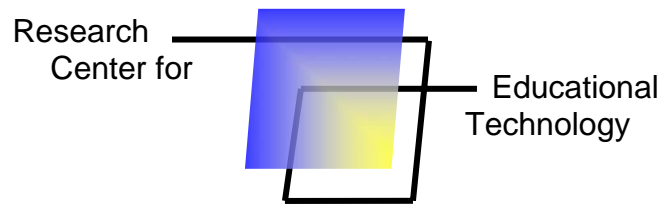


RETHINKING TEACHING AND LEARNING IN UBIQUITOUS COMPUTING CLASSROOMS

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ABSTRACT

Ubiquitous access to digital technologies is becoming an integral part of our business, home, and leisure environments, yet despite a quarter century of educational technology initiatives, ubiquitous computing remains conspicuously absent from our schools. In this chapter, we argue that simply putting more computers in schools will not solve the problem, but rather that teaching, learning, and technology integration need to be reconceptualized within a ubiquitous computing framework before the full educational possibilities inherent in digital technologies can be realized. Using examples from our laboratory classroom, we discuss how teaching needs to be reconceived more as “conducting” than “instructing”; and how learning needs to become more the responsibility of the student and located with him or her in an expanded space and time that extends beyond the classroom; and how technology integration needs to be understood not as an add-on, device-driven enterprise, but one motivated by teaching and learning needs in which multiple technology choices are readily available to teachers and students, both within and beyond the classroom.

“Digital technologies are for education as iron and steel girders, reinforced concrete, plate glass, elevators, central heating and air conditioning were for architecture. Digital technologies set in abeyance significant, long lasting limits on educational activity.”

-- R. McClintock, 1999 (Paragraph 10)

“The most pressing strategic problem for the evolution of public education in the digital age is this: How to restructure a school computer culture that was shaped by conditions that no longer apply.”

-- S. Papert, 2002

In *The Educators Manifesto* (1999), Robbie McClintock argues that the innovations in communications and digital technologies have the potential to dramatically change teaching and learning. He identifies three areas where technological innovations have already changed what is educationally possible.

Firstly, McClintock maintains that the growth of the Internet and broadband, wireless communications 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 approaches must accordingly change from ways of 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 McClintock thinks digital innovations are changing what is educationally possible involves multimedia. Multimedia, he 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 educational strategies, he argues, must accordingly be broadened to include the presentation, manipulation, evaluation, creation and communication of knowledge in a variety of media forms, and the intellectual recognition of skills in such areas.

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 curricular question “What knowledge is of most worth?” must accordingly be rethought.

McClintock maintains that his observations are not normative, but rather factual. Digital technologies change what is educationally possible. The key word here is “possible.” Indeed, the digital revolution may have changed what is educationally possible, but actual teaching and learning have changed little since the last great media revolution, that of printing. In part, this is because of the way computing devices have been placed in schools and classrooms. Until access to computers is ubiquitous, until every student has access to appropriate digital technologies whenever and wherever he or she needs them, what is possible will remain mere potential. Seymour Papert (in Kyle, 2000), for example, asks us to consider what impact the technology of writing might have had on education if there were only three or four pencils in a classroom, or students went to a “pencil room” once a week to use them.

However, ubiquitous access to computing technologies is not enough to make what is possible a reality in schools and classrooms. In this chapter, we will argue that simply putting more computing devices in schools will not revolutionize teaching and learning, but rather that teaching and learning need to be re-conceptualized within a ubiquitous computing framework for the educational possibilities inherent in digital technologies to be realized. Using examples from work in RCET’s laboratory classroom, the AT&T Classroom, we will discuss how teaching needs to be reconceived more as “conducting” than “instructing”; how learning needs to become more the responsibility of the student and located with him or her in an expanded space and time that extends beyond the classroom; and how technology integration needs to be understood not as an add-on, device-driven enterprise, but one motivated by teaching and

learning needs in which multiple technology choices are readily available to teachers and students both within and beyond the classroom.

