Using Handhelds to Link Private Cognition and Public Interaction

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This article discusses the importance of private interactions, in which a student works alone with learning materials, and public interactions, in which a group of students engage in discourse around learning materials. While traditional technology requires that designers choose one type of interaction over another, the authors show how handheld computers can be used to support both types of interaction, leading to increased learning.

The Individual and the Community: Two Approaches to Teaching and Learning

What is the goal of education? One view is that the primary goal of education is to increase the body of knowledge of individual students, each potentially working in isolation. Another view is that the main goal of education is to increase students' abilities to participate in important communities (such as the community of mathematicians or scientists), with the corollary that the particular knowledge possessed by any individual is of less importance than the "distributed knowledge" possessed by the group.

These two perspectives run throughout the educational arena: in theoretical journals we find the cognitivist versus the situative views; in policy debates we find "back to basics" versus teaching for collaboration and innovation; in assessment we find multiple-choice tests versus portfolios; and in technology we find computer-assisted instruction (CAI) versus collaborative groupware.

While there have been attempts to bring these views together, the schism remains. In this article, the use of handheld computers is shown to be a potential middle ground in which both of these goals not only can be met, but are complementary.

The Private and the Public: Two Types of Interactions

We posit that these two camps have remained separate largely due to the types of classroom *activities* that are possible using the technologies that have thus far been available (technologies include books and blackboards as well as electronic technologies such as televisions, calculators, and computers). In particular, we differentiate between two types of interactions available in activities: *private* interactions and *public* interactions (note that this article pertains mainly to face-to-face classroom activities, and not activities designed for distance education).

Private interactions with the environment are those interactions in which students engage with materials individually. To be truly private, the interactions with the environment must take 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 feedback, and avoid any embarrassment that may occur from other students viewing incomplete or incorrect work.

Public interactions with the environment are those interactions in which students engage in discourse (typically face-to-face) while they are engaged with materials. This discourse can occur in pairs, small groups, or whole-class discussions. When students work publicly, they 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.

The benefits of both private and public interactions are clear. In fact, the learning goals appear complementary. However, creating learning activities that incorporate both is a significant challenge, due in large part to the technology available thus far.

When students are provided with desktop computers, two modes of use are typical. One is to put each student at his or her own computer, emphasizing private interaction. While students can talk to each other

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(typically by shouting over or around the computer displays), it is not a simple matter to engage in deep discussion about a student's work. This may require a student to physically move across the room to see the other student's screen, usually leaving his or her own work behind. Coordinating this type of collaboration in a class of 20–30 students is a significant classroom management challenge, as the isolation and size of each student's display makes the switch between private and public work difficult.

The other mode is to have small groups of students (typically two or three) share a single computer, emphasizing public interactions, as there is no way to privately interact with the technology. All actions and states are visible and therefore open to debate, commentary, and discussion. There is little time for individual reflection or experimentation with the environment.

Because the overhead of switching between public and private modes is considerable, the teacher or activity designer must choose one or the other for a given activity.

Implications for Handheld Computers

As alternatives to desktops, we have handheld computers, initially designed as personal computing devices. As a result, they allow students to engage with electronic materials, including complex interactive representations, in a *private* workspace. This allows students to interact privately with the materials, experimenting and reflecting as they see fit, without fear of interruption or embarrassment. Handhelds were also initially designed to allow sharing of information, and so they support infrared beaming and other simple forms of electronic communication. They are also small enough that they can be easily handed to another student, and multiple handheld screens can be put next to each other and viewed at the same time. These features allow students to engage with representations and ideas in a *public* space, collaborating and building joint understandings.

The true benefit of handheld computers, however, comes in the ability to support activities that allow students to seamlessly move between mainly private and mainly public interactions. Such activities have the potential to support students while they engage in tasks that are optimized to build their individual knowledge, while also supporting students as they learn to collaborate and participate in a community of learners.

Examples of Handheld Technology Use

To illustrate how handhelds can support seamless movement between public and private interactions we examine two examples: the large-scale Palm Education Pioneer (PEP) program, and a handheld-based implementation of SimCalc Mathworlds that we call NetCalc.

Palm Education Pioneers (PEP)

From October 2000 to September 2002, SRI International, in collaboration with Palm, Inc., conducted the Palm Education Pioneer (PEP) program. Through PEP we distributed classroom sets of handheld computers to 102 teachers throughout the United States via a competitive grant process. 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, and as a result a wide variety of grade levels and subject areas were represented (for more on the PEP project, see Vahey & Crawford, 2002).

The teachers adopted handheld computers with enthusiasm. Approximately 90% said that handhelds were an effective instructional tool, and over 80% stated that the use of handhelds could improve the quality of learning activities (Vahey, Tatar, & Roschelle, 2007). While these numbers tell us that teachers felt that the use of handhelds was productive, they don't tell us how teachers and students used handhelds.

