TEACHING & LEARNING IN A UBIQUITOUS COMPUTING CLASSROOM

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ABSTRACT

This paper reports on preliminary findings from an ongoing study of teaching and learning in a ubiquitous computing classroom which employs multiple measures and mixed methods to document changes in teaching and learning that result when teachers and students have access to a variety of digital devices wherever and whenever they need them. It identifies ways in which ubiquitous computing environments can support both individual (conceptualizations) and social (uses) construction of knowledge. In particular, it explores the role that unique representations of knowledge supported by a variety of ready-at-hand digital devices can play in supporting and bridging private and public knowledge construction.

In *The Educators Manifesto* (1999), Robbie McClintock argues that digital technologies set in abeyance significant, long lasting limits on educational activity (1999, ¶10). He identifies three areas in which technological innovations have already changed what is pedagogically possible.

The first of these involves the Internet and broadband communications networks. McClintock maintains that new communications technologies have the potential to change schools and classrooms from isolated places with relatively scarce access to information to ones with rich connections to the world and all its ideas. He argues that basic pedagogical strategies must accordingly change from techniques for disbursing scarce knowledge to ways of enabling students "to use with purpose and effect their unlimited access to the resources of our cultures." (¶12)

The second area in which digital innovations are changing what is educationally possible involves multimedia and multiple representations of knowledge. Multimedia, McClintock maintains, "make it increasingly evident that the work of thinking can take place through many forms – verbal, visual, auditory, kinetic, and blends of all and each." (¶13). Basic pedagogical strategies, he argues, must accordingly be broadened to include intellectual recognition of skills in such areas, now too often relegated to the periphery of school curricula.

Thirdly, McClintock points to digital tools designed to "augment human intelligence" (Englebart, 1963); tools ranging, for example, from digital calculators, word processors, databases and spreadsheets to very complex modeling, statistical, and graphical software. He notes that these tools automate lower level intellectual skills, allowing their users to concentrate on higher level thinking, and argues that the basic pedagogical question "What knowledge is of most worth?" must accordingly be rethought.

McClintock maintains that his observations are not normative, but rather factual, however tentative. What is educationally possible has changed. He goes on, for the bulk of his treatise, to argue that these new possibilities should be harnessed to reinvent progressive education. In our research, we have set ourselves a much smaller task. We are exploring what happens when educational possibilities change. We are exploring what happens when teachers and students are given the opportunity to make use of abundant digital resources in pursuit of their regular curricular goals by studying what happens when intact classes from local schools spend extended periods of time in a ubiquitous computing classroom.

BACKGROUND

Ubiquitous Computing

The term "ubiquitous computing" was introduced by Mark Weiser (1991) who wrote, "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (p. 94). He envisioned ubiquitous computing in terms of computers embedded in the environments we inhabit – in walls, chairs, clothing, light switches, appliances, everything -- and connected to each other and the world through wireless communication. Weiser and John Seely Brown (1996) likened ubiquitous computing to two other technologies that have become ubiquitous, writing and electricity, noting that, although these too were once precious and unique, today we take them for granted even though they are integral to our lives and work.

Although, Weiser was the first to coin the term "ubiquitous computing," others explored the notion long before portable digital devices and universal access to the Internet made it seem feasible. As early as the 1970's, for example, Seymour Papert (1980) was predicting "a massive penetration of powerful computers into people’s lives” (p. viii), and with it a paradigm change in teaching and learning. Papert called his approach to learning “constructionism,” viewing it as a variant of constructivism (Piaget, 1952) which “attaches special importance to the role of constructions in the world as a support for those in the head” (Papert, 1993, p.142). Papert argued that by constructing and manipulating “quasi-concrete” representations of knowledge on computers, children would form more robust internal knowledge structures. Papert’s vision also focused on a learner-centered environment in which children programmed computers rather than being programmed by them.

About the same time, Alan Kay had a similar revelation when, considering the work of Marshall McLuhan (1964), he realized that the computer was a medium that had the potential to change the thought patterns of those who used it (in Johnstone, 2003). Kay likened developments in computing to the history of printing and reasoned that computing would only make a difference in people’s lives if it were to become universally available, which he equated with affordable and portable. He thus envisioned a handheld, notebook-sized computer for kids, which he called the “Dynabook.”

It is important to note that while these three early visions of ubiquitous computing all view it as having the potential to induce paradigm change in education on the scale of that resulting from the introduction of printing, the three visions are quite different in focus. Weiser saw ubiquitous computing as involving many computers serving multiple individuals and embedded in inhabited environments, whereas Kay envisioned personal mobile computers that could be carried across environments, and Papert saw one to one computing as a key element regardless of devices. It is also important to note that all three visionaries were writing before the World Wide Web (WWW) was introduced, radically changing, according to Chris Dede (2000), the way that teachers and students think about learning with technology, and the possibilities inherent in ubiquitous computing.

In our work, we view ubiquitous computing as encompassing all three notions of ubiquitous computing as well as the importance of connectivity via the WWW. We view ubiquitous computing environments as learning environments in which all students have access to a variety of digital devices, including computers connected to the Internet and mobile computing devices, whenever and wherever they need them. Our notion of ubiquitous computing, then, is more focused on many to many than one to one, and so includes the idea of technology which is always available but not itself the focus of learning. Indeed, many experts argue that technology will play a more significant and transformative role in education when computing devices becomes more-human centered, less intrusive, and available to students whenever and wherever they need them (Norris & Soloway, 2004; Roschelle & Pea, 2002;).

Research on Ubiquitous Computing

In many ways, ubiquitous technologies have radically changed our everyday lives (consider ATM machines, check-out scanners, cell phones, Internet sites, cable TV, etc), but ubiquitous computing has yet to become a reality in schools (Becker, 2001; Cuban, 2001), and classrooms today are not fundamentally different from classrooms of fifty years ago (Papert, 1993). Pioneering educators, however, have been exploring ubiquitous computing options with promising results (Apple Computer, 1995; Honey & Henriquez, 2000; Ricci, 1999; Russell, Bebell & Higgins, 2004; Rockman, 2003; Silvernail & Lane, 2004; Tatar, Roschelle, Vahey & Penuel, 2003; van t’ Hooft, Diaz & Swan, 2004). In the following paragraphs, some of those findings are reviewed.

Although ubiquitous computing research involves differing technological implementations – 1:1 computing (Apple Computer, 1995; Bartels & Bartels, 2002; Hill, Reeves, Grant, Want & Han, 2002; Honey & Henriquez, 2000); laptop computers (Ricci, 1999; Rockman, 2003; Siegle & Foster, 2000; Silvernail & Lane, 2004; Stevenson, 1998; Zucker & McGhee, 2005), handheld computing (Inkpen, 2001; Norris & Soloway, 2004; Robertson, Calder, Fung, Jones, O'Shea & Lanbrechts, 1996; Roschelle, 2003; Roschelle, Penuel & Abrahamson, 2004 Sharples, 2002; Vahey & Crawford, 2002) -- the changing nature of teaching and learning in ubiquitous computing environments appears relatively consistent across implementations. Findings are accordingly grouped by themes and not devices.

We will first consider changes to the learning environment. Across implementations, researchers have found much greater use of Internet resources (Hill, et al., 2002; Honey & Henriquez, 2000; Zucker & McGhee, 2005) and significantly more presentations communicating findings (Hill, et al., 2002; Honey & Henriquez, 2000). They have found a much greater variety of representations being used to explore, create and communicate knowledge (Apple computer, 1995; Bartels & Bartels, 2002; Danesh, Inkpen, Lau, Shu & Booth, 2001; Hill, et al., 2002; Honey & Henriquez, 2000; Roschell, et al., 2004) including the use of a much wider variety of visual representations, spreadsheets and databases, simulations, and exploratory environments. Such findings suggest that McClintock's (1999) possibilities are becoming reality in some classrooms.