BACKGROUND

The term “ubiquitous computing” was introduced by Mark Weiser of Xerox PARC 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.” Weiser envisioned ubiquitous computers as embedded in the environments we inhabit; others have seen them as devices we carry through those environments (Kay, 2005); while others still have maintained that what is most important about ubiquitous computing in schools is the provision of one computing device for every student (Papert, 1980, 2002; Silvernail & Lane, 2004).

In our work, we view ubiquitous computing as encompassing all three of these notions, as well as the importance of Internet connectivity. We view ubiquitous computing as involving 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 concept of ubiquitous computing is centered on the notion of technologies which are always available but not themselves the focus of learning, and the idea that students and teachers can make informed choices about which technologies to use for particular tasks. We further view ubiquitous computing environments as not bound by the walls of the classroom, but rather both portable and at least partially virtual.

None-the-less, our work at the Research Center for Educational Technology (RCET) is grounded in ongoing research taking place in the AT&T Classroom located on the campus of Kent State University. Each year RCET has brings eight local teachers and their intact classes to spend six weeks in this unique laboratory classroom working on thematic units drawn from their regular curricula.

The AT&T Classroom is a ubiquitous computing classroom. It is currently equipped with enough desktop and wireless laptop computers to provide all students with 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 video over IP technologies, presentation systems, scanners, printers, digital cameras, video and audio recorders, three VCRs, video editing equipment, CD and DVD burners, digital microscopes and scientific probes, wireless Interwrite School Pads, Graphire pads, a Logo robot turtle, and a wide variety of software to support teaching and learning. The AT&T Classroom and its yearly program of extended residences for local classes thus gives teachers and students a chance to explore the educational possibilities afforded by ubiquitous access to digital computing.

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 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 any one of four stations in the observation room, researchers can use AMX control panels to 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, and student work is collected in electronic portfolios. The classroom and its yearly program of extended residences thus gives RCET researchers a chance to study teaching and learning in a ubiquitous computing environment, in depth and across a variety of grade levels, subject areas, teachers, and students.

In the sections which follow, we will draw from the AT&T Classroom experiences to discuss the issues involved in rethinking teaching and learning from a ubiquitous computing perspective. We conclude with some comments on rethinking technology integration in that light.

RETHINKING TEACHING

In *The Educators Manifesto* (1999), Robbie McClintock argues that the digital technologies available today have changed what is pedagogically possible in classrooms. To take advantage of these possibilities, teaching must be rethought; the role of the teacher must be reconceived within a ubiquitous computing context. Three related areas of rethinking seem particularly relevant. For the pedagogical possibilities inherent in ubiquitous computing to be fully realized, teaching must be re-conceptualized as “conducting learning;” it must no longer be thought of as bound by the school building or the school day; and the content and focus of teaching must be re-defined to meet the needs of the 21st Century.

Rethinking Pedagogy

First, as McClintock (1999) suggests, ubiquitous computing means classrooms no longer need be isolated places with very limited resources, but rather should be reconceived as portals with access to abundant resources and rich connections to the world. Teaching, accordingly, need not be confined to walking all students through a limited set of materials, but rather can and should be re-imagined as supporting each and every student’s learning with materials appropriate to his or her abilities and interests. Teaching needs to be thought of less as instruction and more as the facilitation of learning.

We like to think of the role of the teacher in a ubiquitous computing classroom as similar to the role of a conductor of an orchestra. The conductor’s job is to bring together the disparate voices of the orchestra to bring to life a common musical theme. Similarly, the role of a teacher in a ubiquitous computing environment is not only to support individual learning, but to blend individual learning into a shared class experience. Although this not only seems, but is, in some sense antithetical to the standards-based frame dominating American K-12 education today, standards just proscribe what students should know, not how they should learn it, and certainly not how teachers should teach. It moreover can be argued that more students are more likely to reach more learning goals, when teaching is adapted to their learning needs.

Indeed, in ubiquitous computing programs across the country, teachers are making use of increased access to educational resources. 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; Roschelle, Penuel & Abrahamson, 2004) including the use of a much wider variety of visual representations, spreadsheets and databases, simulations, and exploratory environments.

