

Straightforward and Deep Effects of Wireless Handheld Devices for Teaching and Learning in University Settings

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ABSTRACT

This paper presents findings from the two year Handheld Devices for Ubiquitous Learning project that integrated wireless handheld devices (WHDs) into eight diverse graduate courses. Through the analysis of the data and relevant research literature, we inductively developed a theoretical framework for understanding and situating the affordances of WHDs for learning and teaching.

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INTRODUCTION

The Handheld Devices for Ubiquitous Learning (HDUL) project, funded by Harvard's Provost and under the guidance of Professor Chris Dede, sought to determine how wireless handheld devices (WHDs) — which include, but are not limited to, cellphones, personal digital assistants, and handheld gaming devices — could enhance learning and teaching in university settings. During the 2003–2004 and 2004–2005 academic years, HDUL successfully integrated WHDs into eight diverse courses at the Harvard Graduate School of Education (HGSE) and the Harvard Extension School (HES). Interpretation of the data collected from HDUL implementations led us to inductively develop a theoretical framework for understanding and articulating the affordances of WHDs in support of learning and teaching. This paper presents an analysis of this framework through the data collected in the HDUL project and examination of relevant research literature. The results of this analysis provides usable knowledge for educators, designers, and researchers interested in better understanding the psychosocial potentials and limitations, problems, and possibilities of integrating WHDs into educational environments. An interesting finding of this work is the differentiation of WHDs producing both straightforward effects (i.e., *streamliners* – mechanisms that actively improve the efficiency of a process or action) and deep effects (i.e., *enablers* – mechanisms that make an action or process possible that before or otherwise would be impractical or impossible to carry out). The sections that follow make plain and comprehensible the theoretical framework, the educational importance of the study, data sources and evidence, research questions, research methods, and findings of this analytic study.

THEORETICAL FRAMEWORK

Nascent handhelds introduced in the late 1980s and early 1990s (e.g., Apple's *Newton*; 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*). More important than technical advancements are four complementary trends advancing WHDs as interesting tools to study (Dieterle, 2005a; Dieterle & Dede, forthcoming; Dieterle, Dede, & Schrier, forthcoming): (a) the proliferation of WHDs, (b) society's movement towards ubiquitous computing, (c) WHDs fostering media-based learning styles, and (d) WHDs facilitating sophisticated instructional designs based on situated and distributed perspectives on learning.

Proliferating Wireless Handheld Devices

Access and ownership of WHDs is increasing among all demographics and cultures throughout the world, especially among adolescents and young adults (Rheingold, 2002; Roberts, Foehr, & Rideout, 2005). A recent report, *Wireless Industry Indices: 1985 – 2005*, issued by the Cellular Telecommunications Industry Association (2005), illustrates this trend clearly and comprehensively with cellular telephones, one of the first and most pervasive wireless handheld devices. In June 1985, the United States accounted for an estimated 200,000 wireless subscribers. In ten years time, the number of subscribers increased to just over 28 million. In June 2005, wireless subscriptions rose to just under 195 million; described another way, approximately 6 in 10 U.S. citizens holds a cellular telephone subscription.

Similar growth trends in cellular telephony are taking place globally and, in some instances, more intensively than in the U.S. In Italy, the United Kingdom, and Taiwan, for example, the ratio of activated cellphones to residents is greater than one-to-one (International Telecommunication Union [ITU], 2005). Globally, the number of mobile phones surpassed 2 billion in mid 2005 (ITU, 2005).

Among U.S. teens, as Lenhart, Madden, and Hitlin (2005) have found, almost half (45%) report owning a cell phone, with a greater percentage of older teens owning a phone (nearly 3 in 5 teens aged 15-17) than younger teens (nearly 1 in 3 teens aged 12-14). In terms of owning at least one personal media device, such as a cell phone, desktop, laptop, and handheld computer, more than 4 out of 5 teenagers (84%) report owning at least one such device (Lenhart et al., 2005), and more than half (55%) own at least one handheld gaming device (Roberts et al., 2005).

