# Handheld Devices for Ubiquitous Learning and Analyzing

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Handheld Devices for Ubiquitous Learning
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**Abstract**: Wireless handheld devices (WHDs) include but are not limited to cellphones, personal digital assistants and handheld gaming devices. Despite their differences, WHDs offer similar capabilities as they evolve technologically and become staples of American culture. Indeed, students and teachers are increasingly likely to own WHDs, offering educators and learners opportunities to harness the affordances such devices provide. The Handheld Devices for Ubiquitous Learning (HDUL) project seeks to understand the potentials and limitations, problems and possibilities WHDs pose teaching and learning in the 21st Century. During the 2003-2004 and 2004-2005 academic years, HDUL worked with students, faculty and staff from eight diverse courses at the Harvard Graduate School of Education and the Harvard Extension School. At the end of a two-year project, our work has shown that WHDs can be used as (1) *portable research assistants* and (2) *traveling conduits for online learning*. This paper discusses our methods and initial findings situated in current theories of learning and teaching. As the evaluation of HDUL continues, this paper is also a venue to share with community members work to be more fully published at a later date (Dieterle & Dede, forthcoming).

**Introduction –** Wireless handheld devices (WHDs) encompass an array of tools such as, but not limited to, cellphones, personal digital assistants 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, wireless handheld devices (WHDs) share five commonalities: 1) *Connectability* – they connect to the Internet wirelessly via wireless fidelity, or WiFi, 2) *Wearability* – they are wearable and therefore always at the fingertips of the user, 3) *Instant Accessibility* – they turn instantly on and off, 4) *Flexibility* – they can collect data by accommodating a wide variety of peripheral extensions, and 5) *Economic Viability* – they have much of the computing capability and expandable storage capacity of laptops at a fraction of the cost (Dieterle, 2004). While the raw computing power of

WHDs approaches those of laptop and desktop computers, they were never intended to replace their stationary 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.

Nascent handhelds introduced in the late 1980's and early 1990's (e.g., Apple's *Newton*; Nintendo's *Game Boy*) have gained sophisticated computational and connectivity capabilities, morphing and evolving into smart phones, PDA-phone hybrids and next generation handheld gaming devices (e.g., Sony's *Playstation Portable*). Indeed, users of such devices are likely to take greater advantage of the affordances of wireless handheld computers, 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). Beyond technical evolution, handhelds have evolved culturally, becoming staples of American life. For example, nearly 55% of all Americans regularly carry cellular telephones (Baker & Green, 2004). 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 Impetus for HDUL** – 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 or doing email during class, IM-ing 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 potentials and limitations, problems and possibilities WHDs pose for teaching and learning, the Harvard Graduate School of Education (HGSE) established and housed the Handheld Devices for Ubiquitous Learning (HDUL) project, which conducted studies over the 2003 - 2004 and 2004 - 2005 academic school years.

**Startup Decisions** – The HDUL team included members from HGSE's Learning and Technology Center and HGSE faculty and staff from diverse backgrounds and expertise. An early objective of the project was determining which hardware, peripherals, and software to purchase. Utilizing criteria from trade journals (e.g., *Pocket PC Magazine*), online resources (e.g., *palmOne, CNet* and *ZDNet* websites), and best practices from other projects (e.g., Vincent, 2004; Ward, 2005), the HDUL team constructed evaluation matrixes for selecting handheld devices, peripherals such as probeware, and software, which are available in Appendix 1 and in the *Findings* section of the HDUL website (Dieterle, 2005). The HDUL 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 camera). In general, the HDUL team found limited variation among the devices. However, the differences that did exist where significant enough to warrant a well grounded decision[1]. The compelling differences, summarized in Table 1 below, existed in: 1) handheld costs, 2) probeware startup costs and 3) wireless connectivity.

**Table 1** Summary of Evaluation Criteria Variation and Findings

| **Evaluation Criteria** | **Findings** |
|---|---|
| Handheld costs include the handheld, charger and synchronization cable. | Handheld costs among devices varied greatly (Dell *Axim X50* ≈ \$299.00; Toshiba *e750* \$318.00; Palm's *Tungsten C* ≈ \$363.00; HP *iPaq H5550* ≈ \$439.00). |
| Probeware startup costs include the probeware base unit, light sensor, motion detector, pH meter and temperature probe. | Startup costs for devices running Windows Mobile OS (\$415.00) are less than those running Palm OS (\$472.00). The HP iPaq H5550 model requires an additional attachment to run the same probeware. |
| Wireless connectivity via WiFi | All models easily connected to HGSE's WiFi network. However, the Dell Axim we tested required an additional wireless card, which decreases the device's modularity. |

Based upon variation in costs, functionality, and connectivity, HDUL selected the Toshiba e750. While 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.

In order to organize, protect and keep track of the devices and peripherals, HDUL purchased translucent storage boxes. Figure 1 illustrates a typical handheld package participants received during each implementation.