Teachers in the AT&T classroom are also introducing their students to traditional, standards-based content in non-traditional ways. A kindergarten teacher, for example, encouraged her students to use digital photography, tessellation software, a music composition program, and the Logo robotic turtle to explore patterns. A fourth grade teacher allowed his students to communicate what they had learned about plant biology through web pages, videos, and PowerPoint presentations, as well as in traditional written reports.

A sixth grade English language arts teacher had her students include scanned pictures, family trees created using Inspiration software, and family crests created with graphics software in the autobiographies which had been a standard part of her curriculum for several years prior to her AT&T Classroom experience. She told us,

“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 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.”

As suggested by the previous quotation, students in these ubiquitous computing classes learned the curricular concepts their teachers identified as important at least as well if not better than they would have learned them in a traditional classroom setting. We worked with teachers in the 2003/04 and 2004/05 cohorts to create pre and post tests on the big ideas in the units they taught during their time in the AT&T Classroom. Across classes, student pre- to post-test gains in the 2003/04 school year averaged a full effect size (one full standard deviation). An effect size of 1.00 would move a student at the 50th percentile to the 84th percentile. Student pre- to post-test gains in the 2004/05 school year showed an effect size increase of 2.44. In-depth analysis of selected student work from each class also provides evidence of deep conceptual understanding of curricular concepts across student ability levels.

We also documented changes in teaching practices when teachers moved from their traditional classroom settings to a ubiquitous computing environment. Indeed, comparisons of teacher and student activities and the organization of interactions among students and teachers in their regular classrooms with activities and social organization in the AT&T Classroom revealed meaningful differences between settings. The most noticeable difference involved student groupings (Table 1). In the AT&T Classroom, teachers were nearly twice as likely to organize their students into small groups.

Table 1: 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

In addition, 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 their time between teaching from the front of the room, orchestrating presentations from the teacher station and moving among students. Teachers were also much more likely to spend time in classroom management, lecture and discussion, and asking and answering questions in their regular classrooms than in the ubiquitous computing environment of the AT&T classroom. In the AT&T Classroom, teachers were much more likely to spend their time giving directions and demonstrations, supervising activities and talking with their students than in their regular classrooms.

Other researchers are documenting similar changes in teaching. Across ubiquitous computing 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), and are developing lessons that are more project-oriented (Honey & Henriquez, 2000; Norris & Soloway, 2004) and inquiry-based (Norris & Soloway, 2004; Ricci, 1999).

These documented changes in teaching approaches demonstrate a tendency for teaching to become more like conducting and less like instructing in ubiquitous computing environments. However, a good deal more rethinking must be done before the possibilities afforded by ubiquitous computing (and documented in preliminary research) become generally manifest. In particular, rethinking needs to take place at the school and district levels and in schools of education before the culture of teaching can truly change.

Rethinking Boundaries

A second area in which teaching needs to be rethought for the potential of ubiquitous computing to be realized, that of anywhere/anytime learning, requires even more radical re-imagining. Ubiquitous computing diminishes boundaries imposed by brick and mortar spaces and the school day. Mobile computing devices and online virtual spaces make it possible to extend teaching and learning beyond school walls and the school day. Many teachers have long sought ways to make learning more relevant, to bridge the gap between school and the "real" world. Ubiquitous computing can help bridge that gap, but a major rethinking of teaching practice will be necessary before such promise can be realized.

We have seen some indications of this potential in the AT&T Classroom. For example, all students in our classes receive mobile computing or handheld computing devices which most teachers allow them to take with them 24/7. Many teachers encouraged their students to use these devices anywhere and anytime for journaling and other reflective activities, and noted that such usage resulted in improvements in both the quantity and quality of student writing. One teacher, for example, told us,

"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."

Another teacher noted,

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

The students we interviewed concurred and told us that using mobile computers helped them organize their work better and made writing "more fun."

