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THE ROLE OF RESEARCH ON CONTEXTS OF TEACHING PRACTICE IN INFORMING THE DESIGN OF HANDHELD LEARNING TECHNOLOGIES*

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ABSTRACT

One definition of design is "creating something new that fits with reality" (Stults, 1985). This article describes a project in which the researchers started with the intuition that new handheld-based wireless technologies held the promise of creating something new and highly desirable for K-12 education. We saw the potential for handheld-based activities to enable deeply needed *formative assessment,* that is, teachers' and students' own monitoring of learning for the purpose of improving teaching and learning. From prior research and our own experience, we knew of several barriers to the adoption and success of new technologies in K-12 classrooms and (separately) new science inquiry methods. Taking these barriers seriously led us to ethnographically-based activities oriented toward understanding "the reality" to which our designs needed to fit. Initial efforts to understand the variety of attitudes, experiences, and conditions in one school district caused us to make hard decisions about our priorities. In this article, we describe the realities we found and the implications we drew from them for our project, which we argue have broad import for the design of handheld technologies for schools.

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EXAMINING THE PROMISE OF HANDHELD TECHNOLOGY FOR TRANSFORMING ASSESSMENT

A number of research projects, including our own, have begun in recent years with the assumption that new handheld-based wireless technologies hold the promise of creating something new and highly desirable for K-12 science education. In doing so, we built on earlier and concurrent research by ourselves and others (Borovoy, Martin, Resnick, & Silverman, 1998; Borovoy, Martin, Vemuri, Resnick, Silverman, & Hancock, 1998; Mandryk, Inkpen, Bilezikjian, Klemmer, & Landay, 1999; Roschelle, 2003; Roschelle and Pea, 2002; Soloway, 2001; Tatar, Roschelle, Vahey, & Penuel, 2003; Vahey, Tatar, & Roschelle, 2004). However, the particular insight in this project was the potential held by the new technology to transform science instruction through enabling more frequent formative assessment, that is, assessment for the purpose of improving instruction. Unlike summative assessments which are used in record keeping and to measure what students have learned after a unit, formative assessments provide evidence of emerging knowledge and difficulties that can be used while learning sequences are still being designed within a unit. They are oriented toward opening up inquiry. Teachers may make formative assessments and adjust instruction correspondingly, but in the ideal case students will also be involved in self-assessment. Indeed, one goal of education is to produce students who are capable of monitoring their own learning and seeking help when needed.

Earlier research has found that using network technologies to support formative assessment greatly improved student engagement and promoted conceptual change (Bransford, Brophy, & Williams, 2000; Roschelle, Penuel, & Abrahamson, 2004). However, four key barriers were known to stand in the way of such assessment practices becoming widespread: access, pedagogical support, administrative encouragement, and perceived reliability. Average student-computer ratios of 6:1 and 4:1 in classrooms are too high to allow teachers to use technology to find out what individual students know and can do. Visiting a lab once or twice a week can provide more access to the computers but at the expense of their role in informing daily instruction. Support for learning new pedagogical practices is critical to the adoption of new technologies (CTGV, 1997; NCES, 2000). Indeed, without such support, classroom technologies may be significantly underused. Third, administrative encouragement, especially from the principal, may play a critical role in teachers' adoption of new technologies (Means, Penuel, & Padilla, 2001). Last, the *perceived* reliability of teachers' access to technology, not actual access alone, influences how much they adopt technology-supported curricula (Means et al., 2000).

The technological insight of our project was that inexpensive, portable, easy-to-setup, and easy-to-use handheld computers, compared to more rigid and expensive desktop systems, could promote novel formative assessment solutions while helping solve some of the problems of access and perceived reliability, and perhaps requiring less difficult pedagogical adjustment. At the same time, we recognized that new handheld technologies per se would not overcome these problems and that they might even introduce new ones. For example, providing handheld computers to all students increases technology access for all students, but it introduces new challenges to teachers who must orchestrate their use in the classroom. Furthermore, introducing new ways for students to participate in self-assessment and monitor their own learning requires teachers to integrate students' own thinking about their work and learning process into the flow of the classroom, which departs from many teachers' current practices. We argue here that although new handheld computers have tremendous potential for improving learning, designers must first analyze the current configuration of teachers' practices and contexts and consider their implications for developing software requirements at the very beginning of the design process.

