component for education and training by aiding the ongoing practice required for transfer.

Games (and simulations) are promising vehicles that could motivate students at all ages to engage in the extensive, long-term practice that is necessary to tune, automate, and transfer complex skills after direct instruction is completed.

Current views of complex learning and the instructional strategies necessary to support transfer indicate that our failure to support "whole task practice" over time has limited the effectiveness of past instructional design and delivery strategies (see, for example, Clark & Elen, 2006). Games designed to support transfer are ideal vehicles to motivate people to practice and accept corrective feedback. Game-based practice can occur in an increasingly immersive environment where contextual cues, problem difficulty, and novelty can be varied based on the progress made by individuals and groups. Games also provide an ideal setting for group or team practice of analysis and problem solving.

The knowledge integration and transfer goal is very important in industry, government, and military contexts. In work settings, people who are trained often do not have an immediate opportunity to apply what they have learned for some weeks or months after they complete training. Knowledge learned in training decays rapidly if it is not continually applied. Ongoing practice is also critical in formal education settings where complex knowledge must be constantly integrated as mental models and other forms of conceptual knowledge are being constructed by learners. □

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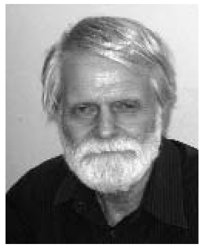
Topics for Debate



Alexander J. Romiszowski

Mobile Phones in Africa:

Transforming Society and (Maybe) Education

An African Scenario in 2003. The country is Mozambique. I was contracted to perform a baseline study and evaluate progress on the planning and implementation of an "Open School" pilot project. This was in the predominantly rural and sparsely populated Province of Nampula, situated in the north of the country. At that time, only about 6% of the secondary school age children of Mozambique were graduating from high school (and even lower in this region).

The Open School project has been applied in a variety of forms in many developing countries, in order to address problems of limited access, especially in secondary and high school education. Perhaps the largest and best-known application of this model has been in Indonesia, where the Sekolah Menengah Terbuka (Open High School) model was first used on a pilot scale in the 1970s, and then in the 1980s and 1990s became the principal manner in which access to high school education was extended to all. Similar approaches have been adopted, with varying levels of success, in several Asian, Latin American, and African nations.

Basically, this model extends the existing secondary schools by linking them to a network of local learning centers. These learning centers typically have not been "hi-tech," but have consisted simply of a space, perhaps in a local church or mosque, where (mostly print-based and some audiovisual) learning materials could be stored and accessed, and where some local tutorial services could be provided by someone, not necessarily a qualified teacher, who would receive some special training in how to support local students in their study of the learning resources.

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In the case of the pilot project in Nampula, well-designed, print-based, self-instructional materials had been developed by staff of the Commonwealth of Learning in Vancouver, funded by the UK government. The teachers in the high schools of the five participating Districts (like counties in the USA, not school districts) were trained to perform their special duties and, at the time I was performing my study, were engaged in selecting the first cohort of students. I particularly recall my days spent in Moma.

The town of Moma is actually a small seaside fishing village, but it is also the capital of quite a large District that goes by the same name. The candidates for the Open School project had traveled in from all parts of the District. Some had walked, or ridden a bicycle, 50 or 100 miles from their home village to the secondary school in Moma.

By what means, though, and how frequently, were the distant students going to make contact with their tutors? There was no public transport, and when it rains, the roads are impassable. There was no effective postal system, and no telephone link from Moma, except to the District capital by primitive radio-telephone. Furthermore, in this pilot project, there was no provision for local tutorial support, as there was nobody available or qualified to give it!

Other questions were concerned with upgrading teaching resources. Computers? Forget it! For one thing, there was basically no electricity in most of the existing high schools. In Moma, there was a diesel-powered generator that would be switched on at sunset and off at 9:00 pm—three hours a day was all the diesel fuel they could afford.

That time was 2003–just four short years ago! Have things changed? You bet–and largely due to the expansion of ***mobile telephony infrastructure***.