Mobile computing also helps teachers to take their classes into the world. For example, a fourth grade class participated in an Ohio-wide stream quality project sponsored by state environmental agencies. They were assigned a local stream to monitor which they did on fall and spring field trips during which they used digital probes to test water temperature, Ph, and stream flow, as well as nets to collect and count organisms in their stream. They recorded their data as they collected it using handheld computers, which they also used to take pictures of the stream site. They then shared their findings with state officials and other classes across Ohio through videoconferencing and data sharing over the Internet.

Indeed, a third way we have seen ready access to ubiquitous computing break down barriers of space and time involves the Internet. Many teachers helped their students communicate with others via email, and most used video teleconferencing over the Internet to connect their students with experts on the topics they were studying, as well as with students in Mexico studying similar topics. All teachers incorporated Internet research into the projects they assigned in very integrated ways that would not have been possible with the limited access of typical classrooms. In all these ways, teachers made the AT&T Classroom less an isolated location and more a portal to the larger world.

Of course, these are very small examples when one considers the enormous potential for teaching and learning outside the school room and school day that are available now. Fully online classes are now being taken by over ten percent of students enrolled in higher education (Allen & Seaman, 2004), and the number of virtual classes being taken by K-12 students is growing fast. The educational possibilities of cell phone technology (Prensky, 2005) and online gaming (Gee, 2003) are being seriously examined by researchers and educators, but in the mainstream educational community, rethinking teaching along anywhere/anytime lines is still tentative at best. It requires serious consideration.

Rethinking Curricula

A third and final way teaching must be reconsidered involves rethinking what is taught. As McClintock (1999) suggests, we must rethink what knowledge is important and what it means to be literate in a digital world. Indeed, a unique consortium of leaders from government, industry, and education, the Partnership for 21st Century Skills (2003), argues that the emphasis of *No Child Left Behind* on core subjects is not enough, but rather that core subjects should include 21st Century content, that they should be taught and learned using 21st Century tools in a 21st Century context, and that learning should be measured using 21st Century assessments. Specifically, they contend (p 6) that students need to learn how to “appropriately use digital technology and communication tools to access, manage, integrate and evaluate information, construct new knowledge, and communicate with others.”

In the AT&T Classroom, we are beginning to see teachers educate their students in the use of such tools. Participating teachers encourage their students to use a variety of digital devices to help them explore their topics both in and outside the classroom. For example, in the 2003/2004 school year (Table 2), all AT&T teachers incorporated word processing, Internet research, and the use of mobile computing into their assignments. Most 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.

Most importantly, all the teachers utilized the available technologies to support their teaching and learning goals. Teachers in these classes used differing technologies to meet differing learning objectives, often in very creative ways. Their students learned to use a variety of digital technologies appropriately to access, manage, create and communicate information. Participating teachers 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.

In their post classroom 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.”

Table 2: Digital Technologies Employed in AT&T Classes in the 2003/2004 School Year

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, document camera
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, document camera
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

Another teacher commented on ways the use of digital technologies 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.”

Indeed, most of the teachers we interviewed commented on the ways in which the use of digital technologies enhanced and expanded students’ communication and problem solving skills.

Of course, these examples also involve small steps. For the full potential of ubiquitous computing to be realized, what is taught must be systematically rethought across the curriculum at the school, district, state and national levels.

RETHINKING LEARNING

If teaching needs to be re-conceptualized to take full advantage of ubiquitous access to digital computing, it follows that learning must similarly be re-imagined. Our work in the AT&T classroom has led us to believe that ubiquitous computing has the potential to make learning truly student-centered and that student-centered learning can also be higher-order learning. We believe that learning needs to be re-imagined by both teachers and students to take advantage of the kinds of supports ubiquitous computing can provide for individual and social construction of knowledge. In particular, students need to be given, and take, responsibility for their own learning.

Four interrelated areas in which learning might be rethought in a more student-centered direction seem particularly relevant in a ubiquitous computing context. These center on engagement and motivation, individualization and choice, collaboration and peer learning, and learning for all students.

