WILD for learning: Interacting through new computing devices anytime, anywhere

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Introduction

We use the acronym WILD to refer to Wireless Interactive Learning Devices[1]. WILD are powerful and small handheld[2] networked computing devices. The smallest handheld computers fit in one hand easily. The user interacts with the device either by touching the screen with a pen-shaped stylus, or by typing with both thumbs on a small keyboard known as a thumb-pad keyboard. The largest are the size of a paperback book and have a keyboard that is large enough to type on with all ten fingers. Their low price point and high usability has captured the imaginations of educators and learning scientists. The promise of harnessing computing where every student has his or her own computer, and where they are available everyday, anytime, anywhere for equitable, personal, effective, and engaging learning give WILD a greater transformative potential than desktop computers.

This chapter provides an account of the learning, education, social, policy, and technical contexts for these developments. We begin by establishing these contexts, and then survey available research and commercial applications for how the properties of WILD computing may facilitate learning. We focus on efforts where the “technology in the WILD” is being used to bring learners into activities previously unreachable--whether due to administrative, time, financial, demographic, previous knowledge, accessibility, or academic constraints. We emphasize the unique features that WILD add to classroom dynamics and to learning in the world, both in formal and informal contexts. In closing, we review the technical convergences and societal trends in WILD computing that will shape this field.

Motivation

As the costs of increasingly capable computers and of Internet access drops, and as the teaching force responds to the latest standards in certification and technological fluencies, we expect that teachers all over the world will increasingly incorporate computers into their classroom practices. Ever more prevalent, and presupposing at least a 1:1 ratio between students and computers, is the concept of “ubiquitous computing” (Weiser, 1991), where computers are embedded in everyday life activities to the point of “invisibility,” so that we unconsciously and effortlessly harness their digital abilities as effort-saving strategies for achieving the benefits of “distributed intelligence” (Pea, 1993).

Within the US, several companies and districts (Edison Schools, Illinois’ School District 203, and the State of Maine, among others) are already supplying every student within their middle- and high-school classrooms with laptops or handheld computers. In a notable large-scale implementation in 2001, Henrico County Public Schools (HCPS) in the state of Virginia became the largest school district in the US to give every student a computer in its middle and high schools, serving 25,000 Grade 6-12 students and teachers.

At a National Research Council workshop on improving learning with information technologies that brought together K-12 educators, learning scientists and technology industry leaders, Pea et al. (2003) characterized 1:1 computing as an essential "first transformation" for realizing the potential of computing to support learning and educational processes. Since the potential for each student to have a personalized Internet-enabled device with them at all times seems within grasp, the challenge now is to combine advances in the sciences of learning with information technology (IT) capabilities to dramatically improve student learning. New research groups and consortia have been formed to explore what the future may hold, and to recommend policies based on international research, such as the G1:1—a global network of collaborative researchers on one-on-one educational computing (http://www.g1on1.org/, accessed July 31, 2005).

Why Handheld Computers, or WILD Learning

Driving this trend for equitable, interactive, Internet-enabled, individualized distribution of technology in schools are handheld computers. Handhelds can cost less than the graphing calculators that math classes in high school typically require, and are quickly rising to prominence as affordable, personalized, portable devices (Roschelle & Pea, 2002; Soloway et al., 2001). More than 10% of U.S. public schools provide handheld computers to students and teachers for instructional purposes (Parsad & Jones, 2005). The popularity of handhelds reflects the desire of schools to make computing integral to the curriculum, rather than only occasionally used in labs, as evidenced by the success of the Palm Education Pioneers program that SRI administered (Vahey & Crawford, 2002): SRI received over 1,400 applications for the 100 classroom awards available. In year-end evaluations, 96.5% of teachers indicated that handheld computers were effective instructional tools, and 93% indicated that the use of handheld computers contributed positively to the quality of the learning activities that their students completed.

Besides affordability, there are seven other device features contributing to the rise in handheld use within schools and beyond: (1) size and portability; (2) small screen size; (3) computing power and modular platform; (4) communication ability through wireless and infrared beaming networks; (5) wide range of available multipurpose applications; (6) ready ability to synchronize and back-up with other computers; and (7) stylus driven interface.

