

Learning via Smart Objects, Intelligent Contexts, and Ubiquitous Computing

Introduction to Articles by Rosenheck and Preis

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The two articles that follow this introduction articulate visions for *smart objects* and *intelligent contexts* in education. The authors of these articles are alumni of Harvard's master's degree program in Technology, Innovation, and Education who took courses from me in 2007. The articles are shortened versions of papers those students wrote for those courses; together, they provide interesting, complementary perspectives on the development of ubiquitous computing for teaching and learning. My brief introduction frames the ideas in those articles within the larger context of federal and corporate investments in sophisticated information and communications technologies.

As the articles describe, ubiquitous computing is a different way of conceptualizing the interface between computers, networks, and people. In this vision of the future, tiny computers are embedded into nearly every artifact and setting, networked so that they intercommunicate. For example, a tree in Harvard Yard might be tagged with information about its botanical characteristics; the tree might also offer to show an historic image of Harvard Yard about the time it was planted or to describe the contribution it makes to reducing local pollution and greenhouse gases.

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Based on the user's response, the building adjacent to the tree might then offer some information.

Highly mobile devices (the theme of the May–June 2007 special issue of *Educational Technology*) may seem similar to ubiquitous computing, but intrinsically it cannot provide the affordances for education that interfaces to smart objects and intelligent contexts promise. These emerging technologies are fundamentally different from today's cell-phones, portable gaming platforms, and personal digital assistants, which deliver communication, entertainment, and information services. The “next generation” of educational technology these articles describe will empower new ways of teaching and learning based on a ubiquitous national technology infrastructure of “intelligent sensors.”

Cyberinfrastructure as a National Investment

In recent years, the National Science Foundation has championed a vision of the future of research that centers on “cyberinfrastructure”: the integration of computing, data and networks, digitally-enabled sensors, observatories and experimental facilities, and an interoperable suite of software and middleware services and tools (National Science Foundation Cyberinfrastructure Council, 2007). Gains in computational speed, high-bandwidth networking, software development, databases, visualization tools, and collaboration platforms are reshaping the practices of scholarship and are beginning to transform teaching (Dede, in press). Scientific and educational resources can now pervade a wide variety of settings, rather than being accessible only in limited, specialized locations.

With cyberinfrastructure, real-time data collection can enable assessing students' educational gains on a formative basis, providing insights into the microgenetics of learning the complex knowledge and skills characteristic of 21st century education. Students can customize and personalize learning environments to a degree never before possible. Extensive “online” learning can complement conventional face-to-face education, and ubiquitous, pervasive computing can infuse smart-sensors and computational access throughout the physical and social environment.

During 2004–2005, with NSF funding, four workshops attended by experts in education were convened by the Computing Research Association. The foci of these workshops were, respectively (Computing Research Association, 2005):

- Modeling, Simulation, and Gaming Technologies Applied to Education
- Cognitive Implications of Virtual or Web-Enabled Environments
- How Emerging Technology and Cyberinfrastructure Might Revolutionize the Role of Assessment in Learning
- The Interplay Between Communities of Learning or Practice and Cyberinfrastructure

Collectively, these groups envisioned a cyberinfrastructure that “provides: (1) unprecedented access to educational

resources, mentors, experts, and online educational activities and virtual environments; (2) timely, accurate assessment of student learning; and (3) a platform for large-scale research on education and the sciences of learning... Moreover, the new educational cyberinfrastructure will make it possible to collect and analyze data continually from millions of educational activities nationwide over a period of years, enabling new advances in the sciences of learning and providing systematic ways of measuring progress at all levels” (CRA, p. 1).

Ubiquitous computing is intrinsic to descriptions of cyberinfrastructure’s evolution. Increasingly, sensors would instrument every setting, providing rich sources of data about what is happening in that context and offering this information to both local and remote observers. Some sensors would be passive; others might reach out to people in the vicinity to offer them services (as with the “intelligent objects” in Harvard Yard, noted above).