Rethinking Engagement & Motivation

Student-centered learning begins with engagement. An engaged student invests herself in learning activities, making learning, even learning that did not start out that way, student-centered. Digital technologies seem to engage students in learning. Indeed, students we interviewed told us time and time again that they thought they learned more in the AT&T Classroom because of the “fun” they had using digital technologies. For example, one student explained,

“I think you learn more if it’s fun because if it’s fun it helps you concentrate and listen.”

Another told us,

“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.”

The students we spoke with repeatedly used computer-based representations to describe a concept or demonstrate how they used a particular computing application to create knowledge. Overall, the majority of students we interviewed described in great detail the projects they were working on including key concepts represented in their work. Their engagement was palpable.

Teachers similarly commented on the sometimes profound effect ubiquitous computing had on student engagement and motivation, noting that these are necessary first steps in higher order learning. For example, one teacher told us,

“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.”

The teachers we interviewed further noted that because students were more engaged in the AT&T Classroom, they could pursue more complex and extended projects than they had in their regular classroom settings. Most thought ubiquitous computing seemed to be particularly supportive of project-based and inquiry learning precisely because of its power to engage students. One teacher, for example, told us,

“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.”

Another summed up her experience as follows,

“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.”

Indeed, all of the teachers we interviewed were surprised by how engaged and how motivated to learn their students were in the AT&T Classroom. Many of them extended the activities they had planned to take advantage of it. Other ubiquitous computing researchers are documenting similar effects. 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 even 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).

Thus, the first way educators need to rethink learning to realize the potential of ubiquitous computing is that they need to plan for and support student engagement. In particular, they need to think in terms of intrinsic, rather than extrinsic, motivation for learning and explore ways of using digital technologies to make learning “fun.”

Rethinking Individualization & Choice

A second way in which educators need to rethink learning to realize the full potential of ubiquitous computing involves individualization of learning and student choice. Most of the teachers we interviewed 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. For example, one teacher commented:

“I tried to give the students more choices about projects because of the different ideas I saw in the classroom.”

It should also be pointed out that ubiquitous access to digital computing devices makes it much easier both to individualize learning and to give students choice simply because, as McClintock (1999) notes, it gives teachers and students access to a wealth of resources beyond the limited resources of the typical classroom. Not only does access to rich collections of materials in a variety of media formats make it possible for teachers to tailor activities for individual students, but giving students mobile computing devices allows them to individualize their own workspaces and so to make their learning their own in a very tangible way.

Teachers in the AT&T Classroom began to take advantage of these rich possibilities and more importantly allowed their students to. They uniformly remarked on the high quality of student work that resulted. We analyzed the work of selected high, average, and low performing students from every class, as well as the work of selected special needs students in almost every class (some classes had no special needs students). Many of the artifacts studied required students to utilize technology to organize, synthesize, or interpret information, describe patterns, create models or simulations using data or information they collected or selected, suggesting that teachers were making use of digital technologies not only to support individualization and student choice, but to support higher order learning.

Students responded with unique, creative, and high quality work. In most of the student artifacts we reviewed, 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 supported big ideas with details and examples, facts, graphics, and symbolic representations in ways that demonstrated students’ ability to communicate their learning.

Other research on ubiquitous computing also shows that the increased individualization of learning and opportunities for student choice afforded by ubiquitous computing 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).

This latter finding, as well as the pre- to post-test gains we documented across AT&T classes, suggests that individualization and choice need not be sacrificed in the standards-based, high stakes testing context griping American K-12 education today, at least not when they are supported by ubiquitous computing. Thus, a second way learning needs to be rethought involves taking advantage of ubiquitous computing to maximize individualized learning and student choice within a framework defined by specific learning goals.

One way to approach this is suggested by the student work samples we reviewed. We saw that students better understood important concepts when they were guided to explore them on their own terms using a variety of digital resources. Indeed, researchers are finding that learning in ubiquitous environments is becoming more efficient (Apple Computer, 1995; Hill, et al., 2002) and that students are becoming “experts” on particular topics (Apple, 1995; Norris & Soloway, 2004). A good deal more rethinking of learning along these lines, however, remains to be done.