Small size, portability, and ready-to-hand

As their name implies, handhelds are more portable than the slimmest laptops, allowing students to use them anytime, anywhere—whether they are taking data samples in the field with *probeware*—specially designed probes that can plug into a handheld's data port, and can sense and measure environmental properties such as dissolved oxygen in water ecosystem projects (Tinker & Krajcik, 2001; Vahey & Crawford, 2002); being an environmental detective in a campus-based learning game (Klopfer, Squire, & Jenkins, 2002); or Googling on handheld web browsers to answer questions they may have that arise in talking with friends. Using probes in the field is among the most popular uses for handheld computers in middle to high-school education—for example, students take their handheld computers and probes to a stream, and take measurements there, which are then collected by beaming to a teacher base machine, for later classroom graphing and pattern analyses.

The German philosopher Martin Heidegger first introduced the complex concept of *ready-to-hand* (*zuhanden*) to describe a condition of interacting with the world as mediated through the use of objects when we care about them, objects whose design allows us to remain *engaged* in the tasks to be accomplished, rather than to focus on the devices themselves (Heidegger, 1927/1973; Winograd & Flores, 1987). Handhelds are ready–to-hand due to their size and features, and their software applications can provide guidance and augmentation of the activities we engage in as they encode, shape, and reorganize our everyday tasks (Pea, 1993).

Roschelle and Pea (2002) described how the handhelds' small size allows teachers to break free from the contrastive teaching paradigms of *"sage-on-the-stage"* (teacher-centered instruction) and *"guide-by-the-side"* (teacher-guided discovery), a partial artifact of desktop technology, because that technology left little space pedagogically and physically for the teacher to occupy once several students were sharing the view and controls of the desktop computers. In classrooms populated by handheld devices, teachers have the choice of conducting classes somewhat as an orchestra conductor: attending primarily to the group performance, to the ebbs and flows of classroom dynamics, while guiding particular students when the need arises. Several WILD applications use this new *"conductor-of-performances"* paradigm: the teachers' computer includes a birds-eye view of the classroom layout, such that every student is represented with respect to their location or group within the classroom, and information about each students' device activity is displayed (e.g., Goldman et al., 2004). The color of each student's device, as displayed on the teacher's screen, show the teacher at a glance the relative proportion of students engaged in the activity, and those waiting to connect to the network or otherwise idle (see Figure 1). Teachers can thus determine which activities each group is engaged in--and even view the content of the students' screens to help guide their support.

==INSERT FIGURE 1 HERE==

Small screen size

The size of handhelds allows them to share space comfortably on the student's desk, leaving room for books and notebooks, in contrast to laptop computers that occupy most of the desk surface. Yet this ready-to-hand screen size affects the types of learning activities in which they are best suited: prolonged periods of reading long text segments may be better suited to wall-sized displays, yet there are many collaborative applications for which these devices are ideal. Beyond merely shrinking the display and images, porting any software to a handheld platform involves significant redesign, particularly for learning, because scaffolding support for complex tasks is integral (Luchini, Quintana, & Soloway, 2004). Among other considerations, text and graphics must be proportioned to maintain readability, the interface must be designed to maximize available screen real estate, and the organization of categories should follow scrolling principles or divide tasks across several screen choice-points for options and menus.

Although handhelds have small screens, their network connectivity permits sharing of the limited screen real state within a team, across different symbolic representations such as a graph, an algebraic equation, and a data table (Goldman, Pea & Maldonado, 2004). One may also increase the available visual field of the display for interactivity and learning by combining several handheld displays (such as CILT's [1998] DataGotchi design concept for a low-cost handheld mathematical collaborative learning tool, described in Roschelle & Mills, 1999, or by using the tiled displays suggested by Mandryk et al., 2001). Other researchers, such as Stanford's BuddyBuzz Project[3], are exploring how to best leverage rapid serial visual presentation (RSVP) techniques to present text by flashing on-screen in rapid succession the words of a document, one at a time at a controllable speed that is as comprehensible and in some conditions several times faster than traditional text display methods. While limiting the amount of information that can be simultaneously presented, smaller screens allow for greater sharing within small groups than bulky desktop displays, as students tilt their screens to share their content, and provide conversational partners with eye-to-eye views enabling perception of nonverbal behaviors otherwise obscured by a large desktop monitor (see Figure 2).