Africa 2007: Explosive–and Intelligent–Use of Mobile Telephony. In December 2006, as part of the work I am currently performing for the UNDP initiative to promote ICT for Development (ICT4D), I attended a session at a workshop on the use of ICT in education, held in the interior of Mozambique. Some participants raised concerns about having to learn about ICT while, in their settings, the basic infrastructure is still lacking. The facilitator responded through a provocative question: "Who of you is not using a cell phone? It turned out that everyone in the room owned a personal mobile phone, and this fact helped to explain how near ICT was to them.

Africa is currently the fastest growing mobile phone market in the world. Over the past five years, the continent's mobile phone use has increased at an annual rate of 65 percent, or twice the global average. For example, In June of 1999, Kenya had 156,000 mobile phone subscribers. By the end of 2004, the country had 3.4 million subscribers, and by June of 2006, this number had grown to around five million–all this despite the fact that only about 200,000 Kenyan households have electricity. People living in rural areas have experience playing radios or record players using car batteries or a combination of battery and solar panels. Nowadays they are using the same equipment to recharge their cell phones.

This explosive growth led the BBC to produce a series of

TV programs, screened in January 2007, on the impact that the mobile phone revolution is having on life in Africa. Paul Mason, the BBC's "Newsnight" business correspondent, traveled throughout Kenya, interviewing people. He reported on events such as the reaction in Kibera, Nairobi, described as "Africa's biggest slum," to the problem of eviction by developers who have often illegally "bought" the land from corrupt local government officials: "One day the bulldozers arrive and your house has gone." But not any more–in 2006, when eviction threatened the residents of Kibera, an activist group used mobiles to call thousands of people from many different settlements to sit down in front of the bulldozers.

As I was writing this column, in Mozambique, I read an article by Terry Calhoun, in the 2/15/2007 edition of *Campus Technology,* an online newsletter: "I knew that in many countries, texting was a primary communication method–but my first exposure to the concept of large-scale, one-to-many communication via text messaging came with the news accounts of the evacuation of extranationals from Lebanon during…hostilities there in 2006–the Swedish government used a series of text messages to get its citizens out of Lebanon, even before the United States had seriously mobilized its effort to just begin getting Americans out." But the Kenyan slum dwellers were using this technology even before the Swedes in Lebanon! And it is interesting to note that the above "gem" was Calhoun's way of introducing the main theme of his article–how USA universities are learning to use text messaging: "Many students are beyond regularly checking e-mail, so sending important and timely communications that way is increasingly fruitless."

Mobile Tech in Africa: An Alternative Infrastructure and Business Model. There are signs that Africa is inventing ways to use mobile phones that are hardly imagined in the developed world. In Africa, landline infrastructure has been so poor that very few people could make a phone call at all. Rather than replacing existing, functional infrastructure, mobiles in Africa have created a new and different infrastructure. For example, most North American mobile phone users receive a bill for their usage every month. This model relies on infrastructure that is missing from many African economies: street addresses, a functional postal system, systems to check consumer credit, and use of checks to pay bills. So, mobile network operators in Africa started selling scratch-off phone cards that allowed use of phones on a pay-as-you-go basis. This strategy has led to an explosion in phone use, as well as creating thousands of new street-vendor jobs.

The community payphone is another innovation. These payphones are operated by local entrepreneurs–ordinary citizens who own a phone, buy airtime from the network, and subsequently sell it to local people who don't own phones themselves. A recent survey reports that 97% of Tanzanians now have access to a mobile phone, thanks to the community payphone model. Similar figures are reported by most Sub-Saharan nations.

What About Education 2007–A "Great Leap Forward"? European R&D scenarios suggest that the necessary technologies and some relevant tools and applications have been available for some time–just waiting for the communications infrastructure to catch up. This has happened, and the time is now ripe for significant progress in technology-based learning, principally through intelligent applications of mobile telephony, in both voice and text mode.