Based on these tendencies, students and instructors are increasingly likely to own one or more WHD — often for reasons other than education — and to bring devices to class and into the field. Because of the pervasiveness of WHDs, it is critical for educators and learners to understand the strengths and limits of WHDs as objects with which to think and learn; a focus of this paper and the work it recounts.

Society's Movement Towards Ubiquitous Computing

Ubiquitous computing provides dynamic, temporal, and contextually specific tools and media in which computers are no longer perceptually foregrounded, instead participating seamlessly and almost unnoticed as an integral part of our daily activities. As powerful computational devices such as WHDs pervade our physical surround on a variety of scales, users obtain ever-present connectivity and access to capture, process, send, and receive information through multiple devices anytime and anywhere. Recent research on the ubiquitous computing interface has led to ambient technology systems that support elders 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). Hardware, networking, and human-computer

interaction innovations challenge the engineering and computer science disciplines (Satyanarayanan, 2001), but the primary implementation barriers for new learning devices are neither technical nor economic, but psychological, organizational, political, and cultural (Dede, 2001). As Norman (1993) cautions, new technologies may streamline process, but before they are introduced and studied in practice “it isn’t always obvious just which parts are critical to the social, distributed nature of the task, which are irrelevant or detrimental. Until we understand these aspects better, it is best to be cautious” (p. 145). Thus it is not only the construction of the tool, but its affordances and limits that must be critically examined before, during, and after integrating a tool into a learning environment.

Media-Based Learning Styles

U.S. teenagers are highly connected to the Internet and have ready access to variety of personal media devices. As described earlier, more than 4 out of 5 U.S. teenagers report owning at least one personal media device (Lenhart et al., 2005) and more than half own a handheld gaming device (Roberts et al., 2005). Nearly 9 in 10 (87%) U.S. teenagers use the Internet, and over half (51%) go online daily (Lenhart et al., 2005). In addition to access and connectivity, the majority of U.S. teenagers use multiple media simultaneously at any given time. As Roberts and colleagues’ (2005) work indicates, more than half of U.S. teenagers report accessing at least one additional medium either “most of the time” or “some of the time” when watching TV (53%), reading (58%), listening to music (63%), and using a computer (65%). In contrast to multitasking, “the proportion of kids who say they ‘never’ use other media in response to these questions ranges from a low of 12% when listening to music to a high of 19% when watching TV” (p. 36).

More interesting to educators, however, is what kids are doing once they get online. Among U.S. teenagers that go online, 4 in 5 (81%) play online games, 3 in 4 (76%) access news, and just under 1 in 3 (31%) seeks out health related information (Lenhart et al., 2005). Besides consuming information, nearly 3 in 5 (57%) U.S. teenagers contribute to the content of the Internet by creating blogs and WebPages; posting original artwork, stories, and photos; and remixing existent content in novel ways (Lenhart & Madden, 2005).

Just as the varied modalities for learning — doing, seeing, and hearing — influence and shape cognition, so too do individuals naturally move toward the activities they prefer for learning. Whether consciously or otherwise, the majority of U.S. teenagers demonstrate a natural inclination towards consumable and constructible media for a variety of purposes.

Learning styles differentiate varying preferred pathways toward knowing and understanding. Many popular learning styles exist, but the three that are widely accepted as standards are (a) sensory-based (e.g., visual, auditory, kinesthetic), (b) personality-based, and (c) aptitude-based, which draws on categorizations such as Gardner's (1983) multiple intelligences. Trends in the consumption, production, and immersion of media by users of all age has led Dede (2005) to propose new media-based learning styles. Going beyond the characteristics typically attributed to the millennials cohort, Neomillennial Learning Styles (NLS) are based on (a) fluency in multiple media, valuing each for the types of communication, activities, experiences, and expressions it empowers; (b) learning by collectively seeking, sieving, and synthesizing experiences rather than individually locating and absorbing information from a single best source; and (c) active learning based on experience, both real and simulated, that includes frequent opportunities for reflection. Emergent tools such as WHDs (Dieterle et al., forthcoming) and multi-user virtual environments (Clarke & Dede, 2005; Dede, Clarke, Ketelhut, Nelson, &

Bowman, 2005) are fostering NLS in students of all ages (Dede, 2005). In the interest of space, this paper will only consider examples related to WHDs.