OUR STRATEGY

To accomplish this analysis, we pursued a strategy of intense engagement in participatory design teams including a small group of teachers, a strategy we have employed in the past on other projects and that has been employed by others in designing handheld applications (Danesh, Inkpen, Lau, Shu, & Booth, 2001; Inkpen, 1999). Beyond our commitment to using handheld computers, the focus of our research, and the human and technical resources allocated by the grant, much of the project in this first phase was open-ended. We did not decide in advance what the assessment software should do, the kinds of setups that would be required, or the levels of involvement in the design process we would expect from different stakeholders. Perhaps most surprising to our colleagues in educational assessment was that we did not even decide ahead of time on what curricular materials we would use as the basis for our assessments! Over the course of the first year of the project, however, we began to constrain both the criteria we would use to judge the quality of designs and the design process itself, largely on the basis of an initial study of the schools where we planned to work (see Roschelle, Penuel, Yarnall, & Tatar, 2004).

The current article describes findings from that study, which employed rapid-ethnographic techniques to understand teachers' work practices and classroom activity structures in context (Holtzblatt & Beyer, 1996; Hughes, King, Rodden, & Andersen, 1995; Simonsen & Kensing, 1997; Suchman, 1995). By *teachers' work practices* we mean not only the instructional and assessment practices that teachers engage in as part of classroom teaching, but also the work they must do to organize those practices. By *classroom activity structures* we mean the organizational structures and patterns of activity that students participate in and come to expect. Finally, we define *context* as comprising influences from multiple levels of systems (e.g., state and local policies, school-wide schedules, cultural practices, and anticipated life paths belonging to different groups of teachers and students) that influence life inside the classroom, as these influences are experienced and interpreted by classroom actors. We know from studies of other educational innovations that seek to transform teaching and learning that work practices and teachers' interpreted contexts strongly influence the level and nature of adoption of those innovations (Cohen & Ball, 1999; Cohen & Hill, 2001; Talbert & McLaughlin, 1999).

In the classroom as well as in the workplace, initial field-based research can reveal similarities and contradictions among different actors' perspectives on the cooperative activities in which they engage (Simonsen & Kensing, 1997), can help to head off problems with user acceptance of new technologies (Wixon & Ramey, 1996), can reveal interests and power asymmetries within work settings and uncover ways that so-called "inefficient" practices are sensible in the context of workers' own practice (Suchman, 1995), and can gain researchers access to implicit knowledge (Holtzblatt & Jones, 1992).

Rapid ethnography is one approach to conducting initial research that maintains a focus on analyzing work practice and that aims at bringing in multiple perspectives on activity more readily into the design process by including non-users with a stake in how the technology functions (e.g., managers, purchasers) in the research (Holtzblatt & Jones, 1992). However, it concedes something to the fast pace of technology design. In particular, rapid ethnography may use multiple researchers from distinct disciplines to collect and analyze data, to encourage the development of multiple perspectives on activity (Hughes, King, Rodden, & Andersen, 1994; Hughes et al., 1995; Simonsen & Kensing, 1997). It may also narrow the focus to a particular area of practice in divergent work contexts, to gain a better understanding of the constraints and opportunities (Hughes et al., 1995; Millin, 2000).

Rapid ethnography suffers from several downsides compared to its more thorough older brother. Because it is more narrowly goal driven, researchers run the risk of overlooking important latent elements of the situation under study, especially those that form direct challenges to the researchers' own goals for change, that work against change, and/or change for the worse the access to power of the least privileged. Rapid ethnography is especially risky in the area of education in which some stakeholders (especially low-income families) may have difficulty expressing their concerns in terms seen as legitimate. Our own work brought us into contact with community representatives who could speak for such stakeholders, but we did not always hear perspectives from low-income families themselves. Nonetheless, it is more affordable, attempts to produce more "actionable knowledge" than traditional ethnography, and is more likely to uncover and address these issues than no ethnographic inquiry at all.

SOURCES OF DATA

Data about the district and teachers were gathered from many sources, including census information, USGS maps, local newspapers, the chamber of commerce, literature produced by the school districts and the schools, the district Web site, books about the region past and present, informal interactions with residents, semi-structured interviews with teachers and principals, meetings with administrators, interactions with non-governmental education services, and classroom-based observations. Three classes of data gathering are described in more detail.

