Using Handheld Technology to Move Between the Private and Public in the Classroom

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Abstract

Research has shown the importance of both private and public interactions with learning environments. Until now there has been little research on how to combine these two types of interactions in productive learning environments. Furthermore, the use of these interactions have traditionally correlated with the metaphor of learning used by instructional designers: designers who focus on private interactions tend to work with the knowledge as *acquisition* metaphor, and designers who focus on public interactions tend to work with the knowledge as *participation* metaphor. In this chapter we show that handheld computers can be used to support both public and private interactions, and we discuss how aspects of both public and private interactions can aid primarily individualistic activities as well as primarily collaborative activities. We present three examples of handheld use that exploit these unique affordances, and discuss how the use of handheld computers can be used to bridge research across different metaphors of learning.

Introduction

Research has shown several advantages to low-cost, networked, handheld computers in education[1]. These advantages include portability, easy integration into existing classroom infrastructure, the ability to take these devices into the field for scientific data gathering, and the potential to make one-to-one computing affordable (Roschelle & Pea, 2002; Tatar et al., 2003; Vahey & Crawford, 2002; Tinker & Krajcik, 2001; Soloway et al., 2001; Staudt and His, 1999).

These features are so important that some predict that handheld computers will result in a transition from occasional, supplemental use of technology in the classroom to frequent, integral use (Roschelle & Pea, 2002), finally allowing the impact of technology to match its promise. Furthermore, studies show the ease with which teachers can integrate handheld computers into existing lessons (Norris & Soloway, 2003; Vahey & Crawford, 2002) and the range of learning activities that can be aided or permitted (Wilensky and Stroup, 2000; Mandryk et al., 2001; Yarnall, Shechtman & Penuel, in press; Abrahamson, Davidian & Lippai, 2000.). Evidence for the potential for widespread impact of handhelds comes not just from research on new handheld devices, but from a similar case: the graphing calculator. With just a fraction of the computational power of today's computers, with a small and low-resolution screen, and without networking support, the graphing calculator has by far the deepest penetration of any educational computing technology (Burrill, Allison et al., 2002; Means et. al., 2003). We believe that this is due, at least in part, to graphing calculators sharing many of the important characteristics of handhelds.

The potential for widespread impact makes handhelds important by themselves; however, handhelds may have additional affordances and constraints beyond those due to impact alone. The exact nature of these differences is of practical and theoretical importance. If the only difference between handheld and full-sized computers is the size of the device, then taking full advantage of handheld computers in the classroom is a simple proposition; we port the traditional uses of educational technology that have been found to be effective to this new, smaller form factor. Then, we attempt to teach within constraints of these smaller devices. However, if the important differences go beyond screen size, we can and must identify and leverage them to avoid unanticipated problems and create new opportunities.

We take the view that there are significant, important, and beneficial differences between handhelds and more traditional educational computing technologies. In this chapter, we will show that by identifying and studying how to exploit these new affordances, we can create situations that simultaneously increase our understanding of the learning sciences while increasing students' ability to learn the complex topics needed for full participation in our math-, science- and technology-rich society. We focus on those interactions typically found in classrooms, and do not address the interactions typically found in distance education and other networked-at-a-distance environments. In particular, we focus on one particular set of affordances: the ability for students to engage in, and move seamlessly between, *private* interactions with their computational environment, and *public* interactions for face-to-face collaboration around the computational environment. We next define what we mean by *private* and *public* interactions, and discuss how the systematic leverage provided by private/public interactions distinguishes handhelds from other educational technologies. Leveraging these affordances provides a platform for advancing research while increasing student learning. We then provide examples from our own research that illustrate how the interaction between the private and public can lead to increased student learning.

Private and Public Interactions

Private interactions with the environment are those interactions in which students can engage with their materials and sense-making processes individually in a focused way. The ability to be focused implies an interaction with the environment that takes place over an extended period of time (at least several minutes), without others being able to see or directly impact the interaction.

When students work privately they can work at their own pace and style, iterate on their work, take time to reflect on (explicit or implicit) feedback, experience imagery and/or free associations, and avoid any embarrassment that may occur from other students viewing incomplete or incorrect work. These benefits have long been identified in the literature on educational computing (Anderson et al., 1995, Schofield, 1995, Suppes & Macken, 1978).

Public interactions with the environment are those interactions in which students engage in active or implicit discourse while they are simultaneously engaged with, or talking about, the product or materials of their work. In the classroom such collaboration typically occurs face-to-face. When students work publicly they can participate in joint sense-making, are exposed to different perspectives, can build on each other's ideas, and learn to participate in a community of practice. They can even benefit from the reflection that occurs from the knowledge that others are (or will be) looking at and thinking about their work. These benefits have long been identified in the literature on computer-supported collaborative work and learning (Dillenbourg, Eurelings, & Hakkarainen, 2001; Vahey, Enyedy, & Gifford, 2000; Harrison, Minneman, & Marriacci, 1999; Tang & Minneman, 1991, 1990; Dourish, Bellotti & Henderson, 1996).

While both private and public interactions with representations have been found to be effective, and perhaps even complementary, aspects of learning, they have been studied in relative isolation in the educational technology literature. As a result, the literature does not provide guidance on how to best combine aspects of private and collaborative learning and representation use. We believe that this isolation is at least partly due to the logistical realities of designing for traditional technology.

When students are provided with desktop computers, two modes of use are typical. One is to put each student at her own computer, emphasizing private interaction. This mode is often used in computer labs with enough computers for each student, classrooms in which every student is equipped with a laptop computer, and classrooms when teachers rotate students through the small number of computer stations under their purview. In the second mode of use, a pair or small group of students share a single computer. In this case, while one student may do more work than another, there is no actual privacy. All actions and states are visible and therefore open to debate, commentary, and discussion.

