Chapter 15: Building University Faculty and Student Capacity to Use Wireless Handheld Devices for Learning

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EXPANDING THE CAPABILITIES OF TEACHING AND LEARNING WITH HANDHELDS

The Handheld Devices for Ubiquitous Learning (HDUL) project at Harvard University is an exploratory study that seeks as its core research question to determine how wireless handheld devices (WHDs) can enhance learning and teaching in university settings. The project is also exploring the potential transferability of WHDs' educational affordances to other contexts, such as K–12 schooling and corporate training (http://gseacademic.harvard.edu/~hdul/). During the 2003–2004 and 2004–2005 academic years, HDUL integrated WHDs into eight diverse courses at both the Harvard Graduate School of Education (HGSE) and the Harvard Extension School (HES). Our research demonstrates that WHDs can be highly useful as (a) portable research assistants, and (b) traveling conduits for online learning through vehicles such as participatory simulations and tools that enhance thinking.

Throughout the project, the HDUL team had to overcome several barriers to building capacity among students, faculty, and support staff. For example, after spending a week in possession of a handheld computer and considering its potential for teaching and learning math, a graduate student presented the following thoughts during a focus group on handhelds and math:

> I think it's an excellent opportunity to have technology in the classroom, but what I would be interested in learning is how the professional development around it would go in terms of encouraging teachers to actually learn the technology, because there are graphing calculators in some classrooms that are not being used at all. So how do you make sure that a teacher is invested in this opportunity and sees that this is something that can be used in the classroom? I know I was confused on how — when I was going through some of the programs.

This student, like many other participants with whom we worked, speaks to technology implementation barriers that are not technical or economic, but psychological, organizational, political, and cultural (Dede, 2001).

When used for teaching and learning, WHDs have been heralded as education's solution to one-to-one computing (e.g., Soloway, Norris, & Curtis, 2001), yet have simultaneously been blamed for a new wave of classroom antics and cheating (e.g., surfing the Web, checking email during class, instant messaging answers during tests). WHDs, like similar technologies, are neither education's silver bullet nor its Pandora's Box. Dismissing these extreme perspectives and interested in understanding the strengths and limits WHDs pose for teaching and learning, a team of faculty, students, and staff from HGSE established HDUL and conducted studies over the 2003–2004 and 2004–2005 academic school years. As discussed later, our motives for investing in HDUL are based on (a) the devices people own and carry, (b) society's cultural and technical movement toward ubiquitous computing, (c) WHDs' potential for harnessing situated and distributed cognition capabilities, and (d) emerging media-driven learning styles. This chapter presents an exploratory study that explicates HDUL's research designs, questions, methods, and results to inform projects that wish to integrate similar technologies into their educational settings to gain from the development, implementation, and capacity-building heuristics we evolved. After describing our project and discussing its findings, we present a conceptual framework for understanding the role of wireless handheld devices in education.

START-UP DECISIONS

The HDUL team (the Team) included members from HGSE's Learning and Technology Center and HGSE students, faculty, and staff from diverse backgrounds and expertise. An early objective of the project was determining which hardware, peripherals, and software to purchase. All of HDUL's purchasing decisions were based on (a) the needs of the HDUL project, and (b) the handheld market and product availability in the summer of 2003. HDUL in no way advocates for a specific operating system, manufacturer, or device. Our intensions for providing this information are to help those in similar circumstances develop a process for informed decisions based on our research and experience.

Utilizing criteria from trade journals (e.g., *Pocket PC Magazine*), online resources (e.g., CNet, Palm, and ZDNet websites), and best practices from other projects (e.g., Vincent, 2004; Ward, 2005), the Team constructed evaluation matrixes for selecting handheld devices, peripherals such as probeware, and software. These evaluation rubrics are available in Appendix 1 and in the Findings section of the HDUL website (Dieterle, 2005a). The Team then contacted vendors to preview handhelds from leading manufacturers (i.e., Compaq, Dell, Palm, and Toshiba), along with various peripherals (e.g., probeware, digital cameras). In general, the Team discovered limited variation among devices, but found the differences that did exist were significant enough to warrant a clear decision. The compelling differences existed in: (a) handheld costs, (b) probeware startup costs, and (c) wireless connectivity. Based on variation in costs, functionality, and connectivity, HDUL selected the Toshiba e750. Although the Toshiba e750 was the best product for our purposes in August 2003, the market is regularly changing, and the device we selected may not meet the specific needs of other programs today.

After determining what to buy, the Team considered how best to store, distribute, and collect materials. The devices and peripherals were housed in a secure closet in the School's Learning Technology Center; access to the closet was restricted to the Team. The Team agreed that hardware would travel in handheld kits, which included both devices and peripherals, instead of traveling piecemeal. Figure 15.1 illustrates a typical handheld kit that participants received during each implementation.

"Insert figure 15.1 here"

By grouping smaller units of hardware into larger coordinated units, the Team could easily monitor who had which hardware, for what purpose, and for what period. Although it initially seemed to be a minor design decision, the cases that we selected proved invaluable when the handhelds traveled with students into the field. We purchased high-quality storage cases — designed for art supplies — over low-end models. Besides being weather resistant, the polypropylene cases protected the equipment during transport in students' bags and from minor falls. We opted for translucent cases to spot check equipment as it was distributed and collected.

During the implementation of the HDUL project, we found this system minimized loss and damage while streamlining dissemination and retrieval of materials. Without established, consistent, and straightforward procedures for checking out and returning equipment, hardware would likely have been lost or underutilized, and scheduling conflicts would have led to frustration and disinterest in the HUDL project. Thus, building capacity among faculty and the Learning and Technology Center staff started with an established procedural infrastructure.