Teacher Interviews

From January-March 2002, a team of four interdisciplinary researchers conducted interviews with 25 teachers (four elementary, three middle school, three high schools; six male, 19 female; four African-American, 19 White) in the district. When possible, individual teacher interviews were conducted by two researchers working in pairs and both parties wrote up reports. Interviews were audio-taped. The teachers were primarily identified through the district technology coordinator. Every chance to locate teachers was pursued—through principals, district listservs, and peer nominations from teachers we interviewed—and four other contacts were made. The interview protocol inquired about teachers' motivation for entering the teaching profession, their educational backgrounds, and the number of years they had been teaching in their school and in this district. We gathered information on learning goals, project activities, the materials used, degree to which students were able to direct aspects of the project, project duration, and the target grade levels of particular projects they had conducted. To learn about their assessment practices, we chose to ask teachers how they came to know about their students' learning before asking about specific formal assessments they might have conducted. We chose this approach because we wanted to know what was important to the teachers in the terms that they used. Additionally, we wanted to elicit both the formal and informal ways teachers make inferences about student performance, and their relative reliance on both. To that end, we asked teachers to imagine particular students who performed well on the project they described and students who did not perform well, and to articulate how they came to know about those students' performance. After we asked about their assessment of students in this open-ended way, we prompted teachers to think about formal and informal ways they assessed student learning before, during, or after the project.

Classroom Observations

Three researchers conducted observations in a total of six classrooms during the months of March, April, and May 2002, visiting individual classrooms three to four times in a single week, making detailed notes describing classroom activities, discourse, and participation structures in science learning activities during that period. Researchers videotaped lessons in three of the classrooms.

Key Informant Interviews

We conducted semi-structured interviews with each of the principals of the schools in which we conducted teacher interviews (three high school, three middle school, four elementary; six women, four men; two African-American, six White). We asked principals to describe their own educational backgrounds, experience in school leadership, their school, and the needs and capabilities of their students. Informal interviews included students from minority groups, two representatives from cultural institutions in the community, and the three Beaufort district administrators who collaborated with SRI International on the original proposal—the Instructional Technology Coordinator, the Director of Evaluation and Assessment, and the Science Specialist at the local Math and Science Hub. Formal interviews were audio-taped, transcribed, and analyzed. Summary documents were created from researcher notes, write-ups, and transcriptions identifying issues and questions in our relationship with the district.

GENERAL DISTRICT CONTEXT AND HISTORY

Beaufort County[1] is a rural district in coastal South Carolina with about 125,000 residents. Roughly 21,000 are school-aged children (5-18). Sixty-seven percent of the population is White, and 24% African American. Beaufort occupies 587 square miles, but these miles are distributed across many large and small islands along the Atlantic coast. This means that travel within the district is restricted to roadways supported by bridges (and in some cases, boats). There is a socio-economic divide between the north part of the county and the south, defined by the border of the Broad River. North of the Broad River are communities like Beaufort and Port Royal, which have larger percentages of working-class and military families. South of the Broad River are more advantaged communities and resort areas, including Hilton Head Island. The non-seasonal population of Beaufort is an increasingly diverse population, divided into roughly five broad groups:

1. The Gullah-speaking African-American community that has lived in the barrier islands of South Carolina since before the Civil War and who lived in relative isolation until the late 1960s, preserving many elements of a distinctive language and culture.

[1] We refer to the county and district by name in this article, both because they are valuable in interpreting the broader context and because the district has been an integral partner in our project. All names of teachers, however, are pseudonyms.

2. Military (roughly 6,500 on active duty) personnel stationed at the Marine Corps Air Station, the Naval Hospital, and the Marine Corps Recruit Depot, and military families.
3. Southern White people with roots in the area.
4. Migrants who came to the area from other parts of the South and the North to enjoy the resort-like quality of life in the coastal Lowcountry (facilitated by the widespread introduction of both air conditioning in buildings and mosquito control beginning in the 1960s).
5. Immigrants from other countries who have come in search of jobs supporting the resort community.

FINDINGS

Four sets of findings or themes emerged from these data gathering activities which significantly influenced our goals for the project and subsequent design activities and processes. We describe those findings in this section, before considering the implications of these findings for designing handheld assessment software for our project.