In theory, students can switch between these modes. However, it is more difficult in practice. In the first case, the isolation and size of each student's display makes the switch between private and public work difficult. Students must switch not only attention but position, moving to another location to see each other's screens, typically leaving their own work behind. The movement back is also heavy-weight, more comparable to completing the composition of an e-mail than to a pause in Instant Messaging. In the second case, most often there are no additional computers for private work. However, even when additional computers are available, it may not be easy for a student to move work from the shared computer to the private one. Furthermore, withdrawing from the shared project must be explained. In general, because the overhead of switching between public and private is considerable, the activity designer must choose one or the other for the class as a whole.

Implications for Handheld Computers

Handhelds hold considerable benefit in this area. They may increase the sense of privacy in private, focused work compared to desktop machines. Second, when used carefully, they afford a range of public uses not previously seen in the desktop world. Third, they can reduce the cost of switching between these states, and this carries with it important pedagogical ramifications.

The interesting question is whether handhelds can provide the opportunity to scaffold students in both private and public interactions. The small, personal screen gives students a private workspace, while beaming (or even handing over the handheld computer) allows the collaborative sharing of information. Furthermore, productive uses of handhelds can integrate aspects of electronic communication (such as sharing an interactive representation) with the norms of face-to-face communication (such as gesture use). As a result, we have the opportunity to support learning activities that build upon *both* private and public interactions, and switch seamlessly between the two.

This opportunity has deep theoretical implications. The importance of finding ways to bridge private cognition and social participation has been recognized in the research community (Norman, 1993; Sfard, 1998). We view handheld technology as a platform that will allow researchers to systematically study what such a bridge may look like. We will revisit this implication later in this chapter.

Examples of handheld technology use

We now look at several examples of the use of handheld technology in education. These examples cover a wide range of use models, grade levels, and content areas. We will show how each has exploited the interaction between public and private interactions in a way that is unique to handheld computers. The examples are those that the authors are most familiar with: the large-scale Palm Education Pioneer program; a detailed investigation of a handheld-based implementation of SimCalc Mathworlds that we call NetCalc; and the variety of environments known as Classroom Response Systems.

Example 1: Palm Education Pioneers (PEP)

From October 2000 to September 2002 SRI International, in collaboration with Palm, Inc., conducted a systematic large-scale evaluation of handheld technology in education. The Palm Education Pioneer (PEP) program distributed classroom sets of handheld computers through a competitive grant process to 102 teachers throughout the United States. A wide range of teaching styles, grade levels, subject areas, and demographics were represented. No requirements were specified in terms of content areas or grade levels: instead teachers were encouraged to create innovative projects in areas they felt were most appropriate.

The goals of the PEP project were twofold: (1) to evaluate the effectiveness of handheld computers in real-world educational settings, and (2) to aggregate the knowledge base of participating teachers to determine benefits, pitfalls, and best practices of handheld computer use in the classroom.

We were surprised at the enthusiasm with which teachers adopted handheld computers: in the first year of use, approximately 90% of PEP teachers stated that handheld computers were an effective instructional tool for teachers, and that they would continue to use the handheld computers after the PEP program was over. Furthermore, teachers overwhelmingly stated that use of handheld computers resulted in more effective teaching activities, as shown in Figure 1.

Insert Figure 1 about here

The PEP project also probed further, to determine the types of learning activities that teachers found most effective with handheld computers. In the initial grant proposals, teachers anticipated that the handhelds would allow for more personalization and more student-directed learning. They planned activities to support these uses. However, while many teachers reported such a benefit at the end of the project (over 80% of teachers, see Figure 2), we also note that even more teachers reported increased collaboration and cooperation as a benefit (over 90%, see Figure 2). Furthermore, we note many teachers reported *both* benefits. This surprised the research team; we had expected teachers working in such a short timeframe (they were typically reporting after only one school-year of use) to concentrate on one usage model before exploring other possible uses.

Instead we found that teachers were able to exploit aspects of both private and public interactions simultaneously in their first year of use.

Insert Figure 2 about here

Teachers' written comments provide us with some detail of what they consider important in both collaborative and individual work. Teachers noted that the mobility of handheld computers was key to allowing more collaboration, as did the easy exchange of information (typically through beaming):

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

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

- I see the students being able to take their thinking and work with [the handheld] right then. I see that handhelds as being essential to helping that thought process along and in the place that the student is at.
- [Using handhelds results in] greater student autonomy and accountability toward assignments and a greater sense of partnership in learning together (teacher and student).
- Science is becoming more student-centered, [with] more true inquiry from the student, [and] less teacher-driven curriculum.

We found these results from PEP intriguing: teachers, left to their own devices and bound by the constraints of available off-the-shelf educational software, found that handheld computers enabled a synergy between collaboration and autonomy. As researchers, we wondered how this could be explicitly leveraged in the creation of handheld-based learning activities. In the next section we discuss an environment designed with both uses in mind.

Example 2: NetCalc

To investigate the potential of handheld computers in education we built upon an already proven educational intervention, SimCalc (Roschelle, et al., 2000), in the creation of *NetCalc*. The goal of SimCalc is to provide access to the mathematics of change and variation (MCV) to all students (see Kaput, 1994; Kaput & Roschelle, 1998; Roschelle et al., 2000). Currently, only a small percentage of students are introduced to MCV, although understanding change is of critical importance for a variety of economic, social, scientific, and technological issues. When students are introduced to MCV, it is typically is in calculus class, a class available to only a small number of students, and one in which students tend to master symbol manipulation without coming to a deep understanding of the topic (Tucker, 1990).