Perhaps as a result, researchers are also documenting changes in interactions among students and between students and teachers (Apple Computer, 1995). They find that learning is becoming more efficient (Apple Computer, 1995; Hill, et al., 2002), and that students are becoming "experts" on particular topics (Apple Computer, 1995; Norris & Soloway, 2004). In addition, researchers note significant increases in collaboration among students and between students in teachers in ubiquitous computing classes (Apple Computer, 1995; Hennessey, 2000; Norris & Soloway, 2004Sharples, 2000; Robertson, Calder, Fung, Jones, O'Shea, & Lambrechts, 1996; Roschelle & Pea, 2002; Vahey & Crawford, 2002).

In these changed learning environments, researchers are documenting changes in teaching as well. Across implementations, they are overwhelming finding that teachers are becoming more student-centered (Apple Computer, 1995; Fung, Hennessy & O'Shea, 1998; Honey & Henriquez, 2000; Norris & Soloway, 2004; Ricci, 1999), more constructivist (Apple Computer, 1995; Rockman, 2003), and more flexible (Zucker & McGhee, 2005). They are moreover developing lessons that are more project-oriented (Honey & Henriquez, 2000; Norris & Soloway, 2004) and more inquiry-based (Norris & Soloway, 2004; Ricci, 1999), and, perhaps as a result, they are assigning more group work (Honey & Henriquez, 2000).

Happily, researchers are also documenting positive effects of ubiquitous computing on students. They are finding improved motivation (Apple Computer, 1995; Ricci, 1999; Vahey & Crawford, 2002; Zucker & McGhee, 2005); engagement (Silvernail & Lane, 2004; Zucker & McGhee, 2005); behavior (Apple Computer, 1995), and school attendance (Apple Computer, 1995; Stevenson, 1998) among students involved in ubiquitous computing initiatives. In addition, research shows such students are better organized (Ricci, 1999; Zucker & McGhee, 2005) and more independent learners (Apple Computer, 1995; Zucker & McGhee, 2005).

Research also shows that ubiquitous access to computing devices can affect student learning (Siegle & Foster, 2000). Researchers have documented increased media literacy (Hill, et al., 2002; Rockman, 2003), improved writing (Apple Computer, 1995; Ricci, 1999; Rockman, 2003; Vahey & Crawford, 2002), and, in some cases, increased scores on standardized tests (Honey & Henriquez, 2000; Stevenson, 1998). In addition, researchers are finding that ubiquitous computing "levels the playing field" for special needs and lower ability students (Hill, et al., 2002; Honey & Henriquez, 2000; Stevenson, 1998).

These preliminary findings suggest that ubiquitous computing can indeed, as McClintock (1999) suggests, support changes in teaching and learning. In the Research Center for Educational Technology (RCET) at Kent State University, we are investigating such changes at the classroom level.

Ubiquitous Computing Classroom

Each year for the past eight years, RCET has brought eight local teachers and their classes to spend half their day every day for six weeks in a unique laboratory classroom, the AT&T Classroom, located on the campus of Kent State University. Participating teachers are chosen through a selection process based on the quality of their teaching and on the fit of their classes and curricula with the work of RCET.

The AT&T Classroom is currently equipped with enough desktop and wireless laptop computers to provide all students with individual (1:1) access to up-to-date computing capacity and Internet access, enough handheld and mobile computing devices for all students to take with them beyond the classroom, distance learning capability via VTEL and Polycom technology, presentation systems, scanners, printers, digital cameras, video and audio recorders, VCRs, video editing equipment, CD and DVD burners, digital microscopes and scientific probes, wireless Interwrite School Pads, Graphire pads, a Logo robotic turtle, and a wide variety of software to support teaching and learning. Each year's cohort of teachers spend a week together in the classroom getting acquainted with its environment and the technology available and working with RCET staff and each other to develop lessons that integrate the use of this technology, and the classroom itself, into their regular curricular practices. They are encouraged to integrate whatever technologies they want into the units they create, but the choice of technologies and extent of their integration is entirely up to the teachers.

As they work with their students in the AT&T Classroom, teachers have the full support of RCET staff members, who not only are available to deal with technology problems, but also to help with lesson planning and to support teacher reflections on their experiences. In addition, the RCET hosts monthly Saturday cohort meetings for any teachers who have come through the program that want to attend. This provides peer support and another avenue for reflection and idea sharing.

The AT&T Classroom is also a laboratory classroom. It is equipped with an observation room with one way glass through which researchers can observe teachers and students as they study traditional curricula in an extraordinary environment. The classroom has with four ceiling mounted cameras and stationary microphones located at all desks and tables throughout the room, as well as wireless mobile microphones to capture teachers and other presenters (including student presentations). From the observation room researchers can manipulate the cameras to record as many as four simultaneous digital videos at a time. In addition, digital cameras are available to document class activities both within and outside the classroom. All student work on computers and mobile computers is collected in electronic portfolios.

The AT&T Classroom and its yearly program of extended residences for local classes thus gives RCET researchers a chance to study teaching and learning with ubiquitous computing in depth across a variety of grade levels, subject areas, teachers, and students.

Theoretical Model

To begin to make sense of the effects of ubiquitous computing on teaching and learning, RCET researchers have developed a model (Figure 1), grounded in their ubiquitous computing experiences, that locates such effects in three broad areas: in the ready availability in ubiquitous computing environments of a wide variety of external, material representations of knowledge; in the particular supports ubiquitous computing provides for individual students' internal conceptualizations and construction of knowledge; and in the unique social interactions and shared uses of knowledge ubiquitous computing enables, through and around which knowledge is constructed. (Swan, Kratcoski, Diaz, van 't Hooft & Juliana, 2004). We use the terms "representations," "conceptualizations," and "uses" respectively to distinguish these domains, and view them as interacting and interdependent in their effects. Distinguishing them also allows us to refine our investigation into the effects of ubiquitous computing to exploring its effects in these three domains.

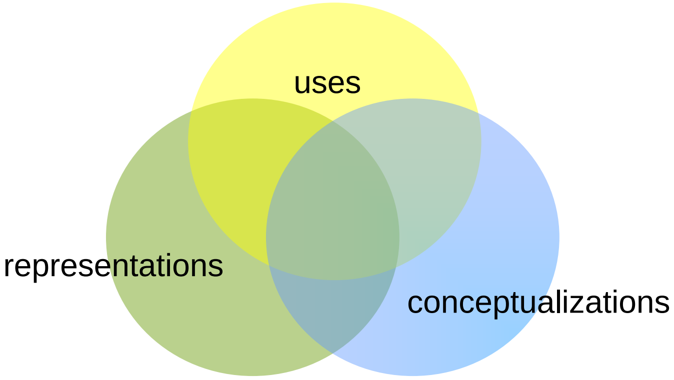

Figure 1
Interacting Affordances of Ubiquitous Computing Environments

The study reported in this paper was thus designed to explore the following research questions:

- What kinds of external representations of knowledge do teachers and students employ to support learning when they have ubiquitous access to a variety of digital computing devices?

- (How) Does such ubiquitous access affect students' conceptualizations of knowledge?

- (How) Does ubiquitous access affect the ways students use knowledge and the social interactions around which knowledge is constructed?