HANDHELDS IN THE HANDS OF USERS

During the project's lifecycle, HDUL successfully introduced WHDs into eight different courses at the HGSE and the HES for a variety of purposes as explicated later in the chapter and summarized in Table 15.1.

Table 15.1 Summary of Courses, Implementations and Sessions

Course	**WHDs Used For**	**Session(s)**
Distributed learning course	Participatory simulations: 2003 — *Environmental Detectives* (Klopfer, 2003); 2004 — *Virus* (MIT Teacher Education Program, 2005)	2003: Face-to-face class meeting consisted one 2-hour session; 2004: Face-to-face class meeting consisted a 1-hour session.
Emerging technologies pedagogy course	Creating and sharing concept maps	Face-to-face class meeting consisted of one 90-minute session.
Math methods course	Learning and teaching math; comparing and contrasting WHDs with graphing calculators	Brief informational meeting with individual students while they signed out and picked up WHD. Face-to-face class meeting consisted one 2-hour session.
Online learning course	Surveying and analyzing data in the field and in real time	Face-to-face class meeting with whole class consisted on two 45-minute sessions. The first session introduced the devices and the hands-on task. The follow up session allowed participants to discuss their experiences with the devices and the results of their surveys.
Qualitative methods and interviewing course	Capturing digital audio interviews and images	Face-to-face class meeting consisted of one 45-minute session.
Science methods course	Learning and teaching science; investigating probeware with WHDs	Face-to-face class meeting consisted of one 90-minute session.
Team learning course	Building collaborative capacity and completing real time polling exercises.	Face-to-face class meeting consisted of one 2-hour session.
Technology and assessment course	Creating and sharing animations, evaluating commercial assessment applications, and completing real-time polling exercises.	Face-to-face class meetings consisted of one 30-minute informational session and one 2-hour session.

Participants in HDUL included HGSE faculty and students and HES continuing education students. In general, the student participants were graduate students in education; many were seasoned teachers and researchers who did not enroll in more than one class that examined handhelds in a given academic year. Their direct experience with handhelds was limited in duration, so they based their comments and reflections on their expertise as educators and researchers in general.

Seeking to maximize both students' and professors' experiences, the HDUL team strove to guarantee that participants: (a) had appropriate opportunity to use the handhelds, (b) recognized and comprehended the affordances of the devices through appropriate scaffolds, and (c) were motivated through authentic tasks and activities to take advantage of the device's affordances. For each course, participants typically received a handheld kit for 1 week. Coordinating with instructors, the HDUL team regulated the distribution and collection of handheld kits to avoid implementation overlaps.

After distributing kits, participants completed a structured introductory activity (Dieterle, 2005c), which covers handling and caring for WHDs, general similarities and differences between desktop and handheld computers, inputting and manipulating data (i.e., inputting text; accessing and producing digital images and videos), networking WHDs (i.e., beaming information from one device to another; connecting to WiFi networks), and how WHDs can be used as personal information managers. Next, participants worked through the "HDUL Overview" website (Dieterle, 2005b), which provides a summary of the promise of ubiquitous computing, a brief history of handheld computers, an overview of wireless handheld devices, illustrative examples of educational software designed for handhelds, general information about probeware and peripherals, and exemplary uses of handhelds in education.

Afterward, participants worked through an assigned task appropriate to the content and context of their courses (e.g., bringing their WHDs into the field and surveying 10 participants, investigating and evaluating handheld educational software packages designed to capture what learners know). Without the two sets of preliminary experiences common to all implementations, HDUL might very well have fallen prey to the "fingertip effect": the false assumption that, left on their own, novices will understand and be sufficiently motivated to take advantage of the functionality of a tool to the same extent as experts (Perkins, 1985, 1993).

Based on individual experiences in relation to the assigned task, students spent a subsequent class in a facilitated discussion about student and faculty perceptions of the strengths and limits of handheld computers for learning, teaching, and researching in that subject area. Data collected from these sessions include transcripts and field notes, following Maxwell's (1996) qualitative design principles. Although the majority of the implementations and integration during the 2003–2004 academic year were structured innovations into courses, the 2004–2005 academic year emphasized and supported individual students who wished to drill deeply into an aspect of learning with handhelds. Data from this latter research includes students' final papers and projects, which are discussed in greater detail next.

KEY FINDINGS OF HDUL

Through the analysis and interpretation of the data collected during course implementations and student semester-long projects, our research has shown that wireless handheld devices are (a) effective portable research assistants, and (b) traveling conduits for online learning. Although this chapter goes into greater detail, Dede and Dieterle (2004) conducted a preliminary seminar on HDUL late in the 2004 spring semester, which is viewable online — http://isites.harvard.edu/icb/icb.do?keyword=k240&pageid=icb.page314.

EFFECTIVE PORTABLE RESEARCH ASSISTANTS

As research assistants, WHDs enable users to:

1. capture what learners know through various educational software packages designed for formative and summative assessments;
2. capture and project learners' opinions in real time during face-to-face, whole-class discussions;
3. conduct surveys in the field and afterward aggregate data to be analyzed by the whole class;
4. capture and analyze real-time data through probeware and calculation software that makes use of a menu-driven interface; and
5. digitally record interviews and capture digital images.