To achieve its goal of democratizing access to MCV, SimCalc builds on three lines of innovation: restructuring the subject matter; grounding mathematical experience in students' existing understandings; and providing dynamic representations. In the creation of NetCalc we built upon key SimCalc principles within the constraints and affordances provided by handheld computers:

- Student creation and editing of *graphically defined* functions through direct manipulation, with an emphasis on piecewise-defined functions. Students can manipulate these functions without ever resorting to the algebraic description, which might be quite complex.

- Links between the graphically defined and editable functions and their derivatives or integrals. For example, as students manipulate a velocity graph, they can see the impact on the corresponding position graph (or vice-versa).
- Links between the graphical representations and motion simulations. As a result, the mathematics is *about something,* and this linking aids students in interpreting the graphs.

To leverage the unique affordances of handheld computers, NetCalc was not intended to be a stripped-down version of desktop SimCalc. Instead we designed a new set of applications and activities based on the principles (and lessons) of SimCalc, as well as on what we learned in the PEP project. This work took place in parallel with the creation of a graphing-calculator version of SimCalc for other classrooms (Kaput & Hegedus, 2002). NetCalc was tested as a one-month replacement unit for an advanced eighth-grade mathematics class in an affluent San Francisco suburb.

During the initial stages of our design research, we found that the interactive representational forms of SimCalc, which were designed for large displays and included rich, detailed graphics, could be modified to be instructionally effective on handheld computers. We then focused on the most appropriate way to leverage the handheld computers in creating the NetCalc activities, paying special attention to the ways in which we could leverage both the small private screens, as well as public interactions such as easy sharing and collaboration[2].

In the following sections we discuss two activities designed for students using NetCalc in-depth: *Match-My-Graph* and *Slot Machine*.

Match My Graph

In Match-My-Graph, students work in pairs. One student, called the *grapher*, creates a function that is hidden from the other students, who is called the *matcher*. An example of a grapher's creation is depicted as the first screen capture in Figure 3, which has a function with a negative slope. The matcher then makes an initial guess of the function, depicted as the function with the positive slope in Figure 3. The matcher beams this initial guess to the grapher, as shown in the final screen capture that shows both functions. The grapher analyzes the two functions and provides a verbal clue to the matcher, which the matcher uses to make more refined guesses. The activity continues until the matcher's function is identical to the grapher's.

Insert Figure 3 about here

In this activity students struggle to create and interpret clues such as "Mine is steeper," "You're going the wrong way," and "Yours is not as fast." We used the same activity structure in three separate instances, each designed to highlight an important mathematical topic. In the first instance of this activity, the grapher and matcher both used position graphs, and the grapher received the matcher's position graph and the motion simulation. In the second instance, the grapher and matcher both used velocity graphs, and the grapher only received the motion (not the graph). In the third instance, the grapher used a position graph and the matcher had a velocity graph, and the grapher received both the motion and the graph. These modifications were made to highlight different aspects of the representational forms that were required for students to build a complete understanding of the target MCV, while also allowing us to study the same interactional forms multiple times across the curriculum unit.

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

This simple Mastermind-like activity is illustrative of the ways that the combinations of private and public interactions can be harnessed using handheld computers. In this face-to-face collaborative activity, it is vital that each student has a private screen. This private screen affords two key aspects of functionality. One is that it keeps the information of the grapher hidden, which is vital to the activity. A second is that it allows both players to privately experiment with the simulations before making their contributions public. In the matcher’s case this is important to make sense of the hints and deliver the next guess: if told that her car is going faster than the grapher’s, she must find out how to make the car go slower. By having a private place to experiment with the simulation, she can build her own understandings while being in control of when to expose her (possibly imperfect) state of knowledge to her partner. In the grapher’s case working privately is important in formulating the next clue: by being able to repeatedly run the simulation he can test out possible hints to determine the hint he feels will be the most effective for his partner.

Of course the public sharing of the matcher’s graph is also key to the success of the activity. The aggregate representation that results from easily beaming the matcher’s guess to the grapher’s handheld allows the game to flow smoothly, and allows the private interactions necessary for the grapher. Finally, we note that it is important that this activity occurs in a face-to-face setting. Students made significant use of gesture, nonverbal hints, and intonation when participating in this activity.

We compare this to using more traditional technology. The use of desktop computers would make this series of interactions cumbersome. It would be quite easy for someone to see the large "private" screens, and it would be difficult for students to engage in face-to-face collaborations with the two monitors between them. Furthermore, the at-a-distance nature of Internet-based collaboration is not amenable to face-to-face classroom conversation, including the use of gesture and other nonverbal communication. The stand-alone nature of the traditional graphing calculator is not amenable to aggregating representations, which is required to allow the grapher to provide appropriate hints.

Slot Machine

In Slot Machine students work individually as they are presented with a series of what appear to be "randomly" chosen set of representations that consists of a position graph, a velocity graph, and an animation (see Figure 4). Students determine which, if any, of the representations in the current set describe the same motion, and click the corresponding set of checkboxes (the representations and checkboxes are color coded, and a white checkbox indicates no match). The computer can check student answers and provide feedback, or students can choose to exchange problems with a partner, who "grades" the other's work. Students received points for getting their individual problem correct and for grading the partner's work correctly. They also received bonus points for correctly answering and grading five problems in a row. The teacher or research team did not use the points in any way. Instead, the students used these points as a way to gauge progress and informally compare their performance with that of other students.

Insert Figure 4 about here

Similarly to the manipulation of probable co-occurrences of stimuli in a real slot machine, each of four progressively more difficult problem sets in our version of slot-machine were carefully designed to result in a high probability of co-occurrence of challenging representational translations. Two problems sets included position and velocity graphs that had the same shape. This similarity is known to be a significant source of confusion both in algebra and calculus learning (Tall & Vinner, 1981; Schorr & Kaput, 2005).