The data show that teachers found two very different benefits of handheld computers. The first was that handhelds allow for more personalization and student directed learning (84% of teachers). The second was that handhelds supported increased collaboration and cooperation (94% of teachers). We found this surprising, as we 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.

We analyzed teachers' written comments to provide detail about what they considered important in both collaborative and individual work. The answer was twofold: mobility and the easy exchange of information (typically through beaming). Teachers said:

- 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 stated 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 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).

We found these results from PEP intriguing: teachers, in the first year of use, found that handheld computers enabled both collaboration and autonomy. We then set out to investigate how we could leverage this result in the creation of handheld-based learning activities.

NetCalc

To leverage the benefits of handheld computers, we built upon an already proven educational intervention, SimCalc (Kaput & Roschelle, 1998; Roschelle *et al.,* 2000), in the creation of NetCalc. To achieve its goal of democratizing access to the Mathematics of Change and Variation, which is the foundation of Calculus (Kaput, 1994), SimCalc builds on three lines of innovation: restructuring the subject matter; grounding mathematical experience in students' existing understandings; and providing dynamic representations.

To exploit what is unique about handheld computers, we did not build a stripped-down version of desktop SimCalc. Instead our design was based on the principles of SimCalc, while keeping in mind what we learned from the PEP project. This work took place in parallel with the creation of a graphing-calculator version of SimCalc (Hegedus, this issue; 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.

While we created several activities in our NetCalc work, due to space limitations we only discuss Match-My-Graph, an activity designed for students using NetCalc (for more detail on this and other activities, see Vahey, Tatar, & Roschelle, 2004; Vahey, Tatar, & Roschelle, 2007). Match-My-Graph is a simple game that students play in pairs. One student, called the grapher, graphs a linear function that is hidden from the other student. The other student, called the matcher, attempts to match this function by graphing his or her own linear function and beaming it to the grapher. The grapher analyzes the two functions and, if they are not the same, provides a verbal clue to the matcher, which the matcher uses to make more refined guesses. An example is shown in Figure 1.

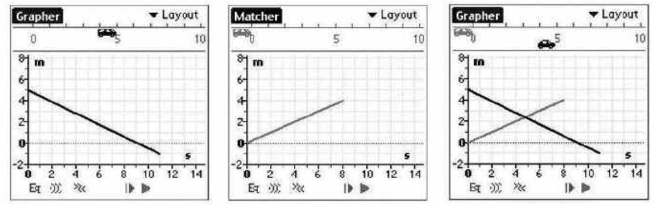

Figure 1. A sequence in Match-My-Graph. The Grapher generates a function, the Matcher generates a guess, which is beamed to the Grapher.

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." While at first imprecise, students soon realize the importance of using precision in language, and also begin to construct a robust understanding of slope. We used the same activity structure in three separate instances, each designed to highlight an important mathematical topic.

This simple activity is illustrative of the ways in which the combinations of private and public interactions can be harnessed using handheld computers. In this 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. A second is that it allows both players to privately experiment with the simulations before making their contributions public. 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 this activity took place in a face-to-face setting. Students made significant use of gesture, nonverbal hints, and intonation when participating in this activity.

To analyze the effectiveness of the NetCalc activities, we turn to two data sources: classroom observations, and test results.

Classroom observations show that students playing "Match" engaged their peers and provided mathematically appropriate hints. Key indicators of engagement are the rate at which hints were provided and the content of 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).

While an analysis of test results from the end of the unit does not allow us to make claims about the effectiveness of any given activity, such analysis is illustrative. As reported in Vahey *et al.* (2004), students did increase their proficiency in the mathematics of change and variation during the NetCalc curriculum. Furthermore, the NetCalc eighth-grade students performed better on AP Calculus items than high school students taking the AP exam, according to published test results (Vahey *et al.,* 2004).

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. In this article, we showed that handheld computers can be used to support both public and private interactions, and presented examples of handheld use that combine the two and led to student learning gains in mathematics. □

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Teacher Uses of Highly Mobile Technologies: Probes and Podcasts

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This article introduces two contrasting ways of using highly mobile information technology for educational purposes. The first example uses mobile devices and scientific probes to gather information; the second uses a combination of mobile and desktop computers to disseminate it by way of podcasts. The examples also show that mobile devices complement, rather than replace, desktop computers.

Introduction

The history of computation is largely a history of miniaturization. From the four-function calculator of the seventies to the smart phone of today, mankind has consistently found ways to squeeze greater computational power into smaller and smaller containers. It was predictable that educators would take advantage of this trend, and they have. This article introduces two contrasting ways of using highly mobile information technology for educational purposes. The first example uses technology to gather information, the second to

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