Teaching Practices: Meaning of Science "Projects"

Initially, some of the researchers imagined inquiry-based pedagogy as a set of instructional and assessment practices embodied in the National Science Education Standards (National Research Council, 2000). For others, including some with extensive experience in teaching science, the standards represented just one formulation of inquiry; they thought alternative conceptions could be used to drive our project. Nearly all of the team members grew concerned, however, when teachers' conceptions of how best to teach science differed from researchers' views, and emphasized instead the importance of students learning basic vocabulary and concepts that are well-established within scientific disciplines, largely from reading texts and performing well-defined, step-by-step laboratories. Initial encounters with the district administration and teachers in the course of proposing the project had suggested inquiry-based and project-based learning in science was widespread.

Instead, we found instruction that followed a "mixed model." It was often hands-on and engaged students in cooperative activity, but was not "inquiry-based" in the way that the National Science Education Standards emphasize. Sandy, a middle-school teacher we interviewed and observed teaching, provides an example. For most activities, students in her classes are organized into peer-led cooperative groups; she gives group members responsibility for undertaking a series of tasks and reporting back to her on their progress. Sandy plays a facilitative role with the groups, floating from group to group as they work largely autonomously. Sandy assigns different kinds of leadership roles for different units.

These roles are typically given names appropriate to the topic they are studying, "head geologist," for example for the unit she teaches on rocks and minerals. Sandy organizes groups of cooperative activities into "units" that often have a real-world connection or driving question. Her "Deltarian" unit, designed to cover both earth science and biology strands in the standards, involved students in deciding whether Earth would be a suitable colony for the alien "Deltarians." However, although the units sometimes had driving questions, in fact, many of the activities are related only indirectly to the driving question, and there was little opportunity for open-ended, student-directed inquiry. Assignments were laid out for students ahead of time, and they did not have to decide how to allocate resources to complete the project.

In general, teachers seemed puzzled by our questions about projects and had a difficult time even envisioning what a "science project" might look like or be. At the same time, most of the teachers believed in the power of *hands-on* science learning activities to clarify difficult science concepts, especially at the secondary level. Teachers report (and we have observed) that hands-on activities are relatively frequent. Additionally, we found that the teachers, who mostly seemed to mix traditional and inquiry-oriented science, were already burdened with the need to manage their attention and the attention of their students in the classroom, both within these hands-on activities and in other activities. We observed several instances of students "lost" in the tasks, even as structured as they were. We noted that teachers could not afford to divert their attention from students and science concepts to managing technology.

Technology Context: Differences in Perspectives

From district officials, we learned about several key technology initiatives and their foci that had been pursued in recent years. The district was coming to the end of what they saw as a major, seven-year initiative in 1:1 computing, a middle-school laptop program. In the two years before our project began, district leaders had begun focusing more on developing teacher proficiency with technology. Its "Training Wheels" program defined a set of core skills teachers were expected to learn to qualify for additional technology expenditures in their classrooms. The Instructional Technology Coordinator had convened a study group of teachers to explore how handheld computers might support assessment, and on the basis of this work the district applied to become a Research Hub for the Palm Education Pioneer program, administered for Palm by SRI International. Palm selected Beaufort to be a Research Hub, and that project brought hundreds of handheld devices to participating district classrooms in the year before our intervention.

From the district's point of view, there was tremendous commitment to technology and widespread availability. However, there was less unanimity in the points of view of teachers and even some principals. Many teachers (and some principals) complained that they did not have effective technology access. They complained that networks worked only intermittently or that they had no access to wireless computing from their classroom. At least one interviewee tied this to a general lack of resources for science ("I have only one graduated cylinder for the whole class!"). We observed that while some schools were well provided with materials, microscopes and science kits, others seemed to be running science labs with only art supplies. While some had state of the art computation, others were using the earliest Macintosh models. Only one teacher would go on to participate in the co-development teams who mentioned a previous bad or inequitable experience during the interviews, and she was the only teacher to drop out.

At the same time, there was wide variety in expertise even among teachers "on the inside." On one hand, teachers like Sandy used the Internet periodically with her students, mostly just to look up information or visit a Web site as part of an extension activity to a lesson. Although she had owned a personal computer for some time and used it to create worksheets for students and write to parents and faculty members, she admitted she was dependent on her husband to help troubleshoot any problems she encountered.

By contrast, because of the influence of the district's prior experience with laptops and handhelds, there are some teachers who were very comfortable using technology in the classroom. Barbara, a fifth grade teacher we interviewed, used her computer throughout the day with her students, and she had experience using handhelds with her students to support some more formal forms of self-assessment as well. She developed checklists for students on her own device and then beamed them to students to use to see if they were following directions in an activity or lab. She had students turn in their checklists so she could assess whether students had completed the assignment. These checklists also helped students keep track of their own progress, an important component within the many hands-on activities that Barbara facilitated.