When using Slot Machine students can complete many problems in rapid succession, allowing for substantial practice in building their representational competency. Slot Machine was developed as a reaction to our participating teacher's concern that students not only build a conceptual understanding of the material, but also practice enough to build familiarity with translating between the different representations. Classroom use data supports the argument that we addressed these concerns. As recorded by logs built into the technology, on average each student solved more than 20 problems in a session (the three sessions averaged 30-minutes each), with 72% of problems answered correctly (each problem had five possible answers). These results indicate that Slot Machine problems were at a level of difficulty that was appropriate for these students, without reaching a ceiling or floor effect (Vahey et al., 2004). Based on this evidence, we conclude that students were engaged in the Slot Machine activity, and were given significant opportunity to practice the challenging and assessment-relevant skill.

Classroom observations suggest that participation in Slot Machine resulted in less discussion than during Match My Graph. However, although Slot Machine is primarily a private activity (in contrast to the primarily public Match My Graph), the incentive of bonus points, combined with the ease of collaboration (pressing the "send" button instead of the "check" button) resulted in students engaging in some collaboration throughout the Slot Machine activities. Classroom observers noted two main impacts of this collaboration. The first, which was most common, was motivational; students enjoyed getting points, and collaboration provided the ability to get "bonus points." Students working with this disposition rarely had significant conversations about the problems they encountered, although collaboration motivated them to stay on track and complete a significant number of problems. The second, less common use, validated our original design goal of collaborative sense-making. For students who were not confident in their ability to solve the problems quickly and accurately, collaboration allowed them to discuss and get feedback from other students to support their building an understanding of the properties of representations that were important. Students working with this disposition rarely engaged in point comparisons, and worked in pairs. In both forms of collaboration, students were in control of when collaboration happened, and with whom. As a result, students could work privately until they felt that collaboration would be useful, and then they were easily able to share their results publicly.

Although it is easy to see how we could implement Slot Machine on desktop computers, we expect that we would not have created the collaboration feature using more traditional technologies. Slot Machine appears to be an inherently private activity. In this sense, it bears some similarity to "drill and kill" activities. However, the focus on both the public and the private helped it transcend mere practice. Slot Machine was set into a deeply collaborative, supportive, yet lightweight framework, which allowed the student to send or show a problem to someone else to check at any time. It is hard to imagine allowing student collaboration using more traditional technologies without a heavier structure that would have forced students to synchronize their activity and interrupted the flow of the activity. Instead, using handhelds, students simply asked a partner if they were ready to be beamed a problem to check, and then pressed the "send" button.

Students' learning

Because the quantitative results of our study were at the month-long level, we cannot make causal claims about the relationship between particular activities and student outcomes. However, it is illustrative to analyze student learning in the month-long replacement unit. As reported in Vahey et al. (2004), all twenty-five students in the class took a pretest and posttest. Out of a total of 33 points, students on the pre-test averaged a score of 9.3 (SD = 4.0), and on the posttest averaged a score of 22.7 (SD = 2.8). This improvement is statistically significant (t(24) = 16.11; p < .0001), and shows that students did increase their proficiency in the mathematics of change and variation during the NetCalc curriculum. Furthermore, the NetCalc students performed well on AP Calculus items when compared to published figures on high school students taking the AP exam (Vahey et al., 2004)

This study provides compelling evidence that learning activities created specifically for handheld computers can lead to impressive learning gains in the conceptually difficult domain of the mathematics of change and variation. Furthermore, these activities were designed to leverage student ability to engage with the environment privately as well as publicly. Although one of the activities described in this chapter was primarily collaborative and the other primarily individualistic, both utilized elements of the other one’s approach and both utilized the system’s ability to support easy switching between the two modalities to achieve success. We now look to a more general use of handheld computers to see how it also leverages the private and public use of representations.

Example 3: Classroom Response Systems

Recent years have seen a rise in popularity of classroom response systems. These systems traditionally consist of each of the following: a set of networked, low-cost handheld devices (which may be as simple as a keypad with the letters A through E), a computer that is used as a central hub to aggregate student responses, and a whole-class display that shows the aggregation of student responses. Each of these components has a key role as teachers pose questions to students, who indicate an answer on their own devices. All answers then appear on the whole-class display in aggregated form, typically as a histogram.

Although the handheld devices used in such systems may not satisfy our earlier definition of handheld computers, it is illustrative to investigate how these systems enable innovative activity structures that exploit the relationship between public and private representation use. We will then draw implications for the current generation of such systems, including the *Navigator* from Texas Instruments and *Discourse* from ETS, both of which employ more robust technology.

A large number of studies show that these relatively simple systems can be effective classroom tools (Abrahamson, Davidian, & Lippai, 2000; Burnstein & Lederman, 2001; Dufresne et al., 1996; Mazur, 1997; Penuel, Roschelle & Abrahamson, forthcoming; Woods and Chiu, in press). Common outcomes include increased student engagement, increased teacher awareness of student knowledge, and increased student understanding of content matter. However, not all uses of classroom response systems achieve this level of success. Figure 5 shows a generalized classroom flow for those uses that have been found to be successful. This figure makes explicit the roles of the teacher, the technology, and the student.

Insert Figure 5 about here

The most effective uses of classroom response systems start with a teacher asking a probing question, with a supporting representation on the whole-class display. While the content is displayed publicly, students engage with it individually and privately, and enter their own response through the handheld device. Because the teacher can require that all students respond, and because the system can maintain anonymity due to the private answer space for each student, there is typically full student participation. The technology aggregates student responses, and displays the aggregation. The teacher then leads a transformative learning conversation in which students are instructed to discuss what they *now* think is the appropriate answer with a partner. This is typically followed with another complete cycle, with the students responding with their current thinking. When teachers carefully lead students through these steps, students tend to converge on the correct answer (Mazur, 1997), and are also more prepared to learn from the short teacher lecture that follows (Bransford & Schwartz, 1999).