Rethinking Collaboration

A third way ubiquitous computing compels a rethinking of learning involves collaboration. Student-centered learning is not just individualized. Because learning is fundamentally a social activity (Lave & Wenger, 1991; Vygotsky, 1978), learning that is student-centered must also involve collaboration. Moreover, research suggests that collaborative learning can very positively affect learning outcomes (Johnson & Johnson, 1989, 1992). Ubiquitous computing affords unique supports for collaborative and peer learning activities. Indeed, researchers across the country have noted significant increases in collaboration among students, and between students and teachers, in ubiquitous computing classrooms (Apple Computer, 1995; Hennessey, 2000; Norris & Soloway, 2004; Roschelle & Pea, 2002; Robertson, Calder, Fung, Jones, O'Shea, & Lambrechts, 1996; Sharples, 2000; Vahey & Crawford, 2002).

For example, most mobile computing devices have beaming capabilities which allow students to easily share their work and/or work collaboratively. Several teachers used such devices to support peer editing and believed it enhanced both the activity and the quality of the resulting student work. One teacher told us that the use of mobile computing *“also seemed to make individual sharing and peer tutoring work better.”* Another commented,

“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 [mobile computing devices] they are editing their own writing more and it keeps getting better.”

Indeed, many teachers noted that being able to access each others' work digitally seemed to motivate students to create higher quality products. One teacher also commented 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.”

Being able to share work on computer screens and across computing devices also seemed to facilitate collaborative group work. As previously mentioned, students in the AT&T Classroom spent more than half their time working on collaborative group projects, much more time in such activities than they did in their regular classroom settings. Several teachers we interviewed remarked on how differently, and how much more successfully, group work progressed when all students had access to computing devices. One teacher, for example commented,

“Students interacted more and more freely. Bullying stopped and the class achieved a sense of itself much 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] Classroom experience in some sense forced kids to interact with each other.”

Students in some classes also shared their work and collaborated with students in Mexico on particular projects, adding a multicultural dimension that clearly enriched their learning experience. Students in one fourth grade class collaborated with students across Ohio and state environmental officials to measure water quality in Ohio streams. One class of kindergarten students collaborated with their parents over email. It is our belief that these kinds of collaborations just touch the surface of what is possible with ubiquitous computing. Online environments, for example, make all sorts of rich collaborations possible. Students online can engage in rich discussions asynchronously across space and time. They can

participate in collaborative simulations and collaboratively create all sorts of products. They can share data, collaboratively analyze it and report their results. Some people are experimenting with collaborative performances across distance. The possibilities are legion but we believe that they cannot be substantively realized until collaborative learning is radically re-imagined to harness the potential of ubiquitous computing on a much larger scale, across schools, districts, and states, at the very least, but ideally at national and international levels.

Rethinking Learning for All Students

A final area in which learning needs to be re-conceptualized to take advantage of ubiquitous computing involves learning for all students. 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, we found that students with special needs and lower abilities were achieving at high levels using the same technology tools as their peers.

Table 3: 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)

Table 3 above shows our ratings of student work samples for students in different ability groups averaged across classes. Work samples were rated on depth of analysis, understanding of concepts, and elaborated communications using a four-point rubric in each category for a possible total score ranging from three to twelve. As previously noted, all student work was of very high quality, but what stands out in the findings is that special needs students were completing work of the same quality as students identified as average learners and almost as high quality as the highest achieving students.

This finding is supported by other research (Hill, Reeves, Grant, Wang & Han, 2002; Honey & Henriquez, 2000; Stevenson, 1998) that is documenting similar achievements by special needs and low ability students in ubiquitous computing programs. It has important implications for educators with regards to student integration and accommodation issues. It also suggests that we need to rethink what and how special needs students can learn given ubiquitous access to digital computing devices.

Indeed, all the teachers we interviewed told us they were amazed at the work their lowest achieving students completed in the AT&T Classroom, and 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.”