==INSERT FIGURE 2 HERE==

Most students are already accustomed to viewing and manipulating information on similarly small-sized screens from using popular portable entertainment and video game consoles. Nintendo has sold over 190 million portable GameBoy computers globally since its release in 1989[4], and this platform has been used in recent educational interventions in schools (Rosas et al., 2003; http://handheld.hice-dev.org/, accessed July 31, 2005). In one of the few studies using handheld gaming computers to study school learning, Rosas et al. (2003)

studied 1274 students from economically disadvantaged schools in Chile, using videogames specifically designed to support the educational goals of 1st-2nd grade for basic mathematics and reading comprehension, over 30 hours of intervention over three months. While they found a significant difference between students in schools where the experimental tool was introduced and where it was not, they did not find any significant difference between the experimental and internal control groups within the school, which they interpreted in terms of a school-internal Hawthorne Effect, with control teachers competing with the game classrooms to improve learners' achievements.

Today, with the Game Boy Advance, Game Boy Dual Screen, Sony's Playstation Portable (PSP), Nokia N-Gage and other mobile videogame consoles, 55% percent of U.S. children 8 through 18 own a handheld videogame player (Kaiser Family Foundation, 2005). Few attempts have been made as yet to turn these gaming devices into educational platforms, although there are arguments that this would be beneficial (e.g. Gee, 2003). The new generation devices come enabled with Internet capabilities, hard drives, and many modular features of WILD educational applications.

Computing power

In terms of computing power, the 2005 handhelds are multi-purpose devices already comparable to a 2000 desktop or 2001 laptop[5]. This CPU power means that the graphics processing capabilities that are familiar from many media-rich web and desktop applications are now available in a hand-held. Moreover, handhelds start up immediately, which contrasts sharply with the long seconds delay upon starting a desktop or laptop computer

Access to diverse communication networks

Handhelds allow collaboration and communication through their wireless Internet access and through their infrared "beaming" feature, which lets users exchange information easily in either peer-to-peer or teacher-student designs (see Tatar et al., 2004 for summary of diverse use scenarios). Directed communication through infrared beaming or Wi-Fi networks has been used to control audiovisual equipment in the classroom, and to share applications, text messages, audio clips, contact information, drawings, and data (Batista, 2001; Myers et al., 2004; Pownell & Bailey, 2001) through the simple physical gesture of pointing the device at the intended recipient.

Wireless connectivity helps eliminates challenges in connecting to the Internet, a key feature for schools. In the most recent U.S. school survey, 32% of public schools in 2003 used wireless connections (Parsad & Jones, 2005), and 92% of these connections were high speed, a large jump from 23% in 2002 (Kleiner & Lewis, 2003). As school wireless connections and networks grow, they increase the ease for students' engagement in peer-peer collaboration and teacher hub-spoke learning scenarios within the classroom, and for student Internet access through their devices.

Access to a broad range of applications

Handheld computers are increasingly attractive to schools as they combine classic organizer and calendar functions with critical software applications: (1) desktop productivity applications, e.g., smaller-screen versions of word processors, (2) the functions of application task-specific devices, e.g., graphing calculators, (3) versatile modular hardware (e.g., scientific probes, cameras, keyboards, GPS), (4) desktop computers (e.g., participatory simulations software, e-mail readers, web browsers), and (5) complex interactions with other networked computers.

Data synchronization across computers

Handhelds can be used as "thin clients" for accessing applications running on web servers, and the "satellite" design of handhelds makes data back-up possible by regular synchronization with a desktop or laptop computer--essential for educational settings to coordinate the flow of teaching assignments and student work.

Stylus input device

Globally it is the *stylus* of handhelds that is influencing purchase decision over desktop and laptop computers. For populations whose written language does not use roman characters, such as Japanese *Kanji*, stylus-driven interaction is a critical feature, permitting text entry in the students' handwriting, rather than requiring complex key sequences for character entry. Taiwanese classrooms, for example, have been observed to use tablet computers[6] primarily for this purpose, casting aside the tablets' keyboards.

Learning Outside Schools

In the U.S. in 2004, 13% of students 8 through 18 years old reportedly already have a handheld computer with Internet access and approximately 39% have a cellphone (Roberts, Foehr, & Rideout, 2005); when broken down by age, the numbers grow faster as students move through high-school: 75% of teenagers between 15 and17 years of age have cellphones, up from 42% in 2002 (NOP World, 2005), and more than 20% of those devices have multimedia capabilities

(NetDay, 2005). If those numbers are surprising, consider that the U.S. lags behind many other countries in cell- or mobile-phone penetration and the numbers of teenagers owning the devices. For example, 95% of the 15-24 year-old population in Japan in 2001 already owned web-enabled cell-phones (Thornton & Houser, 2004); and in New Zealand 73% of students 12-19 years of age own their own devices (NetSafe, 2005).