While success with this very simple technology depends upon a number of factors, the requirements that students (1) have the ability to engage with the material privately, (2) be able to enter their responses privately, and (3) interact with the public display of the class's ideas, are vital. By first responding privately, students engage their existing understandings, and have a stake in the final answer. Because all student answers are then aggregated in a large public display, students can compare their answers with others in the class. This large public display also allows the knowledge-building discussion in which students' knowledge is an object that is available for discussion and analysis.

It is not the technology that is the innovation in such systems, but the integration of technology and pedagogical practices in the creation of a set of productive interactions (Abrahamson et al., 2000; Penuel, Roschelle & Abrahamson, forthcoming). In particular, these interactions are consistent with what How People Learn (National Research Council, 1999; Owens et al., 2002) has identified as the four tenets for creating a productive learning environment: learning environments should be (1) learner centered, (2) knowledge centered, (3) assessment centered, and (4) community centered. The private interactions enable the environment to be learner centered and assessment centered, while the public interactions allow the environment to be knowledge centered and community centered.

We compare this set of interactions to those found in traditional student-centered environments. While students may work privately on a set of problems, and may even share their answers with the whole class, it is quite rare indeed to have complete student participation in a collaborative sharing activity. It is even more rare to then be able to turn this knowledge-sharing activity into a knowledge-building activity that treats student knowledge as an object of discussion.

We also compare this set of interactions to what is found in the traditional CSCL literature. We typically find either a small number of students collaborating at one workstation, or a large number of people collaborating at a distance: in neither case do such systems have as a key learning resource a cohesive representation that immediately aggregates a wide variety of student thinking. We maintain that providing each student with a handheld device allows the easy switching between private and public interactions which enables these new productive learning activities.

A new generation of systems that have been influenced by the original classroom response systems allow for a wider variety of tools and representations to be used by students. Such systems have the potential to allow for even greater advances in student learning: instead of interactions being limited to multiple-choice questions, students will be able to respond in more complex ways, and tap a wider range of knowledge. Students can mark an area of a drawing, specify a graph, participate in an ongoing simulation, and more (Hegedus & Kaput, 2002; Roschelle & Pea, 2002; Wilensky & Stroup, 2000). In these cases, it is even more important that students have a handheld with a private display that can allow them to interact and experiment with the environment privately, as well as a networking infrastructure that will allow students to post their answer as required to engage in a public learning experience.

Implications

This chapter provides an overview of some of the wide range of environments and activities over which handhelds have been used to engage students in both private and public interactions. We now turn to some implications of this work.

The Alignment of Private and Public with Modes of Instruction

Handhelds may provide a way to study the bridge between the two predominant metaphors concerning cognition and learning in the research literature. The first is that of *knowledge acquisition* (Sfard, 1998), in which the mind is a container to store knowledge. Using this metaphor, individuals acquire knowledge through constructing and internalizing cognitive structures (e.g. Newell & Simon, 1972; Anderson, et al., 1995). The second is that of *knowledge as participation* (Sfard, 1998), in which knowledge is displayed by participation in practices located in specific environments. Using this metaphor, knowledge is gained through participating in social processes, and learning is displayed by becoming more central in these processes (e.g. Lave & Wenger, 1991, Hutchins, 1995; Brown, Collins, & Duguid, 1989).

Insert Figure 6 about here

If we classify educational software along two axes—one representing the dimension of "public" to "private" usage, and the other representing the spread from "acquisition" to "participation" models of learning—we can identify a strong historical tendency for private usage to accompany an acquisition model of learning and for public usage to accompany a participation model (Figure 6). Technology that focuses on private interactions is usually aligned with the goal of helping students to build their individual knowledge base. Systems that build on this potential constitute some of the first and most long-lived educational technology interventions, including both Computer-Aided Instruction and Intelligent Tutoring Systems. Such environments seek to build students' individual mental models through a series of guided interactions dynamically constructed to address the needs of the individual learner (e.g. Anderson et al., 1995; Suppes & Macken, 1978). This approach is based on the notions that (1) computers can model or anticipate learning needs, (2) each student has her own path to learning the material and (3) mistakes and missteps can be embarrassing for students, and working individually helps students avoid public embarrassment. Designers of such environments are also (arguably) motivated by the incentive of providing more instruction with less (expensive) human intervention. As such, these environments rarely have support for student collaboration. Furthermore, even when teachers lead whole-class conversations to promote collaboration, such activities are peripheral to the “real work” of individual students working at computers (Gifford & Enyedy, 1999). These environments have been particularly effective in helping learners become more efficient in problem solving tasks. Critics of such environments have characterized them as “drill and kill” applications that are based on an outmoded view of individual cognition that does not prepare students for today’s knowledge-based and highly collaborative workplace.

Uses of technology that focuses on public interactions tend to have a participation model of learning (Sfard, 1998), with collaborative sense-making and knowledge building as their goals. Environments that have been designed for such uses usually include students working together explicitly or implicitly building a distributed knowledge base (Hoadley, Hsi, & Berman, 1995; Scardamalia, Bereiter, & Lamon, 1994). Much of the research on the collaborative use of microworlds also fits into this model, as students work jointly at a single computer to build a shared understanding of a representation or simulation. A great deal of research has emphasized the ways that effective learning activities leverage resources such as the shared screen, gestures, and conversational norms to help students jointly construct meaning, become more proficient in participating in representation-based discourse, and build an understanding of the subject matter (Roschelle, 1992; Vahey et al., 2000; White, 1993). Although these environments may be used privately, they do not by and large have a private space for student work (Roschelle & Pea, 2002), and do not have support for building the understanding of individual students. Instead they rely on the interactional infrastructure to scaffold students. Critics of such environments have characterized them as being inefficient, with the added weakness that students may be under social pressure to conform to their group's possibly incorrect notions and so may promote misconceptions.