WHDs Facilitate Sophisticated Instructional Designs

WHDs have the potential to enable sophisticated types of instructional designs based on situated and distributed perspectives on learning, which are discussed later in the paper. Recent theories of learning focus 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 seen as situated within both physical and psychosocial contexts and as distributed between a person and the tools he or she is using (National Research Council, 2000; Sternberg & Preiss, 2005).

For learning and teaching, WHDs support social interactivity, are contextually sensitive, facilitate cognition distributed between people and tools or contexts, and provide individualized scaffolding (Klopfer, Squire, & Jenkins, 2003). When used in conjunction with constructivist learning principles (Brooks & Brooks, 1993) and guidelines for differentiating instruction (Tomlinson, 1999), handhelds have the potential to change both what and how we teach. Teachers dictating the learning experience are replaced with students following their own trails of interest scaffolded by teachers, peers, and tools for thinking and learning. Students, in turn, engage learning through multiple modalities with varying degrees of complexity, make connections, reformulate ideas, and reach their own conclusions. As Staudt (2005) explains:

Teachers will guide student learning experiences and, particularly in our standards-based environment, will align learning experiences to meet those standards. What the new technology [of WHDs] allows is for students to meet those standards in individual ways, collect personally meaningful data, and use it

to gain understanding of a large inquiry process that begins to replicate the thinking and learning process of real work or advanced study. (p. 2)

Instead of piecemeal information, students are supplied with conditions for focusing on large ideas while socially constructing deep understandings.

Despite the favorable arguments cited above, determining whether WHDs fully realize their potential as tools for teaching and learning in practice is another matter. To begin understanding the impact of WHDs on teaching and learning, the HDUL project and relevant research literature were future analyzed and the results published in this paper.

DATA SOURCES AND EVIDENCE

Participants in HDUL included faculty and students from HGSE and HES. In general, the student participants were graduate students in 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. 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. Course subjects include distributed learning, math methods, online learning, qualitative methods and interviewing, science methods, teaching with emerging technologies, team learning, and technology and assessment. Class sizes, in general, varied from approximately 20 to 50 students.

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 capabilities of the devices (Dieterle, 2005b, 2005c); and (c) through authentic tasks and activities, were motivated to take advantage of the device's affordances. Based on individual experiences in relation to the assigned task (e.g., using WHDs in the field to collect survey information from participants), 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. Participants' direct experience with handhelds was limited in duration, so they based their comments and reflections upon their expertise as educators and researchers in general. While 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.

RESEARCH QUESTIONS

1. To what extent, if at all, can WHDs function within learning environments as communicators, construction kits, information banks, phenomenaria, symbol pads and task managers (based upon Perkins, 1991)?
2. To what extent, if at all, can WHDs function within learning environments to produce straightforward effects?
3. To what extent, if at all, can WHDs function within learning environments to produce deep effects?

METHODS

Ongoing analysis of the data collected from the HDUL project and relevant research literature produced a grounded theory (Strauss & Corbin, 1998) justifying the importance for studying WHDs as tools for thinking and learning, as described earlier. For the current analysis, HDUL

data and relevant research literature were categorized with six etic codes (based on Perkins, 1991). Explanations and descriptions of each category follow.

1. *Communicators* – tools for communicating information from one person to others in various formats utilizing a range of media. Examples of communicators include email, essays, instant messengers, letters, and video conferencing tools.
2. *Construction Kits* – sets of prefabricated parts or tools designed for specified purposes and actions; as in *Lego/LOGO* (Resnick & Ocko, 1991), *LOGO* (Papert, 1980), *Magnetic Poetry*, molecular modeling kits, probeware, and *Tinker Toys*.
3. *Information Banks* – collections of data arranged for ease and speed of search and retrieval; used as a source of explicit information about topics; as in atlases, databases, encyclopedias, and textbooks.
4. *Phenomenaria* – mechanisms that simulate phenomena or environments while supporting the manipulation of variables for the purposes of critical observation and research; as in aquaria, planetaria, terraria, *GenScope* (Hickey, Kindfield, Horwitz, & Christie, 2003), and *River City* (Ketelhut, Dede, Clarke, Nelson, & Bowman, forthcoming).
5. *Symbol Pads* – surfaces designed and utilized for the construction and manipulation of symbols. Examples of symbol pads include chalkboards, paper and pencil, spreadsheet software, and word processors.
6. *Task Managers* – various elements within the learning environment that define, scaffold, and provide feedback on the work undertaken or attempted by learners; as in classroom teachers, cooperative learning group leaders, *Geometry Tutor* (Anderson, Corbett, Koedinger, & Pelletier, 1995), and *Knowledge Forum* (Scardamalia, 2002).