Mobile phones prove a relevant case to consider for learning outside schools, as they often are equipped with organizational and media capabilities (Rasmussen et al., 2004), from photo- and videocameras to music players, and also meet each of the seven WILD characteristics earlier described. Often running the same operating system as handhelds, mobile phones have continued to improve in terms of processor speed, memory, and screen size, even as they shrink in volume and weight (Lindholm, Keinonen, & Kiljander,, 2003) so that many are becoming handheld computers in addition to phones, even adapting keyboards and styluses to the interaction. Using mobile phones, students can interact with learning content anytime, anywhere they choose, and WILD projects have been underway since 2000 to capitalize on the devices' popularity by exploring opportunities for informal learning. For example, companies are providing "learning bites": small pieces of educational content that users can access while they are engaged in a different activity.

The first educational arena where cellphone lessons are being developed and commercially available is *language learning*: from SAT vocabulary to foreign language learning, both through voice-only systems and through SMS text (short message service), phones are delivering content to users traveling on the subway, waiting in line, and sitting at home (Prensky, 2004; Thornton & Houser, 2004). For example, Thorton and Houser (2004) studied Japanese university students receiving brief English vocabulary lessons on their mobile phones, and found that they learned significantly more than students urged to study identical materials on paper or the web.

WILD are also prime targets for gradual and timely health behavior modification programs, as they can potentially infer and leverage context information to deliver just-in time advice or recommendations, at key decision points. Popular downloads of handheld software include support for weight management (calorie calculators, exercise assistants), as well as for quitting smoking, and controlling chronic diseases such as asthma, diabetes and hypertension.

Small bite instruction and health behavior modification WILD interventions have several common design concerns, such as *interruptions*—determining when is it appropriate to interrupt the user with a suggestion, and how to detect when the learning intervention has been interrupted by real world events requiring the user's attention—as well as *context*. "Context" refers to the handheld's ability to use implicit information about its user's whereabouts and activities. Given the ease of adapting a global positioning system (GPS) module to handhelds, and the availability of this information for cellular telephony services, several projects are exploring educational applications that respond to the wearer's current location, sometimes combined with records of previously visited spots. Examples of WILD context-aware applications include *tour guides* (Abowd et al., 1997) and *location-aware language learning applications* that adapt the content presented according to users' location (Ogata & Yano, 2004), *facilitating informal meetings* of study partners within college campuses (Griswold et al., 2002), and *digitally augmenting field trips* (Rogers et al., 2004; Williams et al., 2005).

Rheingold (2002, p. xv) observed how these additional capabilities of context-awareness mean that:

> [H]andheld devices can detect, within a few yards, where they are located on a continent, within a neighborhood, or inside a room. These separate upgrades in capabilities don't just add to each other; mobile, multimedia, location-sensitive characteristics multiply each other's usefulness. At the same time, their costs drop dramatically… the driving factors of the mobile, context-sensitive, Internet-connected devices are Moore's Law (computer chips get cheaper as they grow more powerful), Metcalfe's Law (the useful power of a network multiplies rapidly as the number of nodes in the network increases), and Reed's Law (the power of a network, especially one that enhances social networks, multiplies even more rapidly as the number of different human groups that can use that network increases). Moore's Law drove the PC industry and the cultural changes that resulted, Metcalfe's Law drove the deployment of the Internet, and Reed's Law will drive the growth of the mobile and pervasive Net.

Other informal learning locales where handhelds are becoming more commonplace are *museums* and *exhibitions*. Handhelds can offer in-depth explanations for particular exhibits, additional reference materials, and may create a record of the visitors' museum path for subsequent online access, a WILD use

Roschelle and Pea (2002) categorized as “act becomes artifact.” School and family groups can use this recording feature to later discuss their experiences, reflect on concepts learned, and share souvenir images with others. Handhelds are also being shown to be effective teaching tools for museum guides, facilitating their access to relevant content as visitors’ questions arise, controlling remote exhibits on cue, reporting problems, collecting relevant data, as well as incorporating on-the-job training through small bite instruction (Hsi, 2004).