METHODOLOGY

Subjects and Setting

The Research Center for Educational Technology (RCET) is located at Kent State University in northeast Ohio. Each year RCET brings eight local teachers and their classes to spend half their day every day for six weeks in Kent State's AT&T Classroom. Participating teachers are chosen through a selection process which begins with nomination by their principals. Nominated teachers are asked to submit an application which includes an essay in which they talk about their interest in the AT&T Classroom and what they might want to do there. RCET staff make school visits to interview the nominated teachers and observe their teaching. Teachers are chosen based on the quality of their teaching and on the fit of their proposed curricular units and classes with RCET research. They are not chosen for technology integration experience.

In the 2003/2004 and 2004/2005 school years, sixteen teachers from local schools brought their classes to the AT&T Classroom. Participating teachers included three men and thirteen women ranging in age from their late twenties to late forties. Teachers in the cohort included three kindergarten teachers, one first grade teacher, one second grade teacher, two third grade teachers, three fourth grade teachers, three fifth grade teachers, two sixth grade teachers, and a seventh grade language arts teacher. One of the kindergarten teachers had previously taught in the AT&T classroom.

Table 1: Participating Classes in the 2003/2004 & 2004/2005 School Years

Grade level	**Topic**	***N***
	2003/2004 School Year	
7	Biography	22
6	Autobiography	27
5	What's wild?	20
4	Plant biology	25
4*	Flight	16
3*	Flight	14
K	Patterns	24
K	Space	20
	2004/2005 School Year	
K	Animal Sounds	18
1	Living/Non-living	20
2	Sound & Light	21
3	Force & Motion	21
4	Endangered Animals	25
5*	Sound & Light	24
5*	Sound & Light	23
6	Energy	17

* teachers collaborated to create common units

Participating classes explored regular curricular subjects in integrated units that focused on topics in the areas of English language arts, science, and mathematics. Interestingly, a fourth and a third grade teacher from the same district in the 2003/2004 school year co-developed a unit on flight, so the two classes worked with a similar curriculum and shared some activities. Similarly, two fifth grade classes from the same school in the 2004/2005 school year co-developed a unit on sound and light. Classes ranged from 14 to 27 in number of students, with approximately equal numbers of boys and girls. All classes except the seventh graders (who were selected to fit with scheduling needs) were regular, intact classes. Students in all classes ranged in ability levels and all but two included special needs students. Some classes included minority students and most included special needs students. Table 1 above gives the grade levels, unit topics, and numbers of students in these classes.

Data Collection and Analyses

Data collected from 2003/2004 and 2004/2005 classes included structured classroom observations in both the AT&T and regular classrooms, student pre and post tests on important ideas covered in the units completed, student work samples, clinical interviews with students, structured teacher interviews and teacher reflections, and videotaped observations of selected ubiquitous computing activities. Data analyses included quantitative as well as qualitative methods and centered on descriptive comparisons and thematic analyses. Specific data collection and analysis procedures are discussed below relative to each data source.

Comparative Classroom Observations. To explore changes in teachers' pedagogical approaches, structured observations were made of classes in both their regular classrooms and in the AT&T Classroom. Two observations were made of each teacher in each setting. An observation protocol that elicited categorizations of activity structure (4), teacher activities (12), teachers' position in the room (4), student activities (12), student groupings (4), and technology use (18, including the use of print and other non-digital media). Specific behaviors identified are given in Table 2 below.

Table 2: Categories and Behaviors Observed in Structured Classroom Observations

Category	Behaviors Observed (Codes)
Activity Structure	individual (I), small groups (G), large groups (L), whole class (W)
Teacher Activities	presentation/lecture (P), leading discussions (D), leading inquiry (I), answering questions (A), asking questions (Q), listening (L), giving demonstrations (DM), classroom management (M), supervising student activities (S), other (O)
Teacher Location	teacher station (TS), front of class (F), back of class (B), mingling among students (M)
Student Activities	listening (L), reading (R), writing/seatwork (W), talking (T), asking questions (A), answering questions (Q), gathering materials (M), construction projects (C), research (RS), data collection & analysis (D), presentation (P), other (O)
Technology Used	computers (C), Internet (I), handhelds (H), video/film (V), audio only (AO), overhead (OV), Elmo (E), screen (SC), presentation system (PS), textbooks (T), other print materials (P), manipulatives (M), realia (R), art supplies (A), paper and pencil/pen (PA), boards and chalk/markers (B), microscope/probes/sensors (S), other (O)

Observers noted during each one minute interval of time which of the 50 activities listed occurred. Descriptive statistics were used to record the number of times each behavior occurred. Because observation periods were linked to lessons, and so varied in length from 30 to 45 minutes, relative frequencies of each activity were calculated to reflect the percentage of time during the observation period that each behavior was observed. Relative frequencies were then compared within categories between classroom environments within and across classes.

Student Pre- and Post-Tests. Pre- and post-tests were developed and administered to participating students in their regular classrooms one week before they came to the AT&T Classroom and one week after they returned to their regular classrooms. The purpose of these tests was to assess students' conceptualizations of unit topics by measuring their performance on content examinations. For each classroom involved in this study, the teacher and RCET researchers developed content exams focused on the "big ideas" teachers wanted students to learn. Two similar versions of these tests were created for each classroom. To control for the effect of memory on students' scores on the post test, each student was administered alternative versions on the pre and post administrations. To control for possible test differences, half the class was given each version on each administration.

Overall scores for pre- and post-tests were calculated by simply totaling scores across all questions. Paired samples t-tests were then used to compare pre- and post-test scores and effect sizes for gains in each class calculated using the formula:

$$d = t * \text{sqrt}(1-r) * \text{sqrt}(2/n)$$

where r is the correlation between pre- and post-tests.

Student Work Samples. Artifacts collected for analysis from the AT&T Classroom included student work samples. These were reviewed to explore the kinds and quality of representations of knowledge employed. In addition, complete work samples from three or four students from each class were evaluated for depth of conceptual understanding using assessment criteria (Table 3) developed by Newman and colleagues (Newmann, Secada & Wehlage, 2001; Newman & Wehlage, 1995). The targeted students were selected by the teacher with each teacher being asked to select one student of average ability, one student of high ability, one student with lower abilities and a special needs student if available For each of the three standards (analysis, disciplinary concepts, and elaborated communication) the work samples were given a rating of 1-4, (1 the lowest and 4 the highest) for a possible score of 3-12. Ratings for conceptual understanding were averaged across student work samples and across classes by ability groupings and compared descriptively.

Table 3: Assessment Criteria for Evidence of Conceptual Understanding

Standard	Criteria
Analysis (1-4 points)	This standard is intended to measure the extent to which the student demonstrates higher order thinking, i.e., thinking that goes beyond mechanically recording or reporting facts, rules and definitions or mechanically applying rules, definitions, or procedures. Student performance demonstrates thinking about the subject matter/content by organizing, synthesizing, interpreting, hypothesizing, describing patterns, making models or simulations, constructing arguments or inventing procedures.
Disciplinary Concepts (1-4 points)	This standard is intended to measure the extent to which the student demonstrates the use and understanding of specific concepts. Student performance demonstrates an understanding of important ideas related to the content area/subject matter that go beyond application of basic rules & concepts by elaborating on definitions, making connections to other concepts within the subject, or making connections to other content areas.
Elaborated Communication (1-4 points)	This standard is intended to measure the extent to which a student's performance demonstrates a concise, logical, and well-articulated explanation or argument that justifies the student's answer/work. Performance that meets this standard could include or consist of diagrams, drawings, or other visual representations as well as prose. To score high on this standard, the student must communicate an accurate, complete and convincing explanation or argument.