At about the time that this column will be published, a major conference focused on ICT applications in Africa (IST–Africa2007) will be held (May 9–11, 2007) in Mozambique (see, *www.ist-africa.org*). IST–Africa is an ongoing program whose goal is to apply the results of European ICT-related R&D to African problems.

This event may well promote discussion, and maybe action, on the redesign of earlier initiatives, like the Nampula Open School project, to take advantage of the newly accessible, and relatively affordable, African mobile infrastructure. Among over 130 papers and workshops accepted for presentation at the IST–Africa2007 conference (55 from African nations and 78 from elsewhere), there are 25 that address technology-enabled learning. Five of these deal with aspects of mobile technology, and it is significant that four out of these five are from Africa. So, here is one further sign that Africa may contribute to a "great leap forward" in the intelligent use of mobile telecommunication for educational purposes.

There are also some ongoing USA–Africa "joint ventures" that may yield promising results. Nathan Eagle (Massachusetts Institute of Technology) and Peter Waiganjo Wagacha (University of Nairobi) have developed a mobile phone programming curriculum and are offering courses in both the USA and Kenya. The courses, in addition to teaching the technical skills of programming mobile applications, have an "emphasis on opportunity analysis and product marketing." But will they direct some of the entrepreneurial energy latent in Africa toward "social applications development," to address some of the enormous needs of (especially rural) populations in Africa, in areas such as health, community, and education? I sincerely hope so.

I am convinced, however, that, one way or another, we are on the verge of witnessing massive transformations in African education, both in terms of access and quality, as a result of intelligent applications of mobile technologies. As the slum dwellers in Kibera demonstrated, these technologies enable the people in the communities to take control of their destiny. Who said that schools have to be set up by a central government? That's not how they came to be set up in early village societies. Africa may pioneer the mobile community school in the Global Village. □

In order to post any comments on the views expressed in this column, or to add any further contributions from our own particular vantage points, join me at the following URL: ***http://www.tts-global.com/blog/*** .

Learning Trails

Traversing the European Ed Tech Scene

Kevin Walker

Danube in the Distance

In 1922, the Hungarian artist László Moholy-Nagy used his phone to compose five "emails." More accurately, he composed pictures made of "email." "Technology," he said, "is the pathbreaker here."

Okay. We all know that today's email wouldn't be invented for at least 40 years. In fact, television was yet to be invented, and computers were rooms full of mechanical differential gears. The telephone of course existed, with millions of phones in use when Alexander Graham Bell died that year. What Moholy did, in fact, was to pick up the phone and order some pictures from a sign painter, designed to his specification—pictures made of *email,* which is German for enamel.

Moholy was interested in new technologies, and is perhaps best known for his photomontages and graphic designs balancing text, photos, and abstract shapes. His quote above refers to his belief that in 20th century art, technology had superceded craft with new methods for making and reproducing images. "It is not the person ignorant of writing but the one ignorant of photography who will be the illiterate of the future," he said (Benjamin, 1999, p. 155). And so he was a teacher as well as artist, at the Bauhaus in Germany, where he aimed to unlock his students' creative potential with new technologies.

Communications Convergence

Technology still looms large in his native Hungary, and the issues that concerned him remain important there—long-distance communication, different forms of representation, and constructivism (though of the pedagogical, not artistic, kind). Several future-looking Hungarians are studying these with regard to education.

Look no further than this coming September, when Budapest will host the annual conference of EARLI, the European Association for Research on Learning and Instruction *(http://earli2007live.nqcontent.net/nq/home/)*, as well as the conference "Towards a Philosophy of Telecommunications Convergence" *(http://www.socialscience.t-mobile.hu/call_en.htm).*

What better place? Hungary ranks 23rd in the world in the number of Internet hosts per person (*Economist,* 2005).

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Informatics is a compulsory subject from the fifth grade onward. All universities have broadband connections, and all 5500 primary and secondary schools have Internet access. The Hungarian SchoolNet links every school and holds over 200,000 reusable Learning Objects covering the entire national curriculum, plus lesson plans, methodological and subject-specific support, and basic learning blocks for teachers and students.