Capturing What Learners Know. Participants in an emerging technologies pedagogy course investigated GoKnow's *PiCoMap* (2005a) — concept-mapping software specifically designed for WHDs — during one 90-minute session. Following Novak and Gowin's (1984) concept-mapping model, PiCoMap uses nodes (i.e., bubbles) to represent concepts and propositions (i.e., connecting words) as logical bridges between concepts. Each participant, using a WHD, constructed a PiCoMap with at least four nodes and four connections in a guided activity. After saving their maps to the WHD, participants used the IR ports on their devices to "beam" (i.e., wirelessly transmit small packets of information from one device to another) maps to classmates. Afterward, students discussed similarities and differences among the various maps. Whereas the purpose of this exploratory implementation was to highlight to a group of education master's candidates the possibility of constructing, analyzing, and distributing concept maps on WHDs, others have researched the limitations and possibilities of using handhelds to support learners' production of concept maps. For example, Luchini, Quintana, and Soloway (2003) completed a 9-month classroom study of 33 eighth graders in two science classrooms determining that complex learning activities are possible using handhelds, but that additional work is needed to overcome handheld's small screens. In agreement with the results of Luchini et al. (2003), our participants expressed interest in the concept-mapping capabilities, but expressed concern over screen size.

As another illustration of capturing and sharing student knowledge, participants in a technology and assessment course investigated various commercial assessment products for handhelds designed to capture what students know; they also explored *Sketchy* (GoKnow, 2005b) – an animation application designed specifically for WHDs. The first 30-minute session introduced the devices and the hands-on task. The follow-up 2-hour session allowed participants to talk about their experiences with *Sketchy* in detail, discuss their evaluations of various commercial assessment applications, and use the handhelds as polling tools. Between the first and second sessions, participants were asked to use *Sketchy* to construct an accurate, animated representation of the earth orbiting the sun and to evaluate a commercially available handheld assessment tool through the lens of the course content. At the beginning of the second session, participant pairs shared their animations and discussed the thinking behind their construction. Next, the class viewed "A Private Universe" (Schneps & Sadler, 1989), which demonstrates the power of prior knowledge and the challenges of altering mental models. Afterward, participants reflected on their animations and discussed with their partners the strengths and weaknesses of using *Sketchy* as an assessment tool. Participants likened *Sketchy* to a scaled-down and user-friendly version of Macromedia's *Flash*. Moreover, participants found that dynamic animations of phenomena are able to represent and capture knowledge better than static media such as paper and pencil.

At the conclusion of the activity with *Sketchy*, participants worked in groups of four to discuss one of six assigned, commercially available software applications, including *Classroom Wizard, Discourse, eLearning Dynamics, LearnStar, mClass Assessment Software,* and *Quizzler Pro*. In general, participants described these applications as "making classroom practice more efficient" by streamlining instructional methods. They were encouraged by the capabilities of providing immediate, individualized feedback and of capturing real-time responses, which in turn can subsequently shape and guide instruction. As with all instructional tools, however, participants suggested that educators must understand the limits of such applications. For example, although multiple-choice and short-answer questions are easily processed with handhelds, longer reading and writing assignments and authentic, project-based assessments would be better accomplished on larger screen interfaces.

Capturing and Projecting Learners' Opinions. Similar in nature to the commercially available assessment applications discussed earlier, participants in a team learning course and a technology and assessment course used WHDs and WiFi connectivity to complete online Likert Scale surveys and answer open-ended questions in thought-grabbing exercises. Immediately after participants submitted their responses, the data were aggregated and displayed on a computer projector in real time to facilitate immediate class discussion of the findings.

Conducting Surveys and Aggregating Data. Students and faculty participants took notice of the advantages of conducting surveys in the field and afterward aggregating data to be analyzed by the whole class. As an example, participants in an online learning course brought their WHDs into the field, and each participant conducted surveys of approximately 10 participants and collected results using Microsoft's *Pocket Excel*. Afterward, participants uploaded their data from the WHD. The datasets were then aggregated, and participants analyzed the resulting collective database as an entire class. Whereas surveys generally take place in the field, over the phone, online, or through the mail (Fowler, 2002), researchers typically wait until they return to their desktop or laptop computers to begin analysis. Although analysis with WHDs is not as detailed or thorough as is possible with laptops or desktop computers, the strength of using WHDs for rapid and rudimentary evaluation of data in the field enables formative shifts in research approaches. An additional strength of WHDs is the power to quickly expand dataset samples. In this class implementation, 12 student participants independently surveyed approximately 10 random participants with their WHDs. On aggregation of the data, the collective sample size expanded to 120 participants.

Using Probeware and Calculation Software to Analyze Real-Time Data. Our least successful implementation of the eight occurred with participants in the science methods course, which is interesting as the HDUL Team assumed it to be low-hanging fruit. Participants explored the use of WHDs in science using Data Harvest's (2005) probeware to collect and analyze data in real time during one 90-minute session. Prior to the session, participants had the option of checking out a WHD for the week. However, due in part to the instructor's lukewarm stance about this activity, none of the 20 participants took advantage of the opportunity, and the low motivation of the instructor led to reluctance on the part of students to work with and learn about WHDs before the class-wide meeting. The session began with participants viewing and discussing the Center for Highly Interactive Computing in Education's "Air Quality Experiment" (2001a) and "Stories from the Classroom" (2001b). Next, participants explored and discussed various examples of probeware (e.g., temperature probe), the benefits of probeware for teaching and learning science (Staudt, 2001; Thornton, 1999), and a software interface for processing information. In general, participants spoke positively of the potential of WHDs and probeware for teaching science, but in retrospect wished they had chosen to avail themselves of the opportunity for greater access to the devices prior to the 90-minute session. Such comments suggest that a lack of advocacy by the instructor led to the lack of student interest in previewing the devices for the face-to-face session.