Student Interviews. Quasi-clinical interviews were conducted with each student during the final two weeks of their experience. Interviews were conducted as students were working on computers with reference to that work. The interviews focused on the students' work, including what they believed they were learning from it and the choices they made in producing it, their use of technology in the AT&T Classroom, and differences between the AT&T Classroom and their regular classroom with a focus on what they could do in a ubiquitous computing environment that they couldn't do in a more traditional setting. All interviews were audio-recorded then transcribed and analyzed qualitatively, using constant comparison to detect emergent themes (Janesick, 1994; Lincoln & Guba, 1985).

Teacher Interviews and Reflections. Additional data regarding the impact of ubiquitous computing was gathered from teachers via teacher interviews and teacher reflections. Teacher interviews were conducted with each classroom teacher following completion of their classroom experience and focused on the following questions:

- What did the technology in the AT&T Classroom allow you to do that you could not do back in your regular classroom?
- Did you notice any differences in your students when in the AT&T Classroom?
- Do you think your students' attitudes toward school, motivation to learn and/or self-efficacy was improved by their use of the ubiquitous technology tools?
- Do you think your students' school work improved as a result of their use of the ubiquitous technology tools?

Teacher interviews were conducted in person and audio-recorded, transcribed. In addition, teachers were asked to submit summaries of and reflections on the AT&T Classroom experience. These summaries and reflections were excerpted and added to their interview files. Data from the teacher interviews and teacher reflections was analyzed qualitatively, using constant comparison to detect emergent themes (Janesick, 1994; Lincoln & Guba, 1985) with a particular emphasis on representations, conceptualizations, and uses of knowledge, while, of course, capturing emergent themes.

Videotaped Observations. During the 2003/2004 and 2004/2005 school years, all classes in the AT&T Classroom were videotaped twice weekly to document the kinds of activities taking place in them. RCET staff doing the taping kept time logs of these activities in which they also noted interesting events and interactions. Classes of special interest, such as video conferences and student presentations, were also videotaped. The videotapes were reviewed with a particular eye toward exploring noteworthy representations, conceptualizations, and uses of knowledge evidenced in them.

RESULTS

The study reported in this paper was designed to explore the changing nature of teaching and learning in ubiquitous computing environments. The following research questions were investigated:

- What kinds of external representations of knowledge do teachers and students employ to support learning when they have ubiquitous access to a variety of digital computing devices?
- (How) Does such ubiquitous access affect students' conceptualizations of knowledge?
- (How) Does ubiquitous access affect the ways students use knowledge and the social interactions around which knowledge is constructed?

In the sections which follow, research findings are organized around these questions and themes. The results suggest meaningful changes in the nature of teaching and learning in each of these areas.

Representations

“Representations,” as it is used here, broadly refers to the myriad ways human beings externally represent what they know. As McClintock (1999) notes, digital technologies provide easy and flexible access to multiple ways of representing knowledge and expressing ideas, giving rise to new possibilities for teaching and learning. By examining what kinds of representations teachers and students in a ubiquitous computing classroom employ in their normal course of study, we can begin to explore how they make use of that potential.

Table 4: Digital Representations Employed in 2003/2004 Classes

Grade	Topic	Representations Used
7	Biography	video conferencing (Mexican students), Internet research, PowerPoint (including Vox Proxy audio), journaling on handheld computers, Inspiration (brainstorming), digital photography, digital video, timelines (Timeliner), graphs, Write Out Loud software (reads back text to improve writing), email
6	Family history	digital photography, Inspiration (family crests, family trees), Internet research, PowerPoint, desktop publishing, journaling on handheld computers, video & audio recorders for family interviews, scanner (family photos), clipart, graphics software
5	What’s wild?	Webquests, PowerPoint, Inspiration (concept map), Internet research, journaling on handheld computers, videoconferencing (Stream Quality project), science probes & sensors, spreadsheets, graphs (data analysis), digital photography, desktop publishing, digital video
4	Plant biology	Student-created videos (iMovie), student-created webpages (DreamWeaver), PowerPoint, science probes, time-lapse photography, digital photography, Inspiration (concept map), digital microscope, spreadsheets, graphs, BugScope, handhelds for data collection, Internet, videoconferencing (Mexico), email
3/4*	Flight	Digital photography, Photoshop, digital video, PowerPoint, Internet research, Inspiration (concept map), flight simulator, science probes, graphing software, timelines (Timeliner), scanner, spreadsheets, time capsule & journaling on handheld computers, video conferencing (NASA)
K	Patterns	KidPix (graphics package), digital photography, digital microscopes, scanned images (fabric), Logo robotic turtle, audio recorders, music composition software, tessellation software, Internet, Paint program, email, group reflections using presentation system
K	Space	Digital photography, digital video, Internet (bookmarked websites), video conferencing (NASA), KidPix (graphics package), word processing on mobile devices, PowerPoint, digital KWL charts, presentation system, document camera

* teachers collaborated to create common units

Indeed, teachers and students in 2003/2004 (Table 4) and 2004/2005 (Table 5) cohorts employed a remarkable variety of representations to support learning. For example, in the 2003/2004 school year, kindergarten students used digital photography, tessellation software, a music composition program, and the Logo robotic turtle explore patterns. Sixth graders used audio recorders and handheld computers to collect family stories and recipes. They used Inspiration to create family trees and family crests as well as for brainstorming ideas. They included these as well as digital photographs in bound books of family history that were created using desktop publishing software. One fourth grade classes used time-lapse photography to document carnations' absorption of water and the BugScope Electron Microscope at the University of Illinois to view plant samples in an experiment on water quality, and a variety of hardware and software to collect and analyze data. These students created videos, webpages and PowerPoints to share their findings. Similarly, fifth graders participated in stream quality research using science probes to collect water temperature and Ph values, handheld computers to record their findings, and videoconferencing to communicate them with state officials and others students across the state.

Table 5: Digital Representations Employed in 2004/2005 Classes

Grade	**Topic**	**Representations Used**
K	Animal Sounds	Digital photography, word processing on mobile devices, Internet, claymation, Logo software and Roamer robot, email, Graphire pads, document camera
1	Living/Non-living	Internet, Intel Digital Movie Maker, word processing on mobile devices, Webquests, Intel microscopes, videoconferencing (Akron Zoo), document camera
2	Sound & Light	Digital KWL charts, digital concept webs and Venn diagrams using Kidspiration (concept map), word processing on mobile devices, Photoshop, InterWrite Board, Internet, document camera, digital photography, Excel spreadsheets, PowerPoint, decibel measurements using Pasco sensor probes, Excel spreadsheets
3	Force & Motion	Digital concept webs, Sketchy digital animations, digital photography, digital video, digital probes, Internet research, video conferencing (Inventors Hall of Fame), email, KidPix (graphics package), journaling and word processing on mobile devices, PowerPoint, InterWrite Board, document camera
4	Endangered Animals	Internet, email, word processing on mobile devices, reports using Write Outloud software, claymation and Animation Studio software, digital video to created newscasts/public service announcements using Easy Prompter software, videoconference with the Akron Zoo, document camera
5*	Sound & Light	Internet, word processing, PowerPoint, digital representations of soundwaves using KidPix, digital photography, decibel measurements using Pasco sensor probes, Excel spreadsheets, document camera
6	Energy	Word processing on mobile devices, PowerPoint, Internet, computer designed homes using Better Homes & Garden Home Designer software, video conferencing (energy efficient home), presentation system, document camera

* teachers collaborated to create common units

In the 2004/2005 school year, a second grade class used handheld computers to complete KWL charts telling what they knew, what they wanted to learn, and what they had learned each day. A third grade class used the Internet and videoconferencing as well as a variety of hands on experiments using digital probes to research force and motion. They then created Sketchy and claymation animations to represent important concepts they had learned. A sixth grade class worked on an extended project in which they designed energy efficient homes using CAD software, and in the process used a variety of resources including Internet research and videoconferencing with an architect involved in similar projects to inform their work. These students also developed PowerPoint presentations to share their work with each other and the architect.