Case studies were developed for each code following Yin's (2003) methods for embedded case study design. Analyses of the constructed case studies led to two additional categories (Strauss & Corbin, 1998) that differentiate the affects of WHDs in learning environments.

1. Straightforward effects are the qualities and capabilities utilized by users when initially presented with an innovation or artifact and support surface changes in process and activity (based on Perkins, 1985). Here we have characterized straightforward effects as “streamliners” — mechanisms that actively improve the efficiency of a process or action.
2. Deep effects encapsulate how an artifact significantly affects cognition, social interactions, and the qualities distinctive to individuals (based on Perkins, 1985). Here we have characterized deep effects as “enablers” — mechanisms that make an action or process possible when before or otherwise would be impractical or impossible to carry out.

FINDINGS

As described earlier, etic codes were used in this study to categorize uses of WHDs as communicators, construction kits, information banks, phenomenaria, symbol pads, and task managers. The resulting syntheses are case studies for each category with discussion of their straightforward and deep effects when applicable.

WHDs as Communicators

Communicators — as in email, essays, instant messengers, letters, and video conferencing tools — are tools for communicating information from one person to others in various formats utilizing a range of media. As discussed earlier, emergent 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. Through the convergence of functionality, WHDs serve as

communicators through multiple media (i.e., audio, pictures, video), connecting users to other users both face to face and over distance.

Participants in a qualitative methods and interviewing course observed and discussed the potentials of WHDs as interviewing tools. WHDs can digitally record and store audio and image files. On synchronization with a desktop or laptop computer, files automatically transfer from the device to the computer. Used as communicators, WHDs enable researchers to both capture and present digital files (e.g., photographs, images, audio, and video) when meeting with subjects. 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.” These two examples demonstrate straightforward effect of WHDs as communicators, in which the mechanisms for interviewing and observing are actively improved by making the procedures more efficient.

An example of a deep effect of WHDs as communicators is their influence on micro-coordination of activities (Ling & Haddon, 2003; Rheingold, 2002). Instead of premeditated coordination of events and plans, users of WHDs have the ability to establish or alter plans in action. Moreover, users of WHDs no longer need to know where the parties they wish to communicate are located in order to get in touch with them.

WHDs as Construction Kits

Construction kits — as in *Lego/LOGO*, *LOGO*, *Magnetic Poetry*, molecular modeling kits, probeware, and *Tinker Toys* — are sets of prefabricated parts or tools designed for specified purposes and actions. Participants in a science methods class explored the use of WHDs in science using Data Harvest’s (2005) probeware to collect and analyze data in real time. 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.

As a second example, the University of North Carolina Wilmington's *Project Numina* is exploring the use of WHDs for teaching college-level science and mathematics, including such construction kit applications as *Armchair Applications'* (2002) *Pocket Oscillator*, Display Research Laboratory's (2003) *HandDee Spectrum Analyzer*, and Hypercube Incorporated's (2003) *Pocket HyperChem* as shown in figure 1.

Figure 1. Screen captures of various handheld construction kit applications



Collectively, HDUL and Project Numina's use of WHDs as construction kits supports the visualization of difficult to understand concepts ranging from temperature change to molecular modeling. Whereas access is a prerequisite to use, pervasive access to such tools guarantees neither use nor understanding. As Perkins (1993) warns of the fingertip effect, left on their own, novices will not necessarily understand or be sufficiently motivated to take advantage of the functionality of a tool to the same extent as experts.