The Technical University in Budapest *(http://portal.bme.hu/langs/en/default.aspx)* does probably the most innovative research in the country, in a broad technical sense. András Szûcs, the head of EDEN, the European Distance Education Network *(http://www.eden-online.org/eden.php)*, is based there. EDEN is the largest such network in Europe, established in 1991; it will hold its own conference in June, in Naples, Italy.

Media and Microworlds

Eötvös Loránd University *(http://www.elte.hu/en/)*, the biggest in Hungary, was the first to introduce computers into teacher training programs. There, Márta Turcsányi-Szabó started the TeaM (Teaching with Multimedia) lab *(http://teamlabor.inf.elte.hu/indexe.html)* in 1997. One of its ongoing activities is the development of subject-oriented microworlds for elementary and special education. These are developed in Logo, and include a tool for teachers to create their own microworlds. One aim has been to enable children who speak different languages to share their work; this is not surprising coming from a country whose language is not really spoken by non-natives. English-language versions of TeaM lab's microworlds, called "Creative Classroom," are available through Logotron *(http://www.logotron.co.uk/)*.

Similarly, much of TeaM lab's work is internationally focused—for example, its TeaM Challenge games *(http://matchsz.inf.elte.hu/kihivas/Index_en.html)*, developed by teachers in training. Hungary joined the European Union in 2004, and the lab participates in many EU-funded projects.

One project of TeaM lab that Moholy might be proud of is the "Picture communication portal" *(http://matchsz.inf.elte.ht/Colabs/colaboratories/portal/pict_com.htm)* for children age 10 to 14 from different language cultures, which uses examples from contemporary art pieces for visual modeling, boosting creativity, and sharing their work in a virtual community.

Also of interest is their work on extending mind mapping, into "modular mind maps" (Turcsányi-Szabó & Pluhár, 2003), and "adaptive knowledge maps" (Kaszas & Turcsányi-Szabó, 2003).

Turcsányi-Szabó is now starting a new group at the university called Media Informatics and Technology. "We shall shift a bit away from teacher education," she says, "and concentrate more on the technologies needed for effective learning—or business for that matter."

Mobile Minds

Another strand of research in Hungary concerns mobile learning. Two-thirds of the country's population have mobile phones; it ranks just behind South Korea (*Economist,* 2005). The structure of SchoolNet is such that its Learning Objects can be served mobile phones or palmtops.

T-Mobile is the biggest of three mobile providers, and one of the sponsors of the "Towards a Philosophy of Telecommunications Convergence" conference. The event is organized by Kristóf Nyíri of the Hungarian Academy of Sciences *(http://www.mta.hu/)*, and T-Mobile has sponsored his research for several years now. He has been developing a theory of mobile learning, centered around conversations, and the notion of a "networked mind." A mobile phone is, he says, "a machine which corresponds to deep, primordial human communication urges" (Nyíri, 2003, p. 12). His theory draws from many sources, including the venerable American philosopher John Dewey. It was Dewey who said (in 1916) that the printed word can enable societies that are not based on proximity. As Nyíri notes, Dewey later added that conversations, however, have "a vital import lacking in the fixed and frozen words of written speech….Vision is a spectator; hearing is a participator" (Nyíri, 2002).

Zsuzsannna Kondor, another philosopher at the Hungarian Academy of Sciences, studies a related aspect of mobile communication—that of representation, as related to cognition and literacy. Specifically, she looks for the perceptual and cognitive ground of the difference between verbal and pictorial representations, arguing for a close inter-relatedness of cognition and its representational-communicational framework.

On mobile phones these modes of representation are manifest in the form of SMS (text messages) and MMS (multimedia messages). "The quick and successful adaptation to mobile telephony," she writes, "suggests that people already possess—at least, in part—the cognitive abilities and capacities (required by newly acquired instruments" (Kondor, 2006). But while text messaging has been readily adopted, multimedia messages thus far have not, "because we are not equipped with shared and unequivocally interpretable schemes of images." This is changing, however, as "the rediscovery of images is an ongoing process," stimulated by technology (Kondor, 2005b).