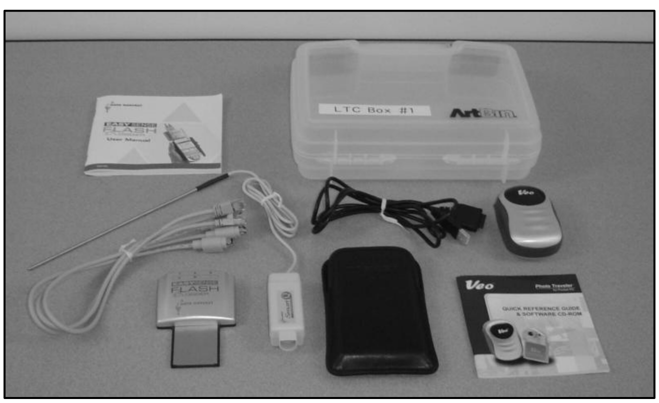


**Figure 1** Typical Package Participants Received During Week-Long Handheld Experience. Items include from left to right: Data Harvest Temperature Probe and Data Logger, ArtBin Quick View Storage Box, Toshiba Pocket PC e750 and USB Power Sync Cable, Sandisk 256MB SD Card, and Veo CF Camera.

[1] All of HDUL's purchasing decisions are based upon 1) the needs of the HDUL project and 2) the handheld market and 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 make informed decisions based upon our research and experience.

**Research Methods and Handhelds in the Hands of Users** – During the project's lifecycle, HDUL successfully introduced WHDs into eight different courses at the Harvard Graduate School of Education and the Harvard Extension School for a variety of purposes as summarized in Table 2 below.

**Table 2** 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 are masters and doctoral students of education, many of whom are seasoned teachers and researchers, who did not enroll in more than one class that examined handhelds in a given academic year. While their direct experience with handhelds was limited in duration, they based their comments and reflections upon their expertise as educators and researchers in general and not their expertise on handheld computers. For each course, participants, both students and professors, typically received a WHD Package (see Figure 1) for one week with an assigned task (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). Based on these individual experiences in relation to the assigned task, the next class was spent 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. While the majority of the implementations and integration of 2003-2004 academic year were structured innovations into courses, the 2004-2005 academic year emphasized and supported students who wished to drill deeply into an aspect of learning with handhelds. Data from this work are students' final papers and projects, which are discussed in greater detail below.

**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 1) effective portable research assistants and 2) traveling conduits for online learning. While this paper goes into much greater detail, Dede and Dieterle (2004) conducted a seminar on HDUL late in the 2004 spring semester, which is available online – http://isites.harvard.edu/icb/icb.do?keyword=k240&pageid=icb.page314.

***As researcher 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 the 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.

*1. 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. In 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. Afterwards, students then 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 et al. (2003) completed a nine-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 Luchini et al. results, 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 products designed to capture what students know and explored *Sketchy* (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 session, participants were asked to use *Sketchy* to construct an accurate, animated representation of the moon orbiting the earth 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 a tool for assessment. 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 capability of providing immediate, individualized feedback and 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, while multiple choice and short answer questions are easily processed with handhelds, longer reading and writing assignments and authentic, project-based assessments would be better served on a larger screen interfaces.

*2. Capturing and Projecting Learners' Opinions*

Similar in nature to the commercially available assessment applications discussed above, 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.

*3. 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*. Afterwards, 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. While 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. Upon aggregation of the data, the collective sample size expanded to 120 participants.

*4. 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. 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; due in part to the instructor's lukewarm stance about this activity, of the 20 participants none took advantage of the opportunity, which suggests low motivation on the part of the instructor and therefore the students to work with and learn about WHDs. 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) 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 interest in previewing the devices for the face-to-face session.

In contrast, Mark Millar, a master's candidate with a strong background in science enrolled in a different course explored in a semester-long project how WHDs relate to physics education. In "*When Three Worlds Collide: Physics, Amusement Parks and Wireless Handheld Computers*," Millar first examines the background of teaching physics in amusement parks, before considering a broad overview of how handhelds are impacting education. Millar then discusses two examples of the use of handhelds to teach physics in amusement parks. The rest of the paper focuses on how wireless technologies can contribute to and change such learning environments.

*5. 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, and, upon synchronization with a computer, files automatically transfer from the device to the computer. While 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 memory cards, making WHDs' storage capability almost limitless. Our in-house tests show that one hour of audio at medium quality requires approximately 40 megabytes. Higher quality files require additional memory, while lower quality files require less. WHDs also enable researchers to 1) capture digital photographs of participants and artifacts that participants bring to the interview, and 2) 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."

***As traveling conduits for online learning***, WHDs facilitate vehicles for participatory simulations serve and 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 high-end and low-end games below 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 the complex scientific and social dynamics underlying threats to our nation's environment, infrastructure, and public health.

The *Environmental Detectives* simulation engaged 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 that was 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 above (Klopfer, 2003). Upon viewing the video, a participant asked what that video had to do with online learning. Interestingly, the participant associates online learning with laptop and desktop computing and not with handheld computers wirelessly connected to the Internet. In terms of shaping mental models, this disconnect is a major psychological hurdle. 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 Palm Pilots, 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 upon by trial and error and rules that are only loosely defined, students break between rounds to describe their experiences, formulate and reformulate hypotheses, and work toward an explanation of the game's phenomena based on testable evidence.