WHDs as Information Banks

Information banks — as in atlases, databases, encyclopedias, and textbooks — are collections of data arranged for ease and speed of search and retrieval; used as a source of explicit information about topics. Within the HDUL study, we did not have an opportunity to study WHDs as information banks directly. Nonetheless, many studies in the medical education community do examine WHDs as information banks. In a recent controlled study, for example, a treatment group of first-year residents received WHDs while enrolled in an evidence-based medicine (EBM) course (Grad et al., 2005). Installed on students' WHDs were clinical decision support systems (CDSS) and clinical information in retrieval technologies (CIRT). CDSS operate by users inputting patient data, and the system retrieving and returning a prediction of the course of a disease and various risk levels. CIRT, on the other hand, “includes databases on information about diseases, therapies, and interpretations of diagnostic test, potentially applicable to decisions about multiple patients” (pp. 734-735). Both categories of applications clearly meet the criteria of databanks.

As part of the experimental design, students in the study were adequately trained on how and when to use the software. After control and experimental students had completed their prescribed medical clerkships, both groups of students completed validated paper-based knowledge assessments. Students from the treatment group performed no better than their peers in the control group who received neither a WHD nor the EBM course. Not surprisingly, when students in the treatment group were allowed to repeat the test with their WHD, their results improved. The common measure given to both control and treatment groups measured *the effects from* the technology, which are generally limited in the short term, and the retest of the treatment

group with WHDs measured the *effects with* the technology. Salomon and Perkins (2005) capture the phenomena thusly:

effects with technology, amplifications of cognitive capability as the technology is used; *effects of*, residual effects without the technology that is due to substantial experience with it; and *effect through*, effects largely with the technology that go beyond simply enhancement to a fundamental reorganization of the cognitive activity in question. (p. 84)

An emergent and important question for educators in all professions is whether they want to measure what students have learned from the technology or if they want to measure what students are capable of doing with access to the technology (Perkins, 1993).

WHDs Facilitate Phenomenaria

Phenomenaria — as in aquaria, planetaria, terraria, *GenScope*, and *River City*— are mechanisms that simulate phenomena or environments while supporting the manipulation of variables for the purposes of critical observation and research. Participatory simulations, a variant of phenomenaria, facilitate individual participation within groups of students studying simulated real-world phenomena in constrained learning environments.

For example, through HDUL, participants in a distributed learning course used WHDs and MIT's (2005) *Virus* to investigate the spread of infectious disease. At the onset of the simulation, everyone begins healthy, and participants are told little more than to meet with as many people in the game as possible without getting sick. Participants “meet” one another by beaming small packets of information to one another through the IR port of their WHD. The *Virus* application keeps track of whom an individual has met. 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.

In the previous year, students enrolled in the same distributed learning course completed *Environmental Detectives* (Klopfer et al., 2003). Working in groups, participants role-play as environmental scientists investigating a toxic spill on the MIT campus. As students explore the augmented environment, their WHD alerts them to virtual characters they can interview and site-specific data in order to determine whether the spill has contaminated ground and surface water. After collecting field data, students analyze their data in order to provide an informed decision to the president of the university.

HDUL participants enjoyed the learning environment constructed during *Virus* and *Environmental Detectives*. During the discussion of the simulations, participants noted that the primary purpose of the WHD was to facilitate learning and provide information that would otherwise be impossible to collect or demonstrate — an illustration of a deep effect of WHDs facilitating phenomenaria. Instead of piecemeal information, the participatory simulations allowed participants to focus on large ideas while socially constructing deep understandings. Through the constructivist discussion sessions that followed both simulations, 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.

WHDs as Symbol Pads

Symbol pads — as in chalkboards, paper and pencil, spreadsheet software, and word processors — are surfaces designed and utilized for the construction and manipulation of symbols. Concept maps, for example, uses nodes (i.e., bubbles) to represent concepts and propositions (i.e., connecting words) as logical bridges between concepts (Novak & Gowin, 1984). HDUL participants in an emerging technologies pedagogy course investigated *PiCoMap*, a concept-mapping software specifically designed for WHDs (GoKnow, 2005a). Every 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 beamed their maps to classmates. Afterward, students discussed similarities and differences among the various maps. The purpose of this exploratory implementation was to highlight the possibility of constructing, analyzing, and distributing concept maps on WHDs. Going deeply into the learning theories and pedagogical practices underpinning concept mapping (Novak, 1998) was beyond the scope of the implementation. Others researchers have investigated the usability strengths and limits of using handhelds to support learners' production of concept maps nonetheless. 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), HDUL participants expressed interest in the concept-mapping capabilities, but expressed concern over screen size.