In contrast, an HGSE master's candidate, who we call Tim, enrolled in a different course, and explored how WHDs relate to physics education. Unlike the science methods instructor, Tim's professor supported his studying WHDs as tools for thinking and learning in connection with the goals of the course through a semester-long project. As a former physics teacher, Tim came to the class with a strong background and motivation in both science and teaching. In "When Three Worlds Collide: Physics, Amusement Parks, and Wireless Handheld Computers," he first examines the background of teaching physics in amusement parks before considering a broad overview of how handhelds are impacting education. Tim then discusses two examples using WHDs to teach physics in amusement parks. In both examples, students collect data via various types of probeware and analyze it in real time with their WHDs. The rest of his paper focuses on how wireless technologies can contribute to and change such learning environments. Indeed as this example illustrates, active support by the instructor can lead to students meaningfully exploring new tools, such as WHDs, as they relate to students' areas of interest and the purview of the course.

Digitally Recording Interviews and Capturing Digital Images. Participants in a qualitative methods and interviewing course observed and discussed the potentials of WHDs as interviewing tools. As portable research assistants, WHDs can digitally record and store audio and image files; on synchronization with a computer, files automatically transfer from the device to the computer. Although the WHDs issued to participants have 96 megabytes of built-in storage space, the devices offer expandable storage capacity through Secure Digital (SD) and Compact Flash (CF) memory cards, making WHDs' storage capability almost limitless. Our in-house tests show that 1 hour of audio at medium quality requires approximately 40 megabytes. Higher quality files require additional memory, whereas lower quality files require less. WHDs also enable researchers to capture digital photographs of participants and artifacts that participants bring to the interview and easily present electronic files such as interview guides and informed consent forms to participants. Beyond the work uncovered in the HDUL implementation, Spinuzzi (2003) has shown that handhelds "lessen the amount of work and equipment needed to collect and analyze observational data."

Taken individually, any of the five facets described earlier can be accomplished by alternative means: audio recorders recording interviews, digital thermometers measuring temperature, desktop applications as tools for assessment and evaluation, and so on. Collectively accomplishing all of these tasks by a single, wearable device, however, illustrates WHDs as effective, portable research assistants.

TRAVELING CONDUITS FOR ONLINE LEARNING

As traveling conduits for online learning, WHDs facilitate vehicles for participatory simulations and serve as artifacts that enhance thinking. Participatory simulations are designed to teach real-world phenomena in active, but constrained learning environments. Participants in these distributed simulations use location-aware handheld computers, allowing them to physically move through a real-world location while collecting simulated field data, interviewing virtual characters, and collaboratively investigating simulated scenarios. The participants described in the following high-end and low-end games were enrolled in a distributed learning course. The focus of the course is to explore the collaborative and learning affordances of various media, such as synchronous and asynchronous discussions, multi-user virtual environments, groupware, and video conferencing. As one example of high-end participatory simulations on WHDs, Augmented Reality (AR) experiences can embed students inside lifelike situations and help them understand things like the complex scientific and social dynamics underlying threats to our nation's environment, infrastructure, and public health.

An example of AR is the *Environmental Detectives,* a simulation that engages participants in a real-world environmental consulting scenario (Klopfer, Squire, & Jenkins, 2003). Participants role-play as environmental scientists investigating a rash of health concerns on campus linked to the release of toxins in the water supply. Working in teams, players attempt to identify the contaminant, chart its path through the environment, and devise possible plans for remediation if necessary. As participants physically move about campus, their handheld devices respond to their location, allowing them to collect simulated field data from the water and soil, interview virtual characters, and perform desktop research using mini-webs of data. At the end of the exercise, teams compile their data using peer-to-peer communication and synthesize their findings. Students participating in these simulations indicated that they felt invested in the situations and were motivated to solve the problem. They moved nearly seamlessly between the real world and the information being presented to them on their WHDs, as they collected data from virtual scientific instruments and accounts from virtual experts and witnesses.

In these types of learning experiences, participants' understandings of the affordances of WHDs were, in some cases, limited to handhelds as personal information managers rather than as devices that support online learning beyond the familiar "world-to-the-desktop." An illustrative example occurred during a follow-up session with an online learning course. After carrying and exploring WHDs for a week, participants in the course came together to discuss the strengths and weakness of WHDs for teaching and learning. In the middle of the discussion, participants viewed a video about the *Environment Detectives* simulation described earlier (Klopfer, 2003). On viewing the video, a participant asked what that video had to do with online learning. Interestingly, the participant associated online learning with laptop and desktop computing, but not with handheld computers wirelessly connected to the Internet. In terms of shaping mental models, this disconnect is a major psychological hurdle and a classic case of "functional fixedness": the tendency to limit objects to established belief systems, which inhibits usage and thinking of objects in novel ways. Yet by mindfully providing thoughtful opportunities for students and faculty to explore and learn with WHDs, we can support their ability to construct rich and diverse understandings of the potential for WHDs in teaching and learning.

In contrast to high-end participatory simulations set in real-world contexts, lower end games utilize less computationally intensive devices, such as palmOne's Zire 31 handheld, and use infrared ports instead of WiFi to transfer information from one device to another. As a low end game begins, participants proceed toward a solution through multiple rounds of play, which typically last between 5 and 10 minutes, repeating the same game with the same parameters. While the beginning of the learning experience is based on trial and error and rules that are only loosely defined, students communicate between rounds to describe their experiences, formulate and reformulate hypotheses, and work toward an explanation of the game's phenomena based on testable evidence, thus refining their behavior in later rounds of the exercise.

In MIT's (2005) *Virus*, participants investigate the spread of infectious disease. At the onset of the game, everyone begins healthy, and participants are told little more than to meet with as many people in the game as possible without getting sick. As the game proceeds and participants meet with one another, seemingly random people become sick. The round ends when nearly everyone is sick. Afterward, group members come together, guided by a facilitator, to discuss their experiences and to propose explanations of how people became sick. Once the group comes to a consensus on a testable hypothesis, the next round begins. This process continues until the group discovers the underlying principles governing the simulation, which include (a) that one participant initially infects others, who in turn pass on the infection and (b) that a genetic characteristic gives a few participants immunity to the infection.