Equity Issues: Controversy in the Group; Controversy with the District

Equity issues within the district were seen differently by different participants and by different researchers. Many teachers told us explicitly that all children were capable of learning; however, researchers with different backgrounds and experiences interpreted these remarks in different ways. One teacher said "The difference between my Advanced Placement kids and my non-college bound kids is that the AP kids think they'll need to know what I'm teaching them later on." Some in our group perceived this as a statement of institutionalized inequity because the teacher was labeling students, while others perceived it as an egalitarian remark because it did not base performance differences in capacity. High school teachers in particular expressed concern about how science fit into the lives of their non-traditional students, and about how well these students were being equipped for better-than-minimum wage jobs.

We heard and sparked conflicts over some demeaning and racialized language we heard. Occasionally, informants did use terms that index racial and cultural stereotypes, such as "White trash" and "forty-acres-and-a-mule." Low-income and/or Black students and parents were thought to want something for nothing. At the same time, some people felt that we were unfair to the district when we reported this issue, and others felt that we had missed the boat by making extensive attempts to contact and try to include the Gullah community when we should have also reached out to the growing Hispanic community.

We did indeed make a special point to reach out to members of the Gullah community, in part because a mechanism existed for doing so and in part because Gullah constitute a large and important community in the county. From long talks with a key informant about the Gullah community, we came to understand that the introduction of handheld computers in Beaufort would be seen as a civil rights issue by many Gullah parents. He emphasized that to be successful handhelds would have to be seen as empowering Gullah students, i.e., to enable the students to become more expressive and capable and to suggest tangible trajectories to higher paying jobs for them in the future. It would be particularly beneficial if students could use the handhelds to demonstrate to their parents how they were learning more. Still, we came to learn that Gullah parents exerted considerable influence over what kinds of new teaching practices can succeed in selected Beaufort schools, and that it would not be easy to gain their trust.

Assessment Practices and the Instructional Practices They Supported

Many of the teachers we interviewed used hands-on activities and small projects to motivate students and promote inquiry skills, but they did not assess those skills except by using more traditional, summative forms of assessment. Many of them did employ informal techniques of assessment to guide their judgments about what their students learned, but they had few ways to share or record their observations and interpretations amidst the busy-ness of their instruction.

Table 1 shows the kinds of assessment strategies or techniques that Beaufort teachers mentioned in their interviews. The most commonly cited strategies employed by teachers are formal student artifact-based assessments of students, especially tests and quizzes. A small number of teachers also mentioned using rubrics as a formal strategy. There were four mentions of the use of student journals. Teachers also mentioned informal strategies such as observation and questioning. Note that the category that we call "observation" is a rather formal term to describe teachers reporting that they looked at the students to know whether they had "gotten it" or not and were on track behaviorally. Almost all

Table 1. Range of Assessment Practices Associated with Hands-On Activities and Student Investigations

Assessment technique	Number of times cited
Formal artifact-focused techniques	87
Tests and quizzes	73
Rubrics	12
Student journals	4
Against formal assessment techniques	2
Informal instruction-embedded techniques	54
Observations of students' behavior	24
Oral questioning of students	21
Drawing inferences from students' questions	7
Against informal assessment	2
Student self-reflection	2

teachers reported monitoring student interest, engagement, and enthusiasm. Few were able to elaborate on how they made these judgments.

Despite the fact that a number of teachers mentioned student self-reflection as a focus of assessment, just two teachers cited student self-assessment as a technique they used in their classrooms. There were two mentions of teachers who said they were against formally assessing students, and two teachers who said they were against the use of any informal assessment techniques. Both of the latter were high school teachers. One pattern that we observed is that elementary school teachers saw their jobs quite differently from middle school teachers, and middle school teachers differed from high school teachers. While elementary school teachers see their jobs as an extension outward of the home, high school teachers tend to see their jobs as an extension downward of the workplace. This created different kinds of issues in accomplishing formative assessment. For elementary school teachers, formative assessment needed to complement their emphasis on motivating students to learn, but for high school students it needed to serve primarily either as an aid to promoting the development of disciplinary knowledge as defined by experts and professional scientists or as a model for interactions in the workplace.