Another example of how “act becomes artifact” through WILD is also taking shape in the form of web-logs, or as they are more commonly known, *blogs*, that permit posting online of multimedia accounts from any device, with little technology training[7]. Covering a wide range of interests, from topic-based to teenage diaries, blogs are growing at an explosive rate and democratizing the distribution of publishing globally-accessible information: from revealing industry secrets to breaking news in war zones, they have become another information source for learners to evaluate, process, and contribute to. Blogs primarily accessed and updated through mobile devices have been termed *moblogs*, and carriers of cellular telephony are quickly incorporating services designed to cater to budding journalists.

Everyone and anyone can distribute content right from their phone to the world via the web; mobile wireless interactive devices are democratizing the exclusive demand of media production. The embedded digital camera has been predicted to be one of the most common features on handhelds and mobile phones, growing from 178 million units in 2004 to over 860 million units in 2009, or 89% of all mobile phone handsets shipped[8]. Several worldwide communities around these photo journalistic moblogs are available online (http://www.rabble.com and http://www.textamerica.com/, both accessed July 31, 2005), often leveraging social networking features to help readers find personally meaningful content, through collaborative filtering. Despite their popularity as forums for creative writing and collaborative critique, there are not yet published empirical studies of blogging for learning. However, we believe that these trends are likely to influence handheld learning and education, as long as privacy and safety concerns are met, because blogs have been shown to be powerful tools for personal and political expression.

Schools and Classrooms

We have covered some of the existing state of the art applications of WILD technologies outside the classroom, implicit and explicit in their learning goals; yet many more await us inside the school walls. Even though many WILD designs are still in the pilot or prototype stages, we will mention the effects that the introduction of these programs had on students' learning gains, and the motivation for the applications, when they are available. We can distinguish two foci within the space of WILD in classrooms: first are three common evaluation dimensions of applications for handhelds that drive the decisions behind their introduction in school: *their lower costs* (already discussed), *the needs of the intended audience*, and *their ties to curricula*. After briefly describing needs and curriculum ties, we concentrate on the five key application-level affordances of WILD (Roschelle & Pea, 2002) that allow for innovation in classroom practices.

First, based on the age, size, and needs of the target audience, is the innovation catering primarily to teachers or administrators? Is it aimed at students, working individually or collaborating in groups? Commercial WILD applications make some school and class administration tasks more efficient and convenient. For example, several companies including Media-X systems, GoKnow, Wireless Generation, ETS, and Houghton Mifflin provide applications specifically meant for schools' administrative tasks, ranging from sharing agenda notes through the handhelds' beaming feature, to accessing data during meetings, to quickly checking on any given students' schedule, record, photo, or parent contact information. Teachers are using tools that let them compare students' essays with available online sources, and tag potential plagiarisms for them to review[9]. Companies have developed software specifically for handhelds and tailored for student assessment for almost all grades and subjects of instruction: from checklists and menus that make for easy diagnosis of reading difficulties in the early grades, to sharing students' progress across subjects and teachers, to student assessment and grade-book aides—particularly helpful for subjects where teachers are not always at a desk, such as physical education, labs, field trips (COSN, 2004).

Many applications cater to individual students' needs in the classroom, and we focus on WILD applications that foster deep understanding, inquiry processes, and collaborative problem solving, whether in small groups or as a whole classroom. Within the realm of student applications, a second evaluation dimension we have identified involves the closeness between the technological intervention and the curricula. Some applications are directly linked with specific publishers' curricula, providing teacher training and development materials as well as addressing specific units in a predetermined sequence matched with school district and state goals. At other times, the technology is much more loosely linked to academic purposes, and provided within the school setting for enrichment or extracurricular activities.

From organization tools, to portable course materials, to recording and archiving the content of blackboards, to recording and listening to audio-related class content, school and university faculty are increasingly supportive of providing handhelds for their students. For example, in 2004 all incoming freshmen to Duke University received an iPod, a digital music player characterized by the additional capacity of a considerable hard drive, and teaching is slowly incorporating audio components across subjects beyond the music department: some courses are using this device to provide news feeds, language learning, interviews and field data collection, and signal analysis, among other uses.

We are particularly interested in applications maintaining an emphasis on inquiry processes, social constructivist theories, and distributed cognition designs; hence, while there are many applications designed for individual use, we concentrate on those that favor collaboration among students. Roschelle and Pea (2002) distinguished five application-level affordances of handheld implementations in schools: (1) augmenting physical space with information exchanges, (2) leveraging topological space, (3) aggregating coherently across all students participating individually, (4) conducting classroom performances, and (5) enabling act becomes artifact.