Although the participants enjoyed learning the content of *Virus*, the goal of playing the game was to examine handheld computers as a learning medium. During the discussion of the game, participants noted that the primary purpose of the technology was to provide experiences to be interpreted through face-to-face discussion, and most of the rich conversations took place between rounds. Instead of piecemeal information, the participatory simulation allowed participants to focus on large ideas while socially constructing deep understandings. Through the constructivist discussion sessions, participants were empowered to follow trails of interest, make connections, reformulate ideas, and reach conclusions. Participants noted that variations among conclusions did not suggest that one participant was right while another was wrong. Instead, participatory simulations provide a learning space which illustrates that real-world phenomena are complex, multiple perspectives exist, and truth is often a matter of interpretation and reinterpretation.

In addition to whole-class investigation, a student, for our purposes named Ellie, enrolled in a distributed learning course used participatory simulations as the basis for her semester-long project.

According to Ellie's work in "Collaboration and Engagement in Educational Handheld Games," educational handheld games that facilitate augmented reality and participatory simulation have the potential to support collaborative educational activities. Although there has been extensive research in related fields, there has been limited work analyzing the collaborative aspects of learning with handheld games in education. In this work, Ellie critically examines one augmented reality game (*Outbreak@MIT*) and three participatory simulation games (*Tit for Tat*, *Sugar and Spice*, and *Genes*).

The common element of the high-end participatory simulations and the lower end games described before is immersion in authentic tasks facilitated by handheld computers. Situated in authentic circumstances that simulate real-world scenarios or phenomena, students filter information and experiences, testing and retesting hypotheses while constructing connections and reformulating ideas. Instead of fumbling with piecemeal information without a goal or purpose, participatory simulations allow students to focus on overarching concepts while socially constructing understandings. Facilitating much of the collaboration are handhelds serving as conduits that pass data between students and devices. Despite the central importance of the handhelds, they are not the focus of the learning activities. Instead, the devices help connect people to people and people to information.

THE VOICE OF THE PRACTICING TEACHERS

During one 2-hour session, participants in a mathematics methodology course compared and contrasted WHDs to TI graphing calculators and discussed their experiences with MRI Graphing Calculator software (Math Resources, 2004), a calculation application that makes use of a menu-driven interface. Such software illustrates the types of data analysis capabilities that handhelds can support. Prior to the session, participants had the option of checking out a WHD for the week. Of the 20 participants, all but 2 took advantage of the opportunity, which suggests high motivation by instructor and students to work with and learn about WHDs. This is in stark contrast to the science methodology course, in which the instructor did not encourage students to check out a handheld kit.

Participants felt that in general their K–12 students would easily take to handheld devices, but expressed varying degrees of confidence about teachers overcoming the learning curve necessary to begin using the devices effectively:

> I think sometimes when you look at students, they gravitate toward this [type of device]. They grew up on GameBoys. They walk around with cell phones taking pictures of each other, so maybe they have greater patience. Maybe they're willing to fumble through this even more so than we as teachers.

This mirrors Tapscott's (1998) observations that many tech-savvy students of today have surpassed their technologically limited teachers. As this participant suggests and as discussed later in this chapter, students are likely to bring WHDs with them wherever they go. Yet affinity for handheld devices is both a blessing and a curse depending on the pedagogical underpinning teachers establish in their classrooms. Although students can likely begin using handhelds shortly after picking them up, they also have a propensity for mischief. As one participant stated, "I'm not going to be able to walk around like I can with a worksheet and see that they're on problem 3. They're going to be playing games, trying to take photos, send them to friends." Students using handheld devices to text message answers to one another during examinations is another example of handhelds offering opportunities that can undercut learning (Muldrow, 2003).

Overall, the limiting factor on effective usage is likely not the constraints of the device, but instead the quality of instructional methods facilitated by the handheld. The same skill set of playing games, taking photos, and text messaging that is exhibited in off-task behaviors, when used appropriately, has strong educational value. Instead of condemning some affordances of the device, teachers and students have the opportunity to take advantage of such capabilities in participatory simulations (Klopfer et al., 2003), project-based learning using probeware (Staudt, 2001), and so on.

Rather than using their WHDs exclusively for educational pursuits outside of school, most students will certainly also use their WHDs for gaming, text messaging, and picture-taking functionalities. Such personalization means that WHDs have the potential to deviate from the path of many traditional pedagogical tools and practices that are useful for academic tasks, but not much else (Perkins, 1992). For example, graphing calculators are school-specific devices used in math and science courses, but are not tools students are likely to use in their extracurricular pursuits. WHDs, however, provide an interesting device for closing the gap between tools with which to think and learn and tools youth use outside of schools. As one math methods class participant states:

> I think there's some really good potential here to bridge the gap between what kids are using at school [and] what they might potentially use on the job. You know, because they're not going to use a graphing calculator to do finance. I just think it's helpful for them to see how they can use the math tool in something like Excel. Then you've done two things: you've taught them new math, and you've also given them that skill that they're going to need when they get to college or the world place.

From a learning and teaching perspective, participants expressed concerns about students using computational devices, both calculators and WHDs, without an understanding of the underlying mathematical concepts and principles. For example, participants found the MRI Graphing Calculator interface and functionality to be useful for higher order operations and calculations, but expressed concerns that this application may not support learners' initial development of mathematical concepts. As one teacher stated:

> Now I'm seeing that the graphing calculators and the handhelds, with the growth of their memory capacity, [are] putting in applications that make the math transparent. First question: how does it affect the mathematics teaching and learning? The learning piece: they're learning nothing. It just does it. It opens the door for higher functions, but at the same time, some of the things you want students to crunch out might be overlooked.