It is important to note that teachers were not required to use any technologies. They were introduced to what was available and encouraged to just use those that met their curricular goals. All teachers incorporated Internet research into their units, and all used PowerPoint presentations to share their findings. All teachers incorporated word processing and/or desktop publishing into their lessons. While these might seem mundane uses of technology, participating classes lacked the resources in their regular classrooms to incorporate these kinds of representations into whole class activities in a meaningful way. It should also be noted that these three involve technologies McClintock (1999) identifies as changing pedagogical possibilities. Thus, even by choosing digital representations that in many ways were closest to traditional representations, teachers and students experienced new possibilities in terms of access to information, visual representation, and digital tools. In this vein, it is interesting to note that most teachers included some lessons on digital and information literacy in their units.

All teachers also incorporated a wide variety of other kinds of digital representations in their lessons, some more than others. Many teachers helped their students communicate with others via email, and most used video teleconferencing to connect their students with experts on the topics they were studying, as well as with students in Mexico studying similar topics. Participating teachers encouraged their students to use a variety of digital devices to help them explore their topics both in and outside the classroom. Many classes used concept-mapping, graphing, and spreadsheets to organize and explore ideas and data. All but the kindergarten teachers developed extended projects in which students demonstrated their learning through technology-based presentations. These included PowerPoint presentations and desktop publishing, but also the creation of websites and digital movies. Two classes created bound books using desk-top publishing software which included digital photographs and graphics.

Most importantly, all the teachers utilized the available technologies to support their teaching and learning goals. They used differing technologies to meet differing learning objectives, often in very creative ways. They also developed ways of assessing technological products and explored new ways to use technology to enhance assessment of student learning, including electronic portfolios, electronic journaling, and/or observational software on their handhelds to assess student learning.

Table 6 below gives structured observation data concerning technology use in observed classes. It compares technology use in regular classrooms with technology use in the AT&T Classroom. It should be noted that at least two observations were made of each class in each setting. The findings are thus derived from a sample of classes that may or may not represent “typical” classes. It also should be noted that the findings given here are also averaged across classes and so obscure substantial differences between classes in both settings. Nonetheless, they do reveal a much greater use of digital technologies in the AT&T Classroom and a much greater use of print technologies (print materials, paper and pencils, chalkboards, etc.) in regular classrooms. While that is, of course, to be expected, the results suggest that the kinds of representations teachers and students were employing in their teaching and learning were meaningfully different in the ubiquitous computing classroom.

Table 6: Comparison of Technologies Used in Regular and AT&T Classroom Observations*

Technology Use	Regular Classroom	AT&T Classroom
computers (C)	30.4	78.6
Internet (I)	13.6	54.4
handhelds (H)	0.0	2.2
video/film (V)	0.4	6.5
audio only (AO)	0.0	0.0
overhead (OV)	2.0	2.6
Elmo (E)	0.0	1.5
screen (SC)	2.3	4.8
presentation system (PS)	0.3	12.7
textbooks (T)	1.6	0.0
print materials (P)	34.6	15.3
manipulatives (M)	0.3	0.0
realia (R)	4.3	4.4
art supplies (A)	0.0	3.3
paper & pecil/pen (PA)	52.8	29.3
boards & chalk/markers (B)	31.3	0.9
microscopes/probes/sensors** (S)	0.0	0.0
other (O)	10.2	19.2

* numbers reflect percentage of lesson time in which each technology was used; as in many cases multiple technologies were simultaneously employed, numbers do not add up to 100

** because observations are snapshots of classroom activity they do not reflect all uses of technology

For example, computers were used more than three quarters of the time in classes observed in the AT&T Classroom as compared with less than one third of the time in classes in their regular settings. Similarly, students accessed the Internet more than half the observed time in the AT&T Classroom as opposed to about one eighth of the time in their regular classrooms. These data are even more significant considering that none of the regular classrooms had more than four computers available to students whereas the AT&T Classroom has enough computers for every student, and multiple computing options. Correspondingly, classes in their regular settings made much greater use of print materials, paper and pencils, and chalk or white boards than did classes in the AT&T Classroom, suggesting a much greater reliance on written language for representing knowledge in the traditional setting and a move towards more visual representations of knowledge in the AT&T Classroom. It is interesting, in this regard, to note that classes in the AT&T Classroom made more use of video and art supplies than classes in their regular setting where they are presumably equally available.

Indeed, in their post experience interviews and reflections, teachers noted the effects of ubiquitous access to computing on the kinds of representations of knowledge they used in their classes. For example, one teacher stated,

> *"The children all had electronic portfolios, and our "daily reflections" were done using the digital camera and my laptop. I also used a projector to type the daily reflections and have the children see what I was doing."*

Another teacher told us,

> *"Students took pictures of demonstrations, graphs, and various other things that helped clarify the science concept being studied. The* [handheld computer] *gave them a different way to record*

> *their investigations. It also gave me the opportunity to assess their knowledge quickly without the paper trail."*

Many teachers commented on the importance of ready access to representations of knowledge. For example, one teacher reported,

> *"The students had a world of information and sources at their fingertips. They were able to learn as much about their animal as the web and other resources had to offer."*

A more traditional teacher commented on ways digital representations enhanced students' learning about the writing process itself,

> *"Students got a better idea of editing and publishing from being able to share their work publicly. Students also benefited from 1:1 access to computers in honing their information searching and evaluation skills. They became more reflective and better writers, perhaps through group revisions, and got good practice typing."*

Most teachers also commented on the ways ready access to digital technologies allowed them to incorporate visual representations more easily and more frequently into their lessons. For example, one teacher noted,

> *"Kids today are more visual learners than ever before. Lessons created by teachers need to visually rival video games, television, and DVDs. During my experience in the classroom, students had an opportunity to create digital representations of their knowledge via a website, PowerPoint and digital movies. Students were very engaged in these projects and took great pride in the quality of their work."*

The sixth grade teacher who brought her family history project to the AT&T Classroom told us that the kinds of representations students could produce with digital technologies made her students' work of considerably higher quality and their enthusiasm for the project much better:

> *"Some students used color coding systems to denote maternal and paternal lines and some used graphics to depict 'favorites' of their ancestors or to show marriages. . . . Students also used Inspiration to create personal coats-of-arms. They used the Internet to access information about heraldry, concentrating on information about the meaning of specific symbols, colors, and shapes. Each student wrote several paragraphs about his or her coat-of-arms. The writing described why certain colors and symbols were selected. I have done this project with students several times; the work done in the* [AT&T] *Classroom is by far the best I have ever seen."*

Many teachers also noted that the ready accessibility of visual representations in the ubiquitous computing classroom helped lower achieving students better understand key concepts. For example, one teacher stated,

> *"With medium and low achieving students, the visual nature of the technology really seems to help the kids understand the concepts more quickly."*

Almost all teachers echoed this observation. It lends support to McClintock's (1999) notion that by broadening the acceptable forms of knowledge representation, digital technologies support wider and more inclusive participation in intellectual endeavors.