Augmenting physical space with information exchanges

The first affordance, augmenting physical space with information exchanges, includes activities where information exchanges are overlaid on the physical movements of students. One such application domain is *participatory simulations* to promote learning about decentralized systems, where each student through his or her device represents an ”agent” or conceptual entity in a simulation of a complex system: a car on the road of a traffic model, or a person coming in contact with a viral disease ecosystem (e.g., Colella, 2000; Wilensky & Stroup, 1999). In participatory simulations, students' memories of their path of data exchanges through close encounters with others drive the inquiry and analysis of the spread of the virus or emergent behavior. Other applications that find a niche within this category are probeware—enhancing the handhelds' data collection possibilities through scientific probe modules (mentioned earlier)—and other uses of handhelds in the field, such as photographing and wirelessly matching field specimens to an online database (e.g., Chen et al., 2004).

Leveraging topological space

Roschelle and Pea (2002) alluded to two ways of leveraging topological space: *geospatial mappings* between the handheld and the real-world that facilitate navigation and context-aware applications, and *semiospatial representations*, in which the spatial attributes of the topological representation are not mappable to spatial attributes of the physical world (except to those of the inscription themselves). Semiospatial representations include Cartesian and other graphs, concept maps, flowcharts, and non-geo-gridded information visualizations generally” (p. 153). WILD applications that use semiospatial representations include concept map makers such as GoKnow's *PiCoMap* (Royer, 2004) and *Pocket Model-It* (Luchini et al., 2004), Kaput and Roschelle's *SimCalc* software for learning about the mathematics of change (Roschelle, Penuel & Abrahamson, 2004), and *Chemation*, a chemistry modeling and animation tool (Scott et al., 2004).

One successful implementation of handhelds within the semiospatial realm that is tightly coupled to curriculum and teacher development is the *CodeIt!* program (Goldman, Pea, & Maldonado, 2004; Goldman, Pea, Maldonado, Martin, & White, 2004) where students interact fluidly with multiple representations of mathematical functions (ordered pairs, graphs, equations, function and frequency tables) to develop rigorous algebra skills. *CodeIt!* is inspired by the curriculum unit *Codes, Inc*, developed by the Middle-school Mathematics through Applications Project (MMAP), which teachers found helpful for transitioning to the use of technology and more applications-based curriculum materials (Lichtenstein, Weisglass, & Erickan-Alper,, 1998).

CodeIt! is set within the real-world context of cryptography, and students working in teams can observe and analyze as changes to any representation propagate across the other representations and the other students' devices. The results from the pilot evaluation of this program are promising, despite extremely heterogeneous groups in terms of age, previous knowledge of algebra, and students' socio-economic background. In four of six of the groups studied, students made significant gains, in some cases raising their scores by 15-30%. Students showed significant gains on test items relating to evaluating exponents and the graphs of functions, validating the handheld's use of semiospatial topographical space, and on one graphical item, 44% of students answered correctly on the post-test, as compared to only 13% on the pre-test. Overall, researchers report a mean increase from pre- to post tests of eight percentage points, with great variability in whether groups functioned well.

Aggregating across all students

The third application-level affordance of WILD identified by Roschelle and Pea is supporting data aggregation across all students. For example, in *ClassTalk* (Roschelle, Penuel & Abrahamson, 2004) students answer multiple-choice questions through their WILD. The answers are aggregated as a histogram, and projected onto a publicly shared display space for the class to discuss and reflect on common misconceptions. We have discussed earlier two evaluation dimensions--target audience and ties to curricula--and commercial applications that aggregate coherently across students offer a great example of the third evaluation dimension we mentioned, cost. Some handheld solutions that aggregate students' input and participation (sometimes preserving anonymity) are developed specifically to maximize cost-effectiveness, such as *ETS Discourse* and *eInstruction*. Often called "classroom response systems," classroom performance or communication systems, these cost-effective solutions offer limited choices through buttons on "clickers" that resemble television remote controls, but leverage the shared displays to make publicly available the classroom's level of consensus on concepts taught, information often missed in traditional instruction.

Such systems can help the teacher focus instructional attention on the issues most significant for the classroom-as-a-whole considered as the unit of learning. To the extent that such systems can provide the powerful learning intervention of formative assessment (Black & Wiliam, 1998) by providing more feedback than usual on learning-teaching inter-relationships, they hold considerable promise for improving learning outcomes for both students and teachers (Davis, 2003). For example, the instructor of a large lecture class can receive real-time feedback on the speed and difficulty of the lecture, and adapt the presentation accordingly. And although answers may be shown anonymously on the shared aggregate display, each student's response can be recorded and linked to the relevant online content for that student to later review on the Internet, as in the Berkeley Digital Chemistry Project (Cuthbert et al., 2005).