Despite this trepidation, the same teacher went on to say, "I think it's a tool where once they know how to crunch it out, [the device] can bring them much further into the subject than they would without it."

Based on our experiences and findings from the HDUL project, we developed a conceptual framework for the role of wireless handheld devices in education, presented in the next section. An earlier version of this framework shaped our design of this project, and we modified and evolved the framework as our findings developed. Although shaped by our HDUL work, we believe the framework provides an overall perspective that generalizes well beyond our specific research.

A CONCEPTUAL FRAMEWORK FOR THE ROLE OF WIRELESS HANDHELD DEVICES IN EDUCATION

Our motives for investing in HDUL are based on (a) the devices people own and carry, (b) society's cultural and technical movement toward ubiquitous computing, (c) WHDs' potential for harnessing situated and distributed cognition capabilities, and (d) emerging media-driven learning styles. In the following, we unpack each of these areas as they illuminate our HDUL findings by capturing the psychosocial potentials and limitations, problems, and possibilities of integrating such a tool in educational environments.

Devices People Own and Carry

Wireless handheld devices encompass an array of tools such as, but not limited to, cellphones, personal digital assistants (PDAs), and handheld gaming devices. They come in a variety of shapes and sizes, have different operating systems, and are used for a range of purposes. Despite these dissimilarities, WHDs share five commonalities: (a) connectability — they connect to the Internet wirelessly via wireless fidelity (WiFi), (b) wearability — they are wearable and therefore always at the fingertips of the user, (c) instant accessibility — they turn instantly on and off, (d) flexibility — they can collect data by accommodating a wide variety of peripheral extensions, and (e) economic viability — they have much of the computing capability and expandable storage capacity of laptops at a fraction of the cost (Dieterle, 2004). Nascent handhelds introduced in the late 1980s and early 1990s (e.g., Apple's *Newton* and Nintendo's *Game Boy*) have evolved considerably, gaining sophisticated computational and connectivity capabilities, morphing into smart phones, PDA-phone hybrids, and next-generation handheld gaming devices (e.g., Sony's *Playstation Portable*). Although particular devices have taken on many common qualities, they nonetheless remain uniquely identifiable and developed for particular audiences. Indeed, such devices offer leading-edge affordances, such as watching TiVo programs (Hansberry, 2005), playing games like Cyan Worlds's *Myst For Pocket PC* (Cyan Worlds Inc., 2005), and utilizing Voice over IP (VoIP), which allows real-time transmission of audio conversations over the Internet instead of phone lines (Hanttula, 2004).

Although the raw computing power of WHDs approaches that of laptop and desktop computers, they were never intended to replace their larger counterparts. On the contrary, recent technological and networking advances for WHDs hybridize the affordances of personal information managers, telephony, wireless Internet connectivity, and global positioning systems (GPS) into mobile, wearable devices designed to accompany users as they engage in everyday activities in the real world.

Beyond technical evolution, handhelds have evolved culturally, becoming staples of life in most of the developed world (Rheingold, 2002). In the United States, for example, nearly 55% of all Americans regularly carry cellular telephones (Baker & Green, 2004), and more than half (55%) of 8- to 18-year-old

Americans own a handheld gaming device (Roberts, Foehr, & Rideout, 2005). As a result, students and instructors are increasingly likely to own such devices — often for reasons other than education — and to bring them to class and into the field, thus providing educators and learners opportunities to harness the functionality of such devices as objects with which to think and learn. The population of students and faculty we studied confirmed that handhelds are increasingly part of their personal worlds.

Moving Toward Ubiquitous Computing

The human-computer interaction trajectory can be thought of in three broad waves (Weiser, 1996). The first computing wave tied many people to a single mainframe computer. Users of such computers had highly specialized skills that were not representative of average citizens, who tended to view computers as esoteric and impersonal. The second wave connected individuals to desktop and laptop computers, thus providing a one-to-one computer–human interaction. As one illustrative example, over half (54%) of all U.S. citizens were using the Internet to some extent, and two in three (66%) had used personal computers as of September 2001 (National Telecommunications and Information Administration, 2002), thus shifting computing from a highly specialized skill to something done by the majority of U.S. society. The third wave is the era of ubiquitous computing: seamless computing, whereby many computers interact with one person on a microscale, many computers interact with many people on a macroscale, and on both levels computers interact in conjunction with other computers. In the first two computing waves, computers — and therefore users — are tethered to specific locations for power and network connectivity. Ubiquitous computing, in contrast is dynamic, temporal, and contextually specific computing in which computers are no longer seen and reside in the periphery of our daily activities (Weiser, 1991). Indeed the visions first articulated in the 1990s are becoming the realities of today. UbiComp 2004, the sixth international conference on ubiquitous computing, showcased ambient technologies that support elder's care networks (Consolvo, Roessler, & Shelton, 2004), objects such as chemical carboys that assess and make decisions about their environments (Strohbach, Gellersen, Kortuem, & Kray, 2004), and noninvasive WHDs that coordinate destination and geospatial information to support navigation through public transportation systems (Patterson et al., 2004). In this evolution, the hardware, networking, and human-computer interaction challenges from an engineering and computer science standpoint are immense (Satyanarayanan, 2001).