These comments highlight an important way ubiquitous computing can facilitate all students’ learning; digital computers support multiple representations of knowledge, and so a variety of meaning making. They allow students who are less facile in traditional classroom ways of knowing to learn in other ways, to find their own voices. *No Child Left Behind* legislation dictates that we support the learning of all students. Research on ubiquitous computing suggests that we can do so if we rethink learning to include multiple ways of knowing supported by ubiquitous access to computers.

RETHINKING TECHNOLOGY INTEGRATION

In the previous two sections, we have discussed how teaching and learning need to be rethought for the potential of ubiquitous computing (McClintock, 1999) to be realized. We have seen indications of how teaching and learning can indeed change in ubiquitous computing environments, and the positive effects that can have on student achievement. It is clear, however, that such positive effects will remain isolated indications until rethinking takes place on a much larger and more inclusive scale. We must radically rethink our notions of technology integration in education in ways that embrace not only ubiquitous computing, but the full potential for new approaches to teaching and learning that ubiquitous computing affords.

The first step in rethinking technology integration is simple but radical. We need to embrace ubiquitous computing. We need to view access for all students to a variety of digital computing devices wherever and whenever they need them as fundamental to the learning enterprise; as fundamental to learning, in fact, as ubiquitous access to books and writing materials. We need to see ubiquitous computing as essential. While this is a radical idea, it is not a ridiculous one. Consider, for example, the fact that education is the only knowledge industry today that does not view ubiquitous computing in this way. Consider as well that books were once the new technology. Ubiquitous computing is an essential part of meaning making in almost every aspect of our everyday lives, indeed in almost every aspect of our students’ lives, except in school. Education must embrace ubiquitous computing or become irrelevant. Consider the fate of Medieval scribes.

We thus must embrace ubiquitous computing and we must make it so. We must ensure that all students have access to a variety of digital technologies wherever and whenever they need them. This second step is possibly a little easier than first because once we realize ubiquitous computing is essential, we can seriously redirect our resources towards that goal. The state of Maine, for example, is moving towards ubiquitous computing by giving laptop computers to every middle school student in the entire state (Silvernail & Lane, 2004). Other initiatives are trying similar things on a slightly smaller but still significant scale. Across the country and around the world, schools, districts, and counties are implementing 1:1 computing initiatives (Johnstone, 2005; Rockman, 2003; Russell, Bebell & Higgins, 2004; Tatar, Roschelle, Vahey & Penuel, 2003; Zucker & McGhee, 2005). And momentum is growing (Wagner, 2005). It is important to remember, however, that as important as these first initiatives are, they

are just steps along a path to ubiquitous computing. We need, for example, to rethink education to incorporate the digital devices most students have and use regularly; cell phones are an obvious example as are gaming devices. Most importantly, we need to rethink teaching and learning within a ubiquitous computing frame.

Indeed, we probably need to stop thinking about technology integration altogether. As critical as large scale technology initiatives are today, they are device focused; they cannot be otherwise. Our thinking must go beyond implementation issues to re-imagine the entire educational enterprise in light of the new possibilities digital devices afford. Seymour Papert (2002) reminds us that we must guard against integrating technologies based on an educational culture that was shaped by conditions that no longer apply. In this chapter we have seen how ubiquitous computing makes possible new approaches to teaching that are more like conducting than instructing, that are not bound by school spaces and times, and that address 21st Century knowledge, skills and attitudes in meaningful ways. We have seen how ubiquitous access to computing can support student-centered learning that is more engaging, more individualized, more collaborative, and more inclusive than what we have come to expect. There are surely other ways teaching and learning can be reconceived in this brave new world.

The Educator's Manifesto (McClintock, 1999) was written more than five years ago, a long time in terms of technology integration, the blink of an eye in terms of educational reform. It was written before *No Child Left Behind* changed the landscape of K-12 education in this country. Its central thesis is, however, if anything, more relevant now than when it was written. Serious consideration of the notion that digital computing has changed what is educationally possible in dramatic ways can help us begin to re-imagine that landscape and transform education to meet the needs of today's, and tomorrow's, knowledge society in ways that might surprise us all.

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