Technology and Tradition

Kondor reaches back to other Hungarian philosophers from the early 20th century to trace how communication technologies have shaped our notions and practice of cognition (Kondor, 2005a). József Balogh, for example, saw the development of the printing press, and the subsequent practice of silent reading, as the first step toward an "over-mechanization" of the word. Typewriters, recording devices, and telephones all made reading and writing easier, but also stimulated superficiality and speediness—a charge similarly leveled at email and SMS today.

István Hajnal, writing in the 1930s, drew similar conclusions, saying that new technologies required new cognitive skills. Specifically, writing and literacy abstracted our consciousness away from the everyday context of spoken, face-to-face orality.

Not surprisingly, Kondor also draws from North American thinkers on communication technologies such as Andy Clark of MIT, and Marshall McLuhan's Toronto circle. If literacy separated individuals from their communities, contemporary social technologies can reconnect them, she says, while also creating whole new types of virtual communities.

Social intelligence, according to Merlin Donald, is closely related to representational skills. "In the age of multimedia," Kondor writes, "the ability to clarify the difference between verbal and pictorial gains special importance" (Kondor, 2006). Now that media and communication are so mobile, they break down the public and private spheres; hence, she says, the traditional role of schools must change. What does it mean when a teacher can be constantly "present," all media are ready at hand for instant communication, and our memories can be easily stored externally?

These are challenges, and technologies, that Moholy would perhaps appreciate. It wasn't until he visited his friend Walter Gropius in 1936, around the corner from where I now live in London, that his work became well known to the Anglophone world. Thanks to long-distance communication and collaboration, the work of the contemporary Hungarians mentioned here is already better known. But mobile technologies accompany mobile lifestyles, and I'm always grateful when we are able to meet face to face. I hope to see some of them in Budapest in September. □

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New Issues, New Answers

Marc Prensky

Who's in Charge?

Who Should Set and Control IT Policy in Our Schools?

As I travel the world speaking at schools, here is one issue that rarely fails to raise its head: How "open" should school IT systems be? What should be blocked, and to what should students have access? The entire Internet? School-approved software only? E-mail? IM? Cell phones? And, most importantly, "Who decides?"

There is no right answer to this, as it depends on many factors, some very specific to particular schools or districts. And while my own preference, as you may have guessed, is for as much openness as possible, it is not my objective here to advocate that position.

What I want to question, rather, is how these decisions are arrived at. I have heard many teachers complain about "IT tyrants" blocking everything they want to use in the name of the kids' safety (which is really sometimes the IT people's *own* safety, so they cannot be "blamed" for any incident that might occur).

On the other hand, I have heard many IT managers say "we're happy to open things up—it's the teachers afraid of the kids doing bad things, or the administration afraid of being sued, or the parents afraid of predators—that prevents us."

And where are the students in all this? As in most things concerning their own education, students are generally ignored. Except, of course, when they "screw up." If just one student sees some porn or gets to MySpace on a school computer, the entire student body is often labeled irresponsible and suffers the consequences. Remind you of any old prison movies?

I don't imagine there is a single school anywhere that doesn't have at least one student who knows how to get around any filters IT can devise. And I would personally maintain there would be more useful learning in having *all* students learn to do this than in whatever they get from what it is that any IT tyrants (whoever they are) do allow.

But whether you agree with that or not, here's my point: The technology that students are allowed to see and use very much affects the quality of their 21st century education. We all know there are several stakeholders in the decision of what kids can do and see: Teachers, IT people, administrators, parents, and, most importantly, the students themselves. So how can any school make responsible policy decisions until all of these groups have had a chance to talk to each other and present their points of view?

My strong recommendation is that at *least* once each year, preferably before any decisions related to IT policy in the school—from what should be filtered, to the use of cell phones, and everything in-between—are made, the head administrator gather representatives from all of the stakeholder groups on stage, preferably in front of the entire student and faculty body, for a discussion and debate. Because technology changes so rapidly these days, I recommend that this be an annual start-of-the-year event.