Co-evolving in the primordial third wave of computing are today's media-saturated, digital kids. A recent report sponsored by the Henry J. Kaiser Family Foundation (Roberts et al., 2005) asserts that nearly all typical 8- to 18-year olds in the United States have used a computer (98%) and gone online (96%). On any given day, more than half of all typical 8- to 18-year-olds in the United States use a computer recreationally (i.e., playing games, instant messaging, emailing, visiting websites and chatrooms), with just over one in four of the same population (28%) spending more than 1 hour engaged in recreational computer use. Beyond desktop computing, more than half (55%) own handheld gaming devices, almost two in five kids (39%) report owning their own cell phones, while 1 in 10 (13%) reports having a WHD. As Brown (2002) captures the phenomenon:

> Today's digital kids think of information and communications technology (ICT) as something akin to oxygen: they expect it, it's what they breathe, and it's how they live. They use ICT to meet, play, date, and learn. It's an integral part of their social life; it's how they acknowledge each other and form their personal identities. (p. 70)

With greater connectivity and the ability to capture, process, send, and receive information through multiple devices anytime and anywhere, we move closer to Mitchell's (2003) vision of ubiquitous computing facilitating the means for electronic nomadicity:

> Gradually emerging from the messy but irresistible extension of wireless coverage is the possibility of a radically reimagined, reconstructed, electronic form of nomadicity — a form that is grounded not just in the terrain that nature gives us, but in sophisticated, well-integrated wireless infrastructure, combined with other networks, and deployed on a global scale. (p. 57)

WHDs' Potential for Harnessing Situated and Distributed Cognition Capabilities

The 1960s marked the beginning of the cognitive revolution, which reconceptualized behaviorist ideas about how people process, acquire, and organize information to develop knowledge and skills. In general, early cognitive science perspectives centered on what a single individual was capable of learning in a setting isolated from everyday activities. More recent theories of learning, however, refocus on the situated and distributed nature of cognition applied to thinking, learning, and doing in workplace and community settings (Lave & Wenger, 1991; Salomon, 1993; Wenger, 1998). Cognition is now seen as situated within both physical and psychosocial contexts and distributed between a person and the tools he or she is using (National Research Council, 2000; Sternberg & Preiss, 2005).

An example of the power of situated learning and distributed cognition is the authors' mentoring of Alex Bick, a high school student from New Jersey (Dieterle, 2005d). In February 2004, Bick contacted us seeking mentorship for his work with handheld computers. Bick was enrolled in an independent research program that allows students to complete individual and original research based on a topic of interest. Through a steady stream of emails, instant messages, and videoconferences with Bick, we helped him refine and clarify his research questions, design, analysis, and findings. On receiving text documents from Bick via email, the authors embedded comments, suggestions, and questions using Microsoft Word's revision tracking capabilities. As his work moved from theory to implementation, Bick and the authors utilized synchronous communication technologies (i.e., instant messaging and video conferencing software) to touch base and discuss ongoing issues and puzzles. While Bick started with a driving motivation to learn more, his interactions with researchers helped legitimize his high school project into solid research valued by the learning and technology community, as demonstrated by Bick's (2005) recent publication in *Learning and Leading with Technology*. Through the mentoring relationship, supported by distributed learning tools, Bick's "intentions to learn are engaged and the meaning of learning is configured though the process of becoming a full participant in a sociocultural practice" (Lave & Wenger, 1991).

Despite the distinction between older and newer formulations of the role cognition plays in learning (Anderson, Greeno, Reder, & Simon, 2000), key differences between learning in and out of school persist (based on Resnick, 1987):

1. Schools focus on individual performance, whereas cognition outside of schools is usually socially distributed;
2. Schools focus on unaided thinking (i.e., thinking without tools, prompts, etc.), whereas outside of schools, tool use is prominent, distributing cognition between a person and an artifact;
3. Schools focus on symbolic thinking (i.e., thinking with abstract representations, rather than more concrete terms related to particular situations), but activities outside of schools involve the particularization and contextualization of abstractions; and

4. Schools focus on general skills, whereas outside-of-school learning tends to focus on situation-specific ideas.

Our students are digital-age learners (Brown, 2002; Dede, 2005; Roberts et al., 2005). Learning environments constructed within classrooms should reflect the world outside of schools to better prepare students for their post classroom lives as citizens in a democratic society, life-long learners, and productive members of the 21st-century workforce (Partnership for 21st Century Skills, 2003). Wireless handheld computers will not fully dissolve the difference between learning in and out of schools, but — as shown in our findings — such devices do support social interactivity, are contextually sensitivity, facilitate cognition distributed between people and tools or contexts, and provide individualized scaffolding (Klopfer et al., 2003).

Emerging Media-Driven Learning Styles

Learning styles differentiate varying preferred pathways towards knowing and understanding. For example, while some people prefer learning by seeing, some prefer learning by doing, and still others, learning by hearing. Just as the varied modalities for learning — doing, seeing, and hearing — influence and shape cognition, so too do individuals naturally move toward the activities for learning they prefer.

Rapid advances in information and communication technology are reshaping the learning styles of many students (Dede, 2005), in part, because of advances in three complementary interfaces (Dede, 2002). The World-to-the-Desktop interface is what most users likely think of when considering human–computer interactions. It provides access to distant experts and archives, enabling collaborations, mentoring relationships, and virtual communities-of-practice via laptop and desktop computers. The Multi-User-Virtual-Environment interface is commonplace to gamers (i.e., players of Sony's *EverQuest* and id Software's *Doom*). Participants' avatars, interacting with computer-based agents and digital artifacts in virtual contexts, guide action through this interface. The third interface, Ubiquitous Computing, in which computers of all quantities, shapes, and sizes are commonly imbued in countless devices and artifacts on varying scales (based on Weiser, 1993). Such interfaces are characterized by users engaging with virtual resources as they move through and interact with a virtually augmented real world.