Improvements in students' content knowledge, motivation, and engagement often result when this technology is introduced. However, students can interact with complex subject matter in richer ways with a full-fledged WILD, an activity researchers have labeled "CATAALYST" ("Classroom Aggregation Technology for Activating and Assessing Learning and Your Students' Thinking," Penuel, Roschelle, Crawford, Shechtman, & Abrahamson, 2004), when it is deployed for class-wide aggregation and reflection. Classroom network technologies in math and science have been shown to augment classroom communication, students' engagement and enjoyment, and to improve students' performance measures, primarily through the teachers' implementation of pedagogical practices that leverage the WILD application capabilities (Roschelle, Abrahamson, & Penuel, 2004 provide a review of the literature on these effects).

Beyond the improvements in equity and extent of participation, and the feelings of support experienced by students, the projection onto a publicly shared display offers a cognitive and conceptual focus of joint attention for each student in the class, rather than focusing on activity and materials in their individual workspaces. The joint display permits "viewing the classroom as a distributed system… [which] can enable relatively simple mathematical behaviors at the individual student level to result in the emergence of more complex group-level mathematical or scientific constructions" (Penuel, et al., 2004, p. 5; also see Hegedus & Kaput, 2004).

Conducting classroom performances

WILD allow teachers to take a conductor's role. However, negotiating and directing students' parallel contributions such that transformative learning conversations become the norm (Pea, 1994) requires masterful conducting efforts. Most of the CATAALYST interventions we have discussed start their cycle with a question designed and posed by the teacher to elicit significant responses. Some large college courses are letting their students give feedback to the lecturer, both student- and professor-initiated. Examples of student-initiated feedback include students posting questions during the lecture onto the aggregated display, and the lecturer can determine whether to pause and answer if sufficient students 'vote' on it (Griswold et al., 2002), and also students giving continuous feedback with regard to the lecture's pace that the instructor can immediately observe in the aggregate display (Scheele, et al., 2003).

Enabling Act becomes artifact

WILD can give users a grasp of their own learning progress, self-monitoring their performance for the purpose of improving teaching (as when instructors use the feedback mechanisms described above) and learning. A promising project where teachers are part of the design team, devoted to giving students the tools and scaffolding necessary to reflect and improve on their learning practices, gauge their understanding, and incorporate mindful data collection activities, is SRI's WHIRL (Wireless Handhelds for Improving Reflection on Learning), currently taking place in disadvantaged districts in South Carolina (Penuel, Roschelle, & Tatar, 2003).

Questions and Directions: Transformative Innovations for Learning futures

The field continues to experiment and discover new areas for expansion, yet we call on colleagues and researchers to ensure that the coming years see not only continued growth in novel ways to interact with the subject matter, but also see an emphasis on learning evaluations. Because of the enthusiasm surrounding its widespread adoption and egalitarian goals, few WILD researchers have developed the complex measurement instruments needed to show across contexts that activities and curriculum have learning consequences for their users. We need new metrics for assessing the roles of WILD in learning and performance, and in relation to the development of interests, motivation and personal identity in the *learning ecologies* (home, school, community, virtual spaces: Barron, 2004) that they traverse with learners.

The future of WILD learning provides an exciting frontier for the learning sciences. In our view, we need to leverage two kinds of convergences to advance WILD learning and teaching. There is a multidimensional convergence of rapid developments related to IT hardware and services, largely driven by steady increases in ICT processing power, memory, and connectivity, resulting in explosive growth in media richness, ubiquitous connectivity, and smart, personalized software services. From 1990 to 2003, there was continued exponential growth in hardware capabilities, including increases in processor speed by a factor of 400, memory size by a factor of 120, wireless connection speed by a factor of 18, and fiber channel bandwidth by a factor of 10,000 (NSF, 2003). However, a second type of convergence would also be very beneficial to societies worldwide: a convergence between the technical integration being pursued by industry, the research and development being advanced by the learning sciences, and the wisdom of practice from K-12 educators.