We recognize that the descriptions above are caricatures of real-world use. By and large, these systems are used in creative ways. Students often find ways to collaborate while using environments designed to be individualistic; they shout across the room, gaze over at other screens, or even leave their workstations en masse to gather around someone else's. Students also work individually while using environments designed to be collaborative; this is seen when students take turns in engaging with the environment, hogging the mouse (Cole, 1995), or making notes on paper. Currently, these uses occur in an ad-hoc manner, are often considered disruptive, and are difficult to incorporate into productive educational activities.

The flexibility of handheld computers, which allow us to design for public and private use, as well as move quickly between the two, provides a platform for creating activities that build upon both metaphors of learning. This can be seen in the two NetCalc activities described earlier, each of which played an important part in our curriculum and engaged students in important aspects of learning conceptually difficult material. Slot Machine can be seen as based primarily on the acquisition metaphor of learning, whereas Match My Graph can be seen as based primarily on the participation metaphor of learning. However, each of these activities employed aspects of both metaphors of learning, enabled by leveraging aspects of both private and public representation use. Similarly, the success of Classroom Response Systems is based on students switching between private and public uses of the technologies, and also integrating the participation metaphor of learning (through transformative learning conversations) and the acquisition metaphor of learning (through individually deciding upon and indicating responses).

Instrumenting the classroom

The second implication of our work with handhelds is that the use of handheld computers can give us a mechanism for *instrumenting* the classroom in a way that was not previously possible (see Means, et al., 2003 for a discussion of classroom instrumentation with technology). Because handheld computers have the ability to be used pervasively throughout the school day, a greater amount of a student's work can be digital. This allows for a collection of the entire corpus of a students' work, as "act becomes artifact" (Roschelle & Pea, 2002). Importantly, this corpus of work will include both private interactions as well as public interactions. This rich corpus of work can provide a rich dataset for teachers, curriculum designers, policy makers, and the learning sciences. By having one environment that can track students' private and public interactions, we can begin the hard work of bringing together the research on learning as individual cognition with learning as increasing participation in a community.

Our observations point to an important area of further research that could be advanced by appropriate instrumenting. With technology that can support and instrument private interactions, public interactions, and the weaving of the two, it is imperative that future research investigate the relative effectiveness of these different forms of interaction with respect to types of content to be learned, as well as individual learner differences. Such research can lead to the creation of learning environments that allow all learners to succeed in learning the important content needed for advancement in today's math-, science- and technology-rich society.

Conclusions

Research has shown the importance of both private and public interactions with learning environments. Until now there has been little research on how to combine these two types of interactions. Furthermore, these types of interactions correlate with the metaphor of learning used by instructional designers, with designers who focus on private interactions working with the knowledge as *acquisition* metaphor, and designers who focus on public interactions working with the knowledge as *participation* metaphor.

In this chapter we showed that handheld computers can be used to support both public and private interactions, and discussed how aspects of both public and private interactions can aid both primarily individualistic activities as well as primarily collaborative activities. We presented three examples of handheld use that exploit these unique affordances, and discussed how the use of handheld computers can be used to bridge research across these different metaphors.

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Author Backgrounds

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Dr. Deborah Tatar is currently an Associate Professor of Computer Science and Member of the Center for Human-Computer Interaction at Virginia Tech. Her research areas include handhelds in classroom-based math and science learning; social justice and policy in the adoption of learning technologies; attention, engagement, and emotion in mediated interaction; embodied interaction and personality in learning; and architectures for classroom connectivity. Previously, she was a Cognitive Scientist at the Center for Technology in Learning at SRI International, a Member of the Research Staff at Xerox PARC, and a Senior Software Engineer at Digital Equipment Corporation.

Dr. Jeremy Roschelle is a Co-Director of SRI International's Center for Technology in Learning (CTL). Dr. Roschelle’s research examines the design and classroom use of innovations that offer the possibility of enabling more people to learn complex and conceptually difficult ideas in math and science. Two running themes in his work are the study of collaboration in learning and the appropriate use of advanced or emerging technologies (such as component software and wireless handhelds) in education. His 2002 paper with Roy Pea, "Walk on the Wild Side," has been influential in understanding the future possibilities for wireless Internet learning devices. Jeremy has been seeking to address large-scale use of innovative technologies in education, both through consulting to companies with a large impact in the market, and by leading the implementation research on scaling up SimCalc to widely varying teachers and classrooms.