Intelligent sensors could play an important role in educational assessment and instructional design, should the digital Lifelong Learning Chronicles (LLCs) envisioned in the Computing Research Association depiction of educational cyberinfrastructure come to pass:

LLCs can offer rich and compelling information to a wide variety of stakeholders. For example, individual learners would have the data they need to make informed decisions about their own learning—what knowledge they need to study, what learning resources are available that best align with their interests and learning style (instead of the one-size-fits-all textbook), what metacognitive skills could be improved, and what strengths and weaknesses they have that may influence future academic and employment choices. Learners will no longer have to take a single-shot, high-stakes assessment, but instead can benefit from continuous embedded assessments that provide multiple opportunities to demonstrate their strengths...For all these stakeholders, a major benefit of the continuous learner data collection is the possibility of much more rapid, informative, and accurate feedback and responsiveness than is possible with today’s practices of occasional high-stakes and summative tests administered by teachers, instructors, and testing agencies during the school year. Data collection can go beyond traditional measures of domain content acquisition to include records of such factors as the processes learners have used in solving problems, information about whether learners are asking for help appropriately, and the way that learners may collaborate, cooperate, and argue with each other. Faster cycles of feedback not only would foster better instructional decision making, but research in learning technology that is better focused on effective design and appropriate uses of that technology as well. (pp. 19–20)

This concept of a cumulative “cognitive audit trail” is both intriguing and frightening in its potential implications for education.

Concerns About Ubiquitous Computing

The Computing Research Association report (2005)

articulates some issues about challenges posed by cyberinfrastructure. One set of concerns deals with ethical issues related to privacy:

One clear example of demands on Cyberinfrastructure, raised particularly with regard to the handling of human data (as opposed to, say, astronomical data), is privacy. Under most conditions of use, data on human subjects and student classroom performance must be anonymized for scientific or public use. There are significant challenges for anonymization, and a community of data privacy, and privacy technology researchers has emerged. Further challenges follow from the fact that different stakeholders may have different access needs for data about student or classroom performance. For instance, we may wish to provide students and their parents with full access to their own data; teachers with full access to data on students currently in their classes, but only summary access to their current students’ past performance; and school community members, administrations, and researchers with only certain kinds of summary information. (p. 32)

These cautions about privacy are echoed repeatedly in the NSF Cyberinfrastructure Council report (2007).

Few would argue that ubiquitous computing is a universally positive technical advance. Certainly, the current national security climate has raised many concerns about individual freedoms versus the public good, and complex ethical choices are involved in creating the sophisticated data collection and student assessment systems envisioned for cyberinfrastructure (Dede, in press). In the commercial sector, large companies such as Microsoft and Google seek to acquire and “own” detailed sources of information about individual users’ needs, wants, and behaviors; this raises another set of concerns.

Crucial questions center around wise use of cyberinfrastructure in ways that promote rather than repress the free exchange of ideas. Further, as educators we have a responsibility to use smart sensors and similar technologies in ways that empower individual self-actualization rather than make early judgments about educational potential that constrain an individual’s life choices thereafter. As the visions described in Rosenheck’s and Preis’s articles—and the cyberinfrastructure initiative—move towards fruition, research is urgently needed on the strengths and limits of this “next generation” of educational computing. □

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Learning with Ubiquitous Computing

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If ubiquitous computing becomes a reality and is widely adopted, it will inevitably have an impact on education. This article reviews the background of ubiquitous computing and current research projects done involving educational *ubicom*. Finally it explores how *ubicom* may and may not change education in both formal and informal settings and discusses the potential advantages and disadvantages.

Introduction

“Ubiquitous computing” is a vision of how people will interact with computers and how those computers will fit into the environment in the future. Researchers have often imagined how ubiquitous computing will shape the office environment and how it will function in the business world (Johanson, Fox, & Winograd, 2002). Considerable work is now underway on how daily life in the home could benefit from ubiquitous technology, including real *ubicom* environments created and used on a wider scale in both Singapore and Korea (Bell & Dourish, 2007).

However, less work has been done on what ubiquitous computing might do for education, either in classrooms or more informal settings. If we assume that some version of ubiquitous computing will one day be a reality, we must consider how this will affect all areas of society, including education.

This article first explains the basic principles of ubiquitous computing and which of its features apply to an educational environment. Next, research on using ubiquitous technology for learning is summarized, and some advantages and disadvantages are identified. Finally, the article explores visions of what classrooms and informal learning opportunities might resemble when they involve ubiquitous computing.

What Is Ubiquitous Computing?

The concept of ubiquitous computing, or “*ubicom*,” began with Mark Weiser’s vision outlined in his article,

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“The Computer for the 21st Century” (Weiser, 1991). He proposed a completely different way for humans to interact with computers, by moving away from the traditional method of accessing everything through the desktop and instead designing interfaces that are more similar to things we do in the physical world. In this vision of the future, small location-aware computers are embedded into nearly everything we use, and they are networked so that they can communicate with each other. Instead of having only one “portal” with which to interact with a network, for example, a computer or PDA, we will access interfaces to interact with many devices in our environments. Once this type of connected environment infrastructure is set up and the interfaces are intuitive enough, computers will become “invisible,” essentially blending into the periphery. People will be