Consider what it will be like to have such learning interwoven into everyday activities and communications, whether in or out of school, across the boundaries of intentionally designed institutions of education to the home, community, workplace and other organizations. Like Department of Defense DARPA agency-funded work in the 1960's that led to many of the core technology innovations we take for granted today (PITAC, 2000) the target should be radical improvements that aim for orders of magnitude improvements in learning and education. These test-beds would demonstrate feasibility and early stage potential of substantively new tools, content, and pedagogies that leverage ICT advances and learning sciences knowledge at the cutting edge of what is possible. As researchers, we need to live in specifically created possible futures as pioneering scouts, and report back what life is like in such possible futures, where WILD technologies become ubiquitously woven in new ways into the fabric of tomorrow's societal learning systems (Pea & Lazowska, 2003). Such expeditions scouting out the future of ubiquitous computer-aided learning would require networking the communities and expertise of diverse stakeholders—K-20 educators and institutions, researchers in the sciences of learning and uses of educational technologies, subject matter experts, advanced telecommunications professionals, education schools, and industry—to plan, invent, explore, and support their design and continuous improvement. Changes in information and computing technologies are proceeding at such a rapid pace that it will take the talented engagements of the educational, research, and technology industries to forge the visions and innovations in tools, environments, and instructional practices that can build on as well as advance the sciences and contexts of learning, teaching, and education. Such partnerships would explore systemic approaches to educational change--aligning standards, curriculum, pedagogy, assessment, teacher development, school culture, and school-home connections, in addition to the use of educational technology. The partnerships would undertake a continuous innovation cycle for educational techniques and technology, where the design of new prototypes would be followed by observation of the use of those prototypes, which would immediately feed back into modifications in the prototype designs.

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Figure captions

***Figure 1*: Teacher's view in Stanford's *CodeIt!,* showing classroom activities: Students actively connected to the system (by circle color), their assignment into groups (by circle's placement), and group's current processing (through observer windows).**

***Figure 2*: Two groups of students working with WILD in the *CodeIt!* Project. Note the closeness of the exchanges, facilitated by device size, and their cohabitation with the multitude of papers students have on their desks.**

[1] WILD is an acronym created at SRI International's Center for Technology in Learning in 2000 by Roy Pea and Jeremy Roschelle when they developed a research program and series of projects on handheld computing for learning, with work together on this topic beginning in 1998. Preparation of this chapter was supported in part by funding from the Wallenberg Global Learning Network, and National Science Foundation grant #0354453.

[2] The first handheld computers used broadly in education were calculators from Texas Instruments, HP, Casio and others, although the Apple Newton had devoted advocates in its brief heyday (1993-97), as did the Psion Organizer (released in 1986).

[3] BuddyBuzz at http://captology.stanford.edu/notebook/archives/000121.html, accessed July 31, 2005.

[4] See http://newswww.bbc.net.uk/1/hi/technology/3754663.stm, accessed July 31, 2005.

[5] This comparison pits reported clock speeds of the HP-Compaq iPaq handheld against Apple Computer's Power Macintosh G4 desktop and Powerbook G4 laptop. In terms of Palm's handhelds, a 2003 Tungsten T model is comparable to the Toshiba Libretto (70CT: Pentium MMX 120 Mhz), a 1997 PC laptop and the 1995 Apple Macintosh 7200, a desktop computer.This comparison is approximate because reported clockspeeds are imprecise measurements of a computer's performance due to differences in instruction sets and optimized code.

[6] Tablet computers are not discussed here, for whereas they share stylus-driven input with handhelds and add a larger screen, their relative lack of power and cost (often twice as much

as comparable laptop computers) reduces their potential to equalize access to the technology for global 1:1 computing.

[7] In March 2005, there were over 7.8 million weblogs, double the number of blogs from October 2004. Companies such as Google, AOL, SixApart, and MoveableType are facilitating the creation of about 30K–40K new blogs daily, increasing the collective size of blogs (often referred to as the ‘blogosphere”) over sixteen times in the last twenty months (numbers tracked by http://www.technorati.com/ and reported in http://www.sifry.com/alerts/archives/000298.html, both pages accessed July 31, 2005).

[8] InfoTrends/CAP Ventures (http://www.infotrends-rgi.com/home/Press/itPress/2005/1.11.05.html).

[9] See *TurnItIn* (http://www.turnitin.com/), *Glatt Plagiarism Services* (http://www.plagiarism.com), or the *Moss* for programming classes—the Measure Of Software Similarity index (http://www.cs.berkeley.edu/~aiken/moss.html) (all pages accessed July 31, 2005).