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Figures

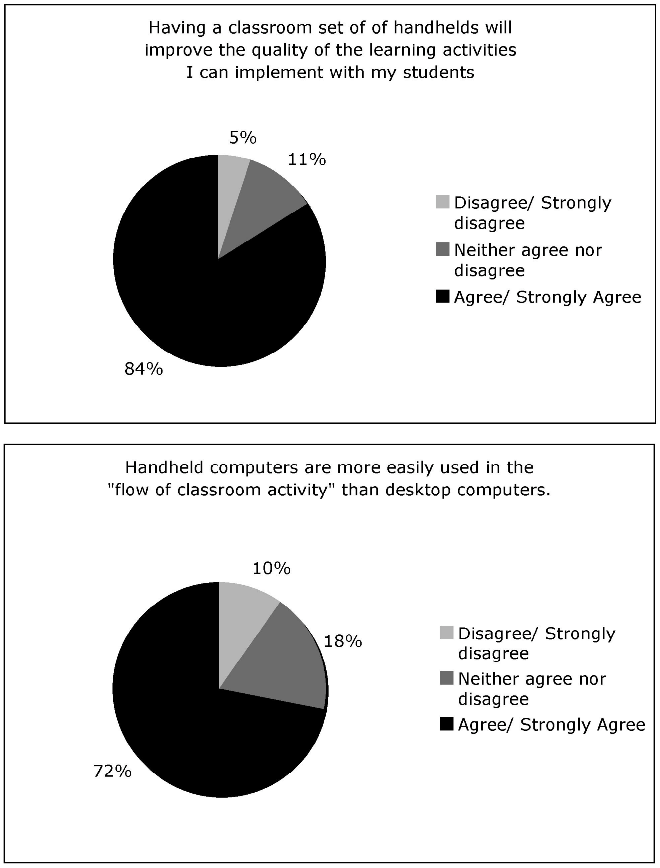

Figure 1: PEP teachers report on effectiveness of handhelds.

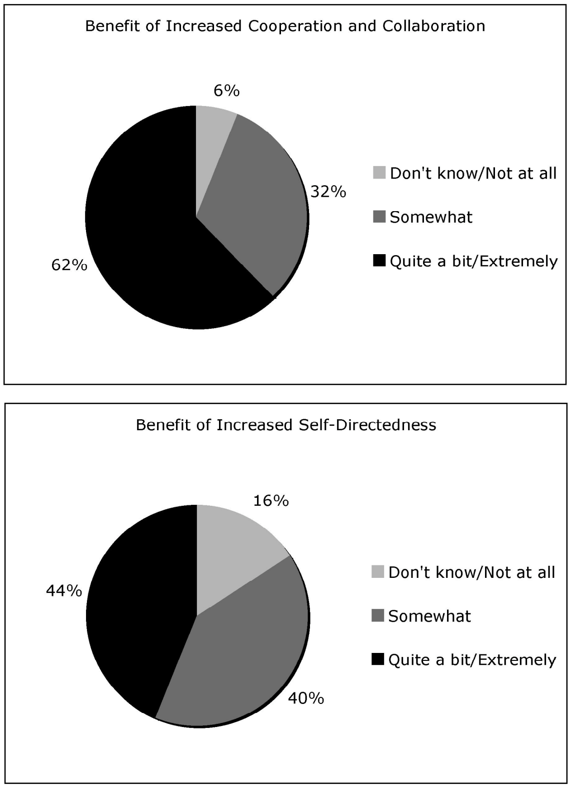

Figure 2: PEP teachers report that handhelds benefit both individual and collaborative work.