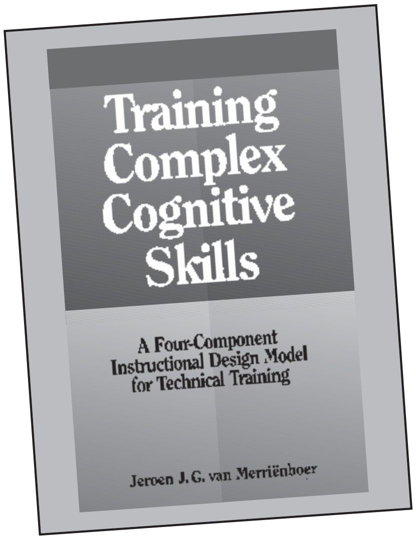
In preparation, all factions should gather information about what other schools around the world are doing (it varies widely). Student views should be carefully considered (it *is* their education after all). Administrators should avoid letting the "scare tactics" of a group's citing one or two bad incidents determine policy. Remember, although there may be bullies in the schoolyard, we don't (or at least I hope we don't) ban recess, because we see the value of recess to all, and recognize the need is to deal with the bullies, not to eliminate exercise for everyone.

Yes, our children are growing up in a world of technology that scares many adults. But they are scared more, I think, because the adults have little idea what is actually going on, than because the dangers to their kids are imminent. Students should, of course, be taught responsible online behavior, just as they should be taught to look both ways before crossing a street. At some point, though, we let our kids go places on their own. Savvy parents and teachers don't let the existence of danger force them into keeping their kids in a technology bubble. Savvy administrators shouldn't (and don't) run from the risk of parent complaints or lawsuits, which happen with or without technology, and do what is best for the kids.

Students hate, and are aware that their education is suffering, when a site they know is perfectly reasonable to use for their schoolwork comes up as "blocked" because of some overly zealous protection scheme. They know we are moving quickly to Internet 2.0, where participation and input are more important than just finding information. Most of them know, or can be taught, how to act responsibly. It is, of course, possible for IT to lock things so tight that there will almost never be an "incident." But the penalty we pay for this is the breadth and quality of our student's 21st century learning.

To make good policy, we need to get all the affected groups—including the students—in one place and "talk it out." In doing so we must remain very aware of whether the "protection" any faction advocates is for the benefit of the students, or for itself. □

Marc Prensky *is an international speaker, writer, consultant, and game designer in critical areas of education and learning. Marc can be contacted at* ***marc@games2train.com*** *.*



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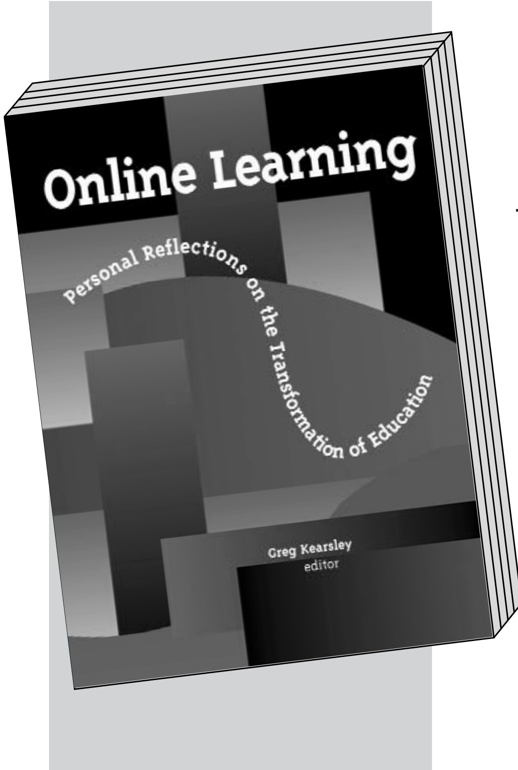

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