CONCLUSIONS

Overall, as the findings in this chapter illustrate, participants found WHDs quite effective as research assistants and tools for teaching and learning, but also highlighted device limitations and the importance of strong pedagogy. Field-based studies were enhanced by the portability of these devices, and both field and classroom studies took advantage of their capabilities to collect, share, and aggregate information. While alternative devices can complete singular operations of WHDs — in some instances, doing a better job — the strength of WHDs as portable research assistances is their diversity of functionality. WHDs also have the ability to function as traveling conduits for online learning: through participatory simulations, students traverse large landscapes (e.g., university campus) and small settings (e.g., classroom) using their devices to display, transmit, and collect virtual information overlaid and infused into the real world. As tools with which to think and learn, WHDs are not tethered to specific workstations. Instead, they travel with learners as they engage the world and each other.

Despite the technical and pedagogical potential, HDUL experienced several barriers and developed key insights while scaling up use of WHDs at HGSE and HES. Without straightforward procedures for checking out and returning equipment, hardware would likely have been lost or underutilized, and scheduling conflicts would have led to frustration and disinterest in the HUDL project. To maximize experiences, participants had appropriate opportunity to use the handhelds, recognized and comprehended the affordances of the devices, and, through authentic tasks and activities, were motivated to take advantage of the device's affordances. A lack of advocacy by an instructor led to an initial lack of interest in students. Some participants, even after rich experiences with WHDs, did not automatically make connections between online learning and learning with Internet-connected WHDs. Teacher participants shared concerns regarding new technologies, especially those their students have already mastered; students engaging in off-task behaviors; and students using computational devices without an understanding of the underlying domain knowledge.

As our findings and conceptual framework indicate, wireless handheld devices are interesting and important tools for study because they are devices people own and carry, society's cultural and technical movement toward ubiquitous computing, WHDs' potential for harnessing situated and distributed cognition capabilities, and emerging media-driven learning styles. Despite their potential, WHDs are not silver bullets capable of solving all of education's challenges. They are, however, devices that are finding their way into classrooms of all shapes and sizes, from primary grades through higher education, because students and teachers naturally bring them along. They are devices that users integrate into their personal lives outside of school to perform a variety of distributed tasks (e.g., text messaging and playing games) and functions (e.g., taking digital pictures and emailing them to family). As educators, we have an opportunity to harness the power such tools afford by using them within the four walls of the classroom and in the real world as portable research assistants and as traveling conduits for online learning. However, if the full power for learning of these devices is to be realized, substantial work is needed in developing strategies for design, implementation, and capacity-building, both technological and human.

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Appendix 1 Matrixes for selecting devices, peripherals and software

Matrix for Selecting Handheld Devices

Operating system questions	• Is your product compatible with Palm OS?
	  o Will it work with the most current Palm operating system or only with a legacy OS?
	  o Does your company intend to continue developing software for the Palm OS?
	• Is your product compatible with Windows Mobile OS?
	  o Does your company intend to continue developing software for the Windows Mobile OS?

Hardware questions	• How much memory comes standard with the device? • How does your product attach itself to a desktop or laptop computer? • Does your product have internal SD and/or CF card slots?

	• How long can I expect the battery of your device to last? o How will this vary when I am using different extensions such as Wi-Fi? • What is the standard warranty for your device?
Software questions	• What software comes standard with your product? • Does it come with a: o word processor o spreadsheet application o Internet browser
Networking questions	• Is your device Wi-Fi compatible? o Is the hardware needed to use Wi-Fi internal or would that require an additional card or extension? • Is your device Bluetooth compatible? o Is the hardware needed to use Bluetooth internal or would that require an additional card or extension?
Examining demo devices	• Can you send me a demo of your product directly? • Can a sales associate visit our campus and model your product? • Do you have contact information of someone that is currently using your product in a school or university?

Matrix for Selecting Handheld Peripherals

Operating system questions	• Is your product compatible with Palm OS?
	  ○ Will it work with the most current Palm operating system or only with a legacy OS?
	  ○ Does your company intend to continue developing software for the Palm OS?
	• Is your product compatible with Windows Mobile OS?
	  ○ Does your company intend to continue developing software for the Windows Mobile OS?

Hardware questions	• How does your product attach itself to the handheld device? • Does your product utilize an internal SD or CF card slot? • Are there specific handheld manufacturers and models that are especially compatible or incompatible with your product? • What is the standard warranty for your device?
Software questions	• What software comes standard with your product? • Will I need to purchase or download additional software to use your product?
Examining demo devices	• Can you send me a demo of your product directly? • Can a sales associate visit our campus and model your product? • Do you have contact information of someone that is currently using your product in a school or university?
Scientific probeware questions	• Besides the handheld device, what is everything that I would need to purchase to begin collecting temperature, pH and motion-related data?

Matrix for Selecting Handheld Software

Operating system questions	• Is your product compatible with Palm OS?
	  ○ Will it work with the most current Palm operating system or only with a legacy OS?
	  ○ Does your company intend to continue developing software for the Palm OS?
	• Is your product compatible with Windows Mobile OS?
	  ○ Does your company intend to continue developing software for the Windows Mobile OS?

Software questions	• What software comes standard with your product? • Will I need to purchase or download additional software to use your product?
Learning and teaching questions	• What learning objectives does your software seek to address? • Are there particular grades that your software is designed for? • How does your software engage student learning? • What research has been conducted to examine teaching and learning with your software? • Does your software use networking capabilities?
Examining demo devices	• Can you send me a demo of your product directly? • Can a sales associate visit our campus and model your product? • Do you have contact information of someone that is currently using your product in a school or university?

<u>Figure 15.1</u> Typical Package Participants Received During Week-Long Handheld Experience. Items include from left to right: Data Harvest Temperature Probe and Data Logger, ArtBin Quick View Storage Box, Toshiba Pocket PC e750 and USB Power Sync Cable, Sandisk 256MB SD Card, and Veo CF Camera.