Indeed, interviews with students demonstrated the ways in which they thought seriously about knowledge representation, perhaps because they were given more choices. Students were able to discuss decisions they made with regards to technology choices when representing specific concepts or ideas in their product creation. For example, in discussing the webquest she had created on "The Wild West" a fifth grade student explained how she selected font and background colors consistent with Southwestern style art, while another classmate who created a webquest on hurricanes chose grays and blues for fonts and backgrounds to represent storms and clouds.

Students also explained how various representations of knowledge helped them learn. For example, one student commented on her use of the Write OutLoud software,

> *"When I was typing, I didn't know when I made a mistake, but then I went to Write OutLoud and I heard tons of mistakes that I did."*

Another student talked about how much he liked videoconferencing, especially a videoconference his class had with the Akron zoo. When asked by the interviewer whether he couldn't just read about the animals they talked about in a book, he answered,

> *"No, you really want to see the animals; and what if you have a question that is not in the book?"*

To summarize our findings concerning the effects of ubiquitous computing on the representations of knowledge employed in classroom activities, we found that teachers and students with ready access to digital technologies employed a much greater variety of representations, especially visual representations to create and communicate knowledge. These findings support the findings of other researchers in the field (Apple computer, 1995; Bartels & Bartels, 2002; Danesh, Inkpen, Lau, Shu & Booth, 2001; Hill, et al., 2002; Honey & Henriquez, 2000; Roschell, et al., 2004). In addition, teacher and student interviews suggest ways in which such ready access to multiple representations of knowledge enhance student learning. In particular, they lend support to McClintock's (1999) notions that by facilitating much greater access to a greater variety of knowledge, broadening the acceptable forms of knowledge representation, and providing tools that automate lower level intellectual skills, digital technologies support wider and more inclusive participation in intellectual endeavors. Indeed, in an important sense, it is the easy access to multiple representational forms for accessing, manipulating, creating and sharing knowledge made possible by ubiquitous computing that support changing conceptualizations and uses of knowledge in ubiquitous computing classrooms.

Conceptualizations

"Conceptualizations" as used here refers to the unique ways in which knowledge is represented, organized, processed and manipulated in individuals' minds. McClintock (1999) argues that digital tools can support a variety of higher order thinking, both by automating lower level functions and by scaffolding construction processes (see also Jonassen, 2000). Although it is, of course, impossible to examine the inner workings of students' minds, we are exploring ways in which ready access to digital technologies affects students' conceptual understanding by examining a variety of evidence including gains on tests of important concepts covered in their learning units, work samples from selected students, quasi-clinical interviews with students working on class projects, and interviews with teachers. The evidence suggests that students in our ubiquitous computing classroom did indeed learn to use a variety of technologies as thinking and learning tools, and that such usage supported their subject area conceptual learning.

For example, in the quasi-clinical interviews, students repeatedly used computer-based representations to describe a concept and/or demonstrate how they used a particular computing application to create knowledge. Overall, the majority of students were able to describe in great detail the project they were working on including key concepts represented in their work. One student pointed out that they were not only learning about content area topics, but that they were learning to use technology to support learning as well. When asked whether he thought he was learning as much as he would back in school, he answered,

> *"Probably more because we are learning about high tech stuff with our normal subjects too."*

Indeed, students told us repeatedly that they thought they learned more in the AT&T Classroom and attributed their enhanced learning to the "fun" they had using digital technologies:

> *"I think you learn more if it's fun because if it's fun it helps you concentrate and listen."*
>
> "*You want to have fun and learn at the same time. If you are bored you don't learn as much because you don't want to focus in to it."*

Teachers similarly commented on the (sometimes profound) effect ubiquitous computing had on student engagement and motivation, noting that these are a necessary first step in higher order learning. Indeed, all the teachers we interviewed mentioned their surprise at how much ubiquitous access to computers and handheld devices affected their students' engagement in learning. For example, one teacher stated,

> *"I learned that the more students are allowed to use technology, the more excited they get about their projects."*

Similarly, another told us,

> *"From my experience in the* [AT&T] *Classroom, I realized the excitement of students when they can see the quality of the work they are creating."*

Still another teacher reported,

> *"My students definitely tried harder and didn't give up as quickly throughout their experience at* [AT&T] *Classroom. Even if they had to do more (i.e., writing) they didn't complain, they just got to work! I also noticed through the video tapes and looking back to day one, that my students' behavior and attention span increased throughout our visit there."*

One teacher noted that when she gave homework assignments to be completed on mobile computers devices, all her students got them done, something she had never before experienced:

> *"Taking the* [mobile computing devices] *home resulted in everyone's homework always being done, and shortened the time frame for getting work done."*

Another teacher observed that his students wrote more in their daily journals when they were using mobile computing devices:

> *"The one benefit I've noticed is that they do write more with the* [mobile computing devices]. *And I believe that much as occurs with reading, the more you write, the better a writer you become."*

Still another teacher noted that the engagement generated around the ubiquitous computing classroom made it possible for her to change her pedagogical approaches, in particular, to individualize her teaching:

> *"The most important thing that I learned is the power that technology has to both motivate students and keep them on task. I was able to work one-on-one with a lot of students because the others were so completely engaged in their own projects."*

This comment may provide some evidence of the changing pedagogical possibilities McClintock (1999) believes inherent in ubiquitous computing environments. One teacher summed up his experience as follows,

> *"Learning was more efficient, students were busier. There was some fooling around at the beginning, but in general students were more engaged, more motivated, more on task, freer."*

Teachers also believed that ubiquitous access to digital technologies affected the quality of students' work, and attributed at least some of that increased quality to the kinds of supports differing technologies gave to particular kinds of learning. They believed this resulted partly from the availability and variability of computing technologies but thought it also developed from the authentic contexts for learning such technologies afforded them. For example, several teachers spoke about using mobile devices to support peer editing:

> *"It also seemed to make individual sharing and peer tutoring work better."*
>
> *"The biggest change has been in their weekly journals. We have been journaling all year and they have always written them but in using the* [mobile computing devices], *peer editing takes on so much more meaning when they can beam to someone rather than trading papers. With the Danas they are editing their own writing more and it keeps getting better."*

Teachers also noted that ubiquitous computing seemed to be particularly supportive of project-based and inquiry learning.

> *"I was really surprised by the quality of the family trees, which far exceeded my expectations. The students' autobiographies were the best I have ever seen."*
>
> *"With my students, I've noticed they are really much more inquisitive. The higher achieving kids take learning to the next step, and I see the other kids trying to do the same. For instance, the other day while working on a unit addressing natural forces, the kids themselves wanted to create a rubric to analyze the material. I've assigned that to them before, but they never before told me that's what they wanted to do."*

Such comments provide further evidence of changing pedagogical possibilities in ubiquitous computing environments. One of the kindergarten teachers in the 2003/2004 cohort had little classroom experience with technology before she brought her class to the AT&T Classroom. Her comments epitomize the ways teaching and learning in such environment can expand teachers' notions of what is possible:

> *"The importance of technology for young children was reaffirmed and I learned about the capabilities of the children when using technology. I learned to think of technology as a tool that adds another dimension to learning."*

That students did use the technologies available in the AT&TAC for learning is demonstrated by the gains students made on tests of conceptual understanding. Table 7 reports pre- to post-test gains for classes in the 2003-04 and 2004-05 school years. All classes pre- to post-test gains were significant at the .05 level, and most were highly significant. The average effect size of gains across classes from pre to post testing was 1.00, or one full standard deviation, for the 2003-04 school year and 2.30, about two and one third standard deviations for the 2004-05 school year. An effect size of 1.00, for example, would move a student at the 50th percentile to the 84th percentile.