IMPLICATIONS FOR OUR DESIGNS FOR HANDHELD ASSESSMENTS

The fact that we found that inquiry pedagogies were less widespread than we had expected forced us to refocus the target of our design work and helped us to narrow some of the requirements of the software we would develop. In the end, by coming to agreement on what we were *not* able to see but had hoped and expected to see, we were able to make an important shift going into the design phase of our work. We re-focused our work away from supporting project-based instruction toward engaging teachers in the co-design of assessments to support hands-on activities. The shift was highly significant in its technological implications. Supporting project-based science would probably have meant supporting connectivity in terms of long-term work with heavy document management needs. In contrast, supporting hands-on science held the opportunity to support more calculator-like ephemera and focus on strong representations to support the creation of meaning. The watchword became simple, focused additions to teachers' existing inquiry-oriented practice.

Some designers in the field of ubiquitous computing are contemplating how to provide comprehensive access to school documents (see Chang & Sheu, 2002), but designing software for handheld devices to manage complex documents works largely against the grain of design ideals of reliability and simplicity typically associated with handheld software. In contrast, the kinds of tools this study suggested would be more successful were much more in keeping with the kind of focused, easy-to-use applications that have been successful on handhelds among teachers and students, such as probeware, memos and to do lists, and other single-function tools (Crawford & Vahey, 2002). The findings that few teachers engaged in extended projects in science, while initially disappointing, proved to be a relief and helped to refocus the project in a sensible way that would allow us to develop applications on handhelds that were as simple and focused as have been successfully designed for schools in the past.

The contrast between the perception among administrators that technology was widespread and the reality of access as experienced by teachers was disconcerting to us at first, especially as we began our design process. We concluded that we were unlikely to reach deeply enough into the community with the resources we could devote to relationship-building during rapid ethnography to reach the concerns of teachers who were truly mistrustful of technology. However, we marked it as a future challenge and also interpreted this lack as implicating simplicity more deeply as a design necessity for our interventions. In particular, we recognized the need for our project to be relatively independent of reliance on building-level technical support, or even the wireless networks available in many classrooms. Although working under this constraint prevented us from realizing some of the benefits others have reported from using wireless networks in classrooms, it did not restrict the kind of student-student or teacher-student wireless communication afforded by even the most basic handheld devices.

Beaufort teachers' perceptions that the level and distribution of reliable technology access in school buildings is not unusual; many schools' and districts' access on paper does not reflect the infrastructure that could be relied upon for a ubiquitous computing initiative. The distribution of computer and Internet access in school buildings often limits the potential integration of technology-supported initiatives in schools (Means & Penuel, 2003; Means, Penuel, & Padilla, 2001). Although ubiquitous computing initiatives such as laptop programs have attempted to overcome these limitations by providing all students with access to computers, such initiatives have often run into difficulty and become quite costly when educators begin to rely on network and Internet access for their technology-based instruction. In this very district, a middle-school laptop initiative was accompanied by expensive upgrades to building infrastructure and considerable frustration when the network was down; moreover, district officials had to factor in additional costs of removing downloaded material from students' hard drives at the end of every year, just to maintain their functionality (Penuel et al., 2001). Ubiquitous computing initiatives need therefore to consider carefully before choosing hardware and software that relies on access to school networks and to consider the possibility that there may be lower-cost alternatives that are more manageable and less frustrating for teachers.

Two kinds of design implications followed from our interpretations of the inequities of opportunity in the district. One is that when we found that no African-American teachers applied to work with us in co-development, we knew that we needed to solicit the participation of an after-school, community-based program serving Gullah students. From our initial observations, we knew that these Gullah students could rapidly become expressive users of computer technology. This, in turn, pushed us toward more expressive activities compared to the more analytical push from participants in schools.

Ubiquitous computing initiatives frequently have as a key goal the promotion of equity of computer access to all students (Penuel et al., 2001); therefore, it is no surprise that groups that have been marginalized within the school system may seek to influence the direction of those initiatives. A concern for equity should push designers to consider, as we did, identifying groups that could participate in the design process that we had not initially imagined would be part of the project and emphasizing particular kinds of activities that these groups find valuable for students.