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 or as few people in the game without getting sick. As the game proceeds and participants meet with one another, seemingly random people become sick. The round ends when everyone or nearly everyone is sick. Afterward group members comes together, guided by a facilitator, to discuss their experiences and propose explanations of how people became sick. Once the group comes to consensus on a testable hypothesis, the next round begins. This process continues until the group discovers the underlying principles governing the simulation, which include 1) that one participant initially infects others, who in turn pass on the infection and 2) that a genetic characteristic gives some participants immunity to the infection.

While the participants enjoyed learning the content of *Virus*, the primary purpose 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 support face-to-face interaction, 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, to make connections, to reformulate ideas, and to 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 that 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 enrolled in the distributed learning course used participatory simulations as the basis for her semester-long project. According to Schrier'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. While 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, Schrier critically examines one augmented reality game (*Outbreak@MIT*) and three participatory simulation games (*Tit for Tat*, *Sugar and Spice*, and *Genes*).

**The Voice of the Practicing Teachers –** Participants in a math methodology course compared and contrasted WHDs to TI graphing calculators and discussed their experiences with *MRI Graphing Calculator* software (2004), a calculation application that makes use of a menu-driven interface, during one 2-hour session. 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 to work with and learn about WHDs. 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.

As this participants suggests, students are likely to bring WHDs with them wherever they go. Yet, this affinity for handheld devices is both a blessing and a curse. While 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 handhelds devices to text-message answers to one another during examinations is another example of handhelds offering opportunities that can undercut learning (Muldrow, 2003). Despite this off-task behavior, the same skill set of playing games, taking photos, and text messaging – when used appropriately – has strong educational value. Instead of condemning the affordances of the device, teachers and student have the opportunity to take advantage of such capabilities in participatory simulations and for collaboration as discussed earlier in this paper.

Instead of using their WHDs for educational pursuits outside of school, students will likely use their WHDs for gaming, text messaging, and picture-taking functionalities, meaning WHDs have the potential to deviate from the path of many traditional pedagogical tools and practices that are useful for schoolish 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 the real world. WHDs, however, provide an interesting device for closing the gap between tools with which to think and learn and tools found 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.

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 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 and that's what all of us moving to there. It opens the door for higher functions, but at the same time, some of the things you want to crunch out might be overlooked.

Despite this trepidation, the same teacher went on to say that "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."

**Conclusions** – Overall, as the examples in this paper illustrate, participants found WHDs quite effective as research assistants and tools for teaching and learning, but tended to understand 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. WHDs also have the ability to function as traveling conduits for online learning. Through participatory simulations, students traverse large landscapes (e.g., university campus) or small settings (e.g., classroom) using their devices to display, transmit and collect virtual information overlaid and imbued 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. Wireless handheld devices are not silver bullets capable of solving all 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 researcher 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?<br>  ○ Will it work with the most current Palm operating system or only with a legacy OS?<br>  ○ Does your company intend to continue developing software for the Palm OS?<br>• Is your product compatible with Windows Mobile OS?<br>  ○ Does your company intend to continue developing software for the Windows Mobile OS? |
| Hardware Questions | • How much memory comes standard with the device?<br>• How does your product attach itself to a desktop or laptop computer?<br>• Does your product have internal SD and/or CF card slots?<br>• How long can I expect the battery of your device to last?<br>  ○ How will this vary when I am using different extensions such as Wi-Fi?<br>• What is the standard warranty for your device? |
| Software Questions | • What software comes standard with your product?<br>• Does it come with a:<br>  ○ word processor<br>  ○ spreadsheet application<br>  ○ internet browser |
| Networking Questions | • Is your device Wi-Fi compatible?<br>  ○ Is the hardware needed to use Wi-Fi internal or would that require an additional card or extension?<br>• Is your device Bluetooth compatible?<br>  ○ 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?<br>• Can a sales associate visit our campus and model your product?<br>• 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?<br>  o Will it work with the most current Palm operating system or only with a legacy OS?<br>  o Does your company intend to continue developing software for the Palm OS?<br>• Is your product compatible with Windows Mobile OS?<br>  o 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?<br>• Does your product utilize an internal SD or CF card slot?<br>• Are there specific handheld manufacturers and models that are especially compatible or incompatible with your product?<br>• What is the standard warranty for your device? |
| Software Questions | • What software comes standard with your product?<br>• 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?<br>• Can a sales associate visit our campus and model your product?<br>• 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?<br>  o Will it work with the most current Palm operating system or only with a legacy OS?<br>  o Does your company intend to continue developing software for the Palm OS?<br>• Is your product compatible with Windows Mobile OS?<br>  o Does your company intend to continue developing software for the Windows Mobile OS? |
| Software Questions | • What software comes standard with your product?<br>• 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?<br>• Are there particular grades that your software is designed for?<br>• How does your software engage student learning?<br>• What research has been conducted to examine teaching and learning with your software?<br>• Does your software use networking capabilities? |
| Examining Demo Devices | • Can you send me a demo of your product directly?<br>• Can a sales associate visit our campus and model your product?<br>• Do you have contact information of someone that is currently using your product in a school or university? |