While it may not seem surprising that students learned what teachers wanted them to learn, it is important to document that students did learn the intended content and not just technological skills. The data show students learned the content very well, especially in the 2004-05 school year.

Table 7: Average Pre/Post Test Gains in Effect Sizes by Grade Levels*

Grade Level	Effect Sizes of Gains 2003/04*	Effect Sizes of Gains 2004/05**
K	0.52	
grade 3	1.41	
grade 4	2.03	
grade 5	1.06	
grade 6	0.21	
grade 7	1.46	
Grade 1		1.59
grade 2		1.61
grade 3		2.29
grade 5		2.75
grade 5		3.84
grade 6		1.30

* test scores were only available for one kindergarten (patterns) and one fourth grade (flight) class
** test scores were not available for the kindergarten and the fourth grade classes

Analyses of selected student work samples support findings concerning pre- to post-test gains, and provide evidence of student learning at high levels (Table 8). On a scale of 3-12 (with 3 being the lowest), the artifacts across classes averaged a score of 9.9 (range of 5.0-12.0) with regards to authentic intellectual achievement, placing student work in general at the highest levels of conceptual understanding. Of particular interest are comparisons across ability groupings which show that special needs students' work was at levels equal to average students. Work created by students with higher ability levels had an average score of 10.5, a very high level of conceptual understanding. For students of average ability, the work samples averaged 9.5 (still in the highest level), and work sample ratings averaged 8.7 for students with lower abilities. The lower ability students were the only ones who didn't fall into the highest category of conceptual understanding, but their work is at the upper reaches of the second bracket. The work of students with special needs averaged 9.3, which is statistically similar to the work of average ability students and similarly at the highest level of conceptual understanding. This is an important finding which may lend support to McClintock's (1999) argument that by broadening the acceptable forms of knowledge representation and providing digital tools to support lower level intellectual skills, digital technologies support more equitable and inclusive participation in conceptual work.

Table 8: Average Conceptual Understanding Scores for Ability Groups Across Classes*

	Average Score Across Classes
high ability	10.0
medium ability	9.4
low ability	8.5
special needs	9.3

* overall scores possible range goes from 3(low) to 12 (high)

The high quality of student work, as previously noted, was remarked upon by all participating teachers. All teachers who had special needs students in their classes particularly commented on the "leveling of the playing field" for these students. Such finding supports findings by other researchers in the field (Hill, et al., 2002; Honey & Henriquez, 2000; Stevenson, 1998). Traditionally the special needs literature describes the use of assistive technology tools for supporting meaningful mainstreaming of struggling students, or the use of intervention-based software to facilitate learning. In the AT&T Classroom, however, the students with special needs and lower abilities were achieving at high levels using the same technology tools as their peers rather than assistive technology. This finding has important implications for teachers and administrators with regards to student integration and accommodation issues. It clearly deserves further investigation.

Student work samples were further studied to yield descriptive data regarding student performance. A number of the artifacts studied required students to utilize technology to organize, synthesize, or interpret information, describe patterns, create models or simulations, etc., suggesting that teachers were making good use of digital technologies as tools for supporting higher order learning. In most of the artifacts, there was good evidence that students had developed a deep understanding of key concepts and ideas related to the content area they were studying, in that they were able to elaborate on specific concepts and make connections between concepts. In addition, the majority of the work samples encompassed details and examples in ways that demonstrated students' ability to communicate their learning, including supporting details, facts, graphics, and symbolic representation.

In summary, our findings concerning the effects of ubiquitous computing on AT&T Classroom students' knowledge conceptualizations indicate that students were more motivated to learn and more engaged in learning. Both teachers and students agreed this resulted in higher quality student learning, and indeed, pre- to post-test gains as well as analyses of student work revealed high levels of conceptual understanding. Similar findings have been reported by researchers in the field (Apple Computer, 1995; Hill, et al., 2002; Ricci, 1999; Stevenson, 1998; Vahey & Crawford, 2002; Zucker & McGhee, 2005). Taken together, they provide some evidence that ubiquitous access to digital tools may, as McClintock (1999) suggests, facilitate higher level thinking, and so support corresponding pedagogical changes.

Uses

In our work on ubiquitous computing, we use the term “uses” to refer to the activities and interactions through and around which knowledge is negotiated and constructed. As pedagogical possibilities change in ubiquitous computing environments, new social organizations evolve around new approaches to teaching and learning. By examining interactions among teachers and students in a ubiquitous computing classroom, we can begin to explore how classroom cultures are changing in response to such possibilities.

Table 9: Percentage of Class Time Students Spent in Identified Groupings Across Classes

	Regular Classroom	AT&T Classroom
individual	12.96	8.52
small groups	31.31	58.73
large groups	7.78	0.00
whole class	47.95	32.75

Indeed, comparisons of teacher and student activities and the organization of interactions among them revealed meaningful differences between classroom settings. The most noticeable difference involved student groupings (Table 9). In the AT&T Classroom, teachers were nearly twice as likely to organize their students into small groups. Students spent more than half their time in the AT&T Classroom working in small groups, while they spent less than a third of their time similarly engaged in their regular classrooms. In contrast, students spent the most time in their regular classroom setting, almost fifty percent, engaged in whole class activities, while in the AT&T Classroom, they spent less than one third of their time working as a whole class.

Table 10: Percentage of Class Time Teachers Spent in Identified Locations Across Classes

	Regular Classroom	AT&T Classroom
teacher station	3.24	20.65
front of class	68.03	46.51
back of class	0.22	0.00
mingling	28.51	32.84

Accordingly, teachers spent over two thirds of their time at the front of their classes in their regular classrooms, whereas in the AT&T Classroom they alternated between teaching from the front of the room, orchestrating presentations from the teacher station, and moving among students (Table 10). It should be again noted that these data are derived from a sample of lessons (two in each setting) that may or may not represent “typical” classes. They do, however, suggest a tendency for teachers to become more “facilitators of learning” in the ubiquitous computing classroom and less “disbursers of knowledge,” a change McClintock (1999) argues is made possible by digital computing. Findings comparing teacher (Table 11) and student (Table 12) activities in the two settings lend support to this interpretation.

Table 11: Percentage of Teachers' Time Spent in Identified Activities Across Classes*

	Regular Classroom	AT&T Classroom
lecture	3.46	0.00
discussion	12.96	5.46
inquiry	2.38	2.62
giving directions	29.81	36.24
answering questions	10.15	4.59
asking questions	18.36	13.54
talking	6.26	16.59
listening	10.58	7.42
demonstration	1.94	5.90
classroom management	19.01	12.23
supervising activities	43.84	54.80
other	5.62	7.64

* as, in many cases, activities were simultaneously engaged in, numbers do not add up to 100

For example, teachers were more likely to spend time in lecture and discussion, and asking and answering questions in their regular classrooms than in the ubiquitous computing classroom. They also spent a good deal more time on classroom management in their regular class settings. On the other hand, in the AT&T Classroom, teachers were more likely to spend their time giving directions and demonstrations, supervising activities and talking with their students than in their regular classrooms.