Our findings about teachers' current assessment practices suggested that we needed to structure the design process to allow explicitly for differences in pedagogical approaches and philosophy. Consistent with our approach to our initial research, Shepard (1997) recommends that researchers avoid direct confrontation about differences in instructional philosophy and preferred methods for teachers. We were prepared to strategize about how to handle this. We knew that we as researchers could set some boundaries about the kinds of assessments they would support and those that the project would not support. We decided that it could be valuable for teachers to explore the conceptual underpinnings of the project, but in ways that did not force them to adopt researchers' perspectives. In this way, we thought, the project might have a better chance at achieving fundamental changes to instruction and assessment in the ways we had originally hoped.

A chief advantage of allowing room for a diversity of instructional philosophies and approaches to flourish in the early stages of the design phase is that the team can more effectively minimize barriers to adoption during later phases of the design cycle. The kinds of teachers we encountered in the district would not likely adopt a handheld assessment application that calls for significant involvement of students in self-assessment up front and that minimizes teacher involvement. By contrast, a tool that could support either teacher-directed assessment or more student self-assessment might prove more versatile; they could allow teachers to become comfortable with using the technology first before exploring newer formats for formative assessment.

POSSIBLE IMPLICATIONS FOR DESIGNING OTHER HANDHELD APPLICATIONS FOR SCHOOLS

We imagine that other researchers and designers will encounter situations similar to ours, in that they will face situations where handheld computer applications designed to improve teaching and learning itself will still require teachers to overcome significant barriers to implementation and may ask teachers to change (even if in small ways) their teaching practices. Our study suggests the value of beginning the design process with a careful analysis of teachers' current work practice, the prevailing structures for participation in the classroom, and the contexts that shape instruction and assessment. These studies can help direct designers and teachers working together to envision the kind and degree of change that new technologies may introduce into instruction and the kinds of supports teachers will need to implement new handheld technologies. These studies also identify differences and similarities in values, pedagogical beliefs, and practices that are likely to shape how teachers adopt what developers produce. Ultimately, to produce usable designs for classrooms, designers of handheld technologies will also need to produce designs that are valued and work with the kinds of classroom realities that teachers experience.

Studies such as ours are important for another reason: handheld computers are not simply small desktop computers. Roschelle and Pea (2002) list a number of ways that handheld devices are different from desktop computers: they augment physical space with information; they leverage geographical and semiotic space; they aggregate across individuals easily and rapidly; they position teachers as conductors of classroom performances; and they enable ephemeral actions in the classroom to be captured as artifacts for later reflection. Each of these affordances needs to be considered, they argue, when considering the potential of different designs to augment learning in a particular context. We would argue here that initial field research can provide useful information to guide designers in considering just which affordances are likely to be perceived as valuable to users of software for handheld devices.

The kinds of analyses we conducted in the research reported here—into teachers' orchestration of small groups and their assessment practices, for example—yielded valuable information about which unique affordances of handheld devices might be best aligned with teachers' and researchers' goals for participation in the project. Because our teachers liked to direct student assessment activities rather than let students reflect on their own, we could anticipate that teachers would enjoy the fact that, in contrast to when students use desktops, teachers are not relegated to the side but can orchestrate the performance of multiple groups in a coherent way. Because we planned to provide all students with handhelds and teachers were excited about this possibility, we did not have to directly challenge teachers' beliefs about self-assessment. We could instead ensure that we drew on the rapid data-aggregation capabilities of handheld computers in designing the software, which might (or might not) be found useful to teachers for formative assessment and thus transform their views about involving students in self-assessment. We also learned that it would be important to emphasize the affordances of handheld computers for creating spatial representations using easily-controlled styli, since these kinds of representations would draw on non-linguistic and expressive skills of students that teachers and our Gullah informants wanted to elicit. Finally, we realized from our research that it would be important to de-emphasize the capabilities of handhelds to turn "acts" into "artifacts," since network capabilities were limited and teachers had little time outside class to review the artifacts they might have created in class.

The unique affordances of new handheld devices call for new foci of research on computers in educational settings. Roschelle and Pea (2002) suggest that researchers will need to pay closer attention to classroom roles and rules as they mediate handheld use and to how new devices introduce different divisions of labor within the classroom. We would add that our research on the contexts of teachers' practice in Beaufort suggests the importance of examining roles and rules in the classroom before handhelds are introduced and of anticipating likely teacher responses to changes in those roles and rules. On the basis of such research and conjectures, it is much easier to consider which affordances of handheld devices teachers are likely to perceive as threatening and which ones they are likely to embrace. As with most initiatives, the success of ubiquitous computing initiatives that use handheld computers will turn on those perceptions.

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