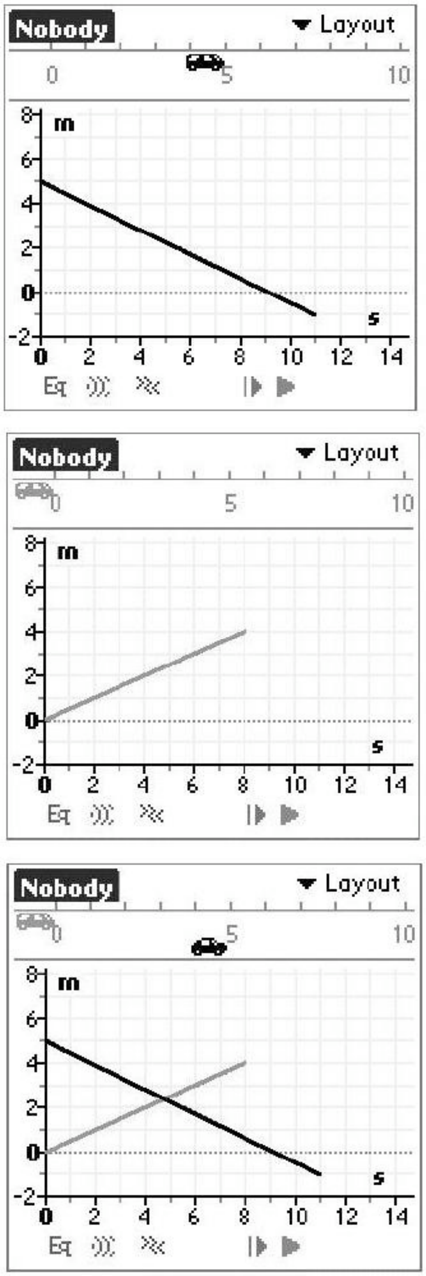

Figure 3: Screen captures from Match-My-Graph

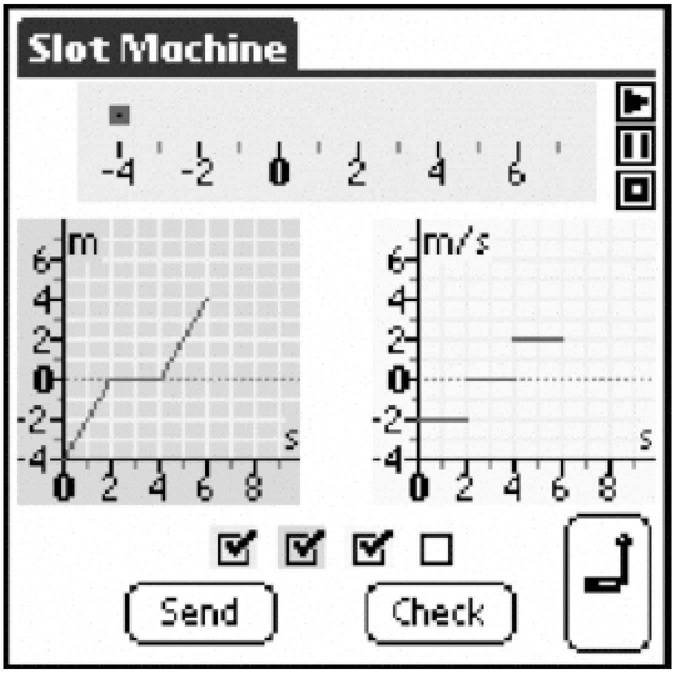

Figure 4. Screen capture from Slot Machine

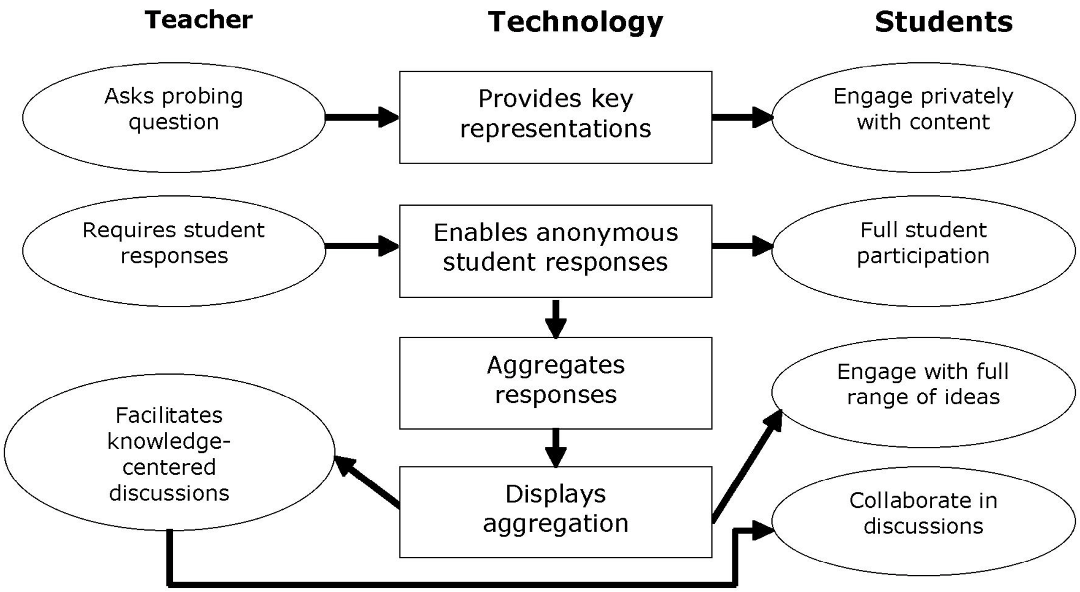

Figure 5. Activity flow for effective use of Classroom Response Systems

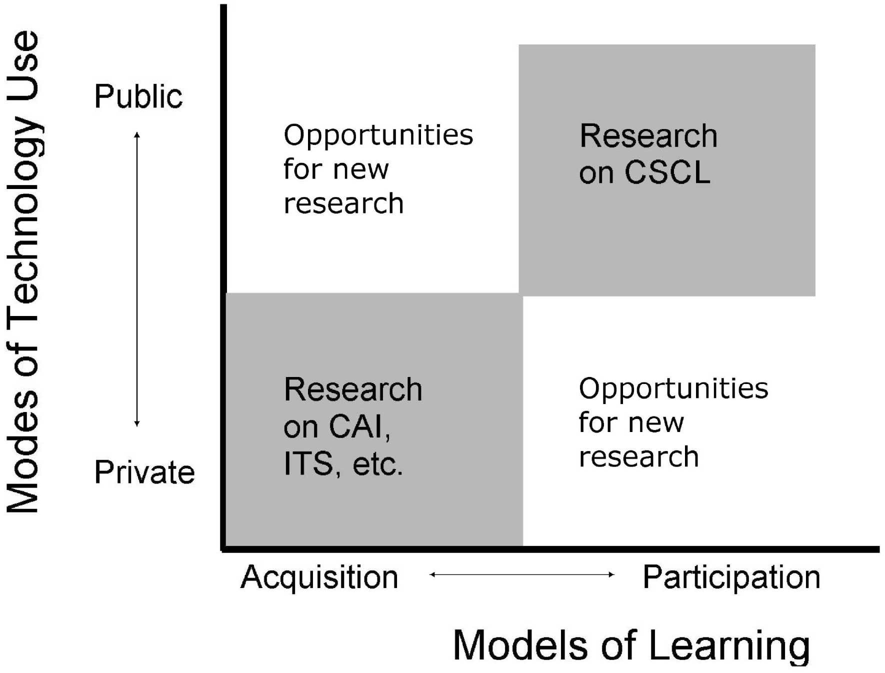

Figure 6: Modes of technology use and models of learning

Footnotes

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[1] For readability, we refer to such devices as “handheld computers” or “handhelds.” This loose category includes devices with the following characteristics: high mobility (that is, are small enough that elementary school students can hold in one hand and carry from place to place), small footprint, the computational and display capabilities to provide cognitively-empowering interactive representations, and the ability to support collaboration through flexible electronic networking.

Devices included in this definition are PDAs, smart phones, some tablet computers, networked graphing calculators, and the new generation of handheld gaming systems. Devices not included in this definition include desktop computers (not portable); most laptop computers (intrusive in interactions); traditional cell phones (poor interactive display capabilities); and traditional graphing calculators (no electronic networking).

[2] Although the focus of this chapter is a set of technology-based activities, we stress that paper-based activities played an important role in our classroom. Fortunately, we found that the use of handheld technology allowed a natural shift between technology- and paper-based activities, and students could easily move between different tasks and technologies.