Similarly, whereas students spent more time in their regular classrooms answering and asking questions than in the AT&T Classroom, in the AT&T Classroom, they spent more time talking and listening to each other. In the AT&T Classroom, students also spent fully four times as much time working on construction projects than they did in their regular classrooms. In their regular classrooms, students spent almost twice as much time engaged in seat work. Although it could be argued that class time in the AT&T Classroom might be seen as "special" and an opportunity to depart from normal routines, it should be remembered that classes spent six weeks there and that new state standards and No Child Left Behind regulations dictate curricular objectives that must be met. Moreover, such findings mirror those of other researchers in the field who report that teachers in ubiquitous computing environments are becoming more student-centered (Apple Computer, 1995; Honey & Henriquez, 2000; Norris & Soloway, 2004; Ricci, 1999), more constructivist (Apple Computer, 1995; Rockman, 2003), more project-oriented (Honey & Henriquez, 2000; Norris & Soloway, 2004), and more inquiry-based (Norris & Soloway, 2004; Ricci, 1999). It seems fair, therefore, to maintain that the observational findings at least provide preliminary evidence for the changing possibilities in ubiquitous computing environments.

Table 12: Percentage of Students' Time Spent in Identified Activities Across Classes*

Student Activities	Regular Classroom	AT&TAC
listening	62.85	82.75
reading	25.05	24.67
seatwork	41.68	24.67
talking	34.13	65.50
asking questions	9.94	4.59
answering questions	19.44	7.21
gathering materials	6.05	5.90
construction projects	10.80	44.54
research	14.25	14.41
data analysis	0.00	0.00
presentation	5.83	0.00
other	0.65	3.06

* as, in many cases, activities were simultaneously engaged in, numbers do not add up to 100

Interviews with teachers support such contention. All teachers, for example, remarked on how much easier it was to manage their classes in the AT&T Classroom. One teacher who was nervous about bringing her class to the AT&T Classroom because she wasn't sure she could manage them there, remarked,

> *"I learned classroom management is easier in technology-based teaching, not harder."*

Most teachers said they were surprised at the way they could work with individual students or groups of students without worrying about what the rest of the class was doing. One teacher, for example, noted,

> *"It's much more student-centered there. The technology keeps them engaged so I can go around and do one-on-one."*

Other teachers echoed this theme and pointed out that because management issues were reduced, they could give their students more independence:

> *"I also learned the value of open-ended software and letting the children have some independence when learning new software. It rejuvenated my teaching."*

> *"I tried to give the students more choices about projects because of the different ideas I saw in the classroom."*

Teachers also noted that classroom dynamics changed in the ubiquitous computing classroom. For example, one teacher reported,

> *"Students interacted more and more freely. Bullying stopped and the class achieved a sense of itself, sooner than they would have in their regular classroom. At the beginning of the year, I gave students cards on which they told who they would like to sit near. I just redid them and found that they had changed dramatically. The* [AT&T] *experience in some sense forced kids to interact with each other."*

One change in classroom dynamics that most teachers commented on was that students became "experts" in the ubiquitous computing classroom:

> *"During the lesson I gave the students very little instruction on using the software. Once they got on the computers, the students found this software very user friendly and flexible. As students discovered specific tools and graphics, they shared what they had learned with their peers. Several students became class experts on specific aspects of the programs."*

Ubiquitous computing researchers report similar findings (Apple Computer, 1995; Norris & Soloway, 2004). Teachers particularly noted that certain students who had been marginalized in their regular classrooms took on leadership roles in the AT&T Classroom, for example,

> *"This particular student is now acting like a leader, and I think the students now perceive him as a leader instead of a nerdy geek. There are times I'll sit with one group showing them how to do something on the computer, and he'll do the same with another group. He has really assumed the role of teacher with other students since the* [AT&T] *experience."*

In a similar vein, all teachers remarked on the way ubiquitous computing seemed to "level the playing field" for students of varying abilities. For example, one teacher stated,

> *"I believe that I must always teach to my students' strengths and use those strengths to help students overcome their weaknesses. Technology levels the playing field for students, especially those students on Individualized Education Programs. Most of my students had strengths in technology and had the opportunity to become more accomplished. Technology helped my students to become empowered. Because of the variety of the hardware and software at the lab, all of my students were successful on some level."*

Another said,

> *"In particular, the special education students bloomed. They could go at their own pace and technology seemed to emphasize their strengths as opposed to their weaknesses. It had a leveling effect. One special education student's autobiography was one of the best in class, much better than his earlier work."*

Still another teacher told us about a particular special needs student:

> *"She understands her work a little better, and she gets her homework done a lot…She never used to do her homework. Now she's excited to do her homework with the Palm and keyboard… I use Sketchy as a way of helping her understand material. She used to sit in a corner all by herself and not interact with the other kids. Now she is communicating more with other students since she now has something in common with them."*

Many ubiquitous computing researchers report similar leveling effects (Hill, et al., 2002; Honey & Henriquez, 2000; Stevenson, 1998).

Teachers also all found the ubiquitous computing environment to be more supportive of collaborative learning than there regular classrooms. For example, one teacher noted,

> *"It also seemed to make individual sharing and peer tutoring work better."*

Several teachers used handheld computers to support peer editing and found that students were much more enthusiastic about the process. One teacher's comments illustrate their observations,

> *"The biggest change has been in their weekly journals. We have been journaling all year and they have always written them but in using the Danas, peer editing takes on so much more meaning when they can beam to someone rather than trading papers. With the Danas they are editing their own writing more and it keeps getting better."*

Another teacher noted that being able to share work on computer screens and over the presentation systems gave students increased pride in their work:

> *"The* [AT&T] *experience also taught me the value of sharing student work. Giving a grade for a project is not enough, students need peer affirmation of performance."*

Students' comments support teacher interview and observational findings. For example, one student told us how *"great"* it was in the AT&T Classroom. When asked why, she spoke about collaboration with student "experts,"

> *"Cause you can tell them if you have a problem or something because you know who they are. A lot of people in here know a lot about computers."*

Another student, asked a similar question, spoke about project-based learning,

> *"You design things more and do experiments rather than just read."*

Many students also mentioned another way ubiquitous computing was changing the ways they created and used knowledge. They told us that mobile computing was allowing them to take ubiquitous computing beyond the classroom. Students reported using handheld computers not only in the AT&T Classroom, but on field trips, back in their regular classroom, at home, after school, and on the bus. Many of the students reported that they found them to be most useful for organizational types of school-related activities. Most said that they preferred using the handhelds over writing things by hand and that using them for writing assignments made the work *"easier"* and/or *"more fun."*

To summarize our findings concerning the effects of ubiquitous computing on the interactions among students and teachers in the AT&T Classroom and the social uses of knowledge therein, we found that teaching and learning was more student-centered, more collaborative, more project-oriented, more constructivist, and more flexible in the ubiquitous computing environment. We also found a "leveling of the playing field" for students with special needs and lower achieving students in that environment. Such findings suggest that ubiquitous access to digital tools can support at least some of the pedagogical changes McClintock (1999) identifies.

CONCLUSIONS

The research presented in this paper documents changes in teaching and learning in a ubiquitous computing classroom and suggests that these changes are related to the supports such environments provide for new representations, conceptualizations, and uses of knowledge ubiquitous computing environments afford. It thus adds to our theoretical understanding of teaching and learning in ubiquitous computing environments. Specifically, the classes we observed used multiple representations of similar concepts and visual as well as textual representations to explore topics. Teachers in these classes allowed students representational choice and encouraged student constructions and sharing in a variety of representations including presentation to audiences beyond the classroom. We also observed changes in interactions among students and between teachers and students that seemed to support the social construction of knowledge. Finally, we found significant gains in conceptual understanding among students. Of particular interest in this regard were findings which suggest learning in ubiquitous computing environments may help close gaps in academic gains between special needs and regular students. These results provide preliminary evidence that the pedagogical changes suggested by McClintock (1999) are, however tentatively, being embraced by teachers and students in ubiquitous computing classrooms. They clearly deserve further investigation.

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