As a second illustration of WHDs as symbol pads, participants in a technology and assessment course investigated *Sketchy* (GoKnow, 2005b), an animation application designed specifically for WHDs. Between introductory and discussion sessions, participants used *Sketchy* to construct an accurate, animated representation of the earth orbiting the sun. At the beginning of the second session, participant pairs shared their animations and discussed the thinking behind their construction. Afterward, participants reflected on their animations and discussed with their partners the strengths and weaknesses of using *Sketchy* as a tool for thinking, learning, and capturing what students know. Participants compared *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.

As tools for thinking and learning, PiCoMap and Sketchy illustrate opportunities for deep effects of WHDs as symbol pads. An additional example of a deep effect brought about by WHDs as a symbol pad is the epistemological shift in graphical representation of data. For example, Pullano (2005) demonstrates that eighth grade students who use probeware and data analysis software (a) exhibit a more formal and deeper understanding of the interrelated concepts of slope and rate of change, (b) demonstrate a greater ability to verbally interpret graphs, and (c) nearly eliminate an iconic interpretation of graphs in general.

WHDs as Task Managers

Task managers — as in classroom teachers, cooperative learning group leaders, *Geometry Tutor*, and *Knowledge Forum* — are elements within the learning environment that define, scaffold, and provide feedback on the work undertaken or attempted by learners. A primary capability and straightforward use of WHDs is as personal information managers (PIM), which store and

organize a user's address book (i.e., contacts), calendar, memos, and task lists (i.e., to-do-lists). Working in conjunction with other devices, a user synchronizes PIM data from their handheld and desktop computers through wireless or wired connections.

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. Similar technology-supported pedagogies have also been explored in Project Numina's *Student Response System* (Heath et al., 2005).

At the Indiana University School of Medicine, as Hatfield and Bangert (2005) report, third-year medical students complete clerkship rotations at hospitals, clinics, offices, and various other medical facilities in disciplines such as surgery, pediatrics, and neurology. Accompanying students are WHDs that facilitate the collection of clinical encounter experiences (CEE) data. Once collected, CEE data is then uploaded to a secure, central server and processed into CEE reports. From the server, preceptors and students access the reports for assessment and reflective purposes. Based on the information provided by the reports, instructors can intervene and make appropriate schedule changes if, for example, a student is not engaging the types or frequency of experiences necessary to meet the desired learning objectives.

CONCLUSIONS

Students and instructors of all ages are likely to own WHDs and to bring them with them to class and into the field, thus providing educators and learners opportunities to harness the capabilities of such devices. As the number of devices rapidly increases and networking infrastructures expand, society moves towards an era of ubiquitous computing. Untethered from power and

connectivity cables, WHDs are tools that travel with users as they go about their daily activities, distributing computation and knowledge between the user and the tools that person is accessing. With technological advances and personalization of tools such as WHDs come propensities for media-based learning styles. Collectively these four trends provide a strong basis for critically examining WHDs for teaching and learning.

Analyses of HDUL and complimentary research projects illustrate WHDs as communicators, construction kits, information banks, phenomenaria, symbol pads, and task managers in a wide variety of learning environments in university settings. Within categories, characteristics of both straightforward and deep effects emerged. The affordances utilized by users when they were initially presented with a WHD and those activities that supported surface changes in process and activity characterize straightforward effects. Deep effects show a more pronounced influence by affecting cognition, social interactions, and making possible what before or otherwise would be impractical or impossible to carry out. For those educators, designers, and researchers considering or using WHDs in their teaching and practice, the analytical framework and case studies presented here provide lenses through which to analyze and consider WHDs as tools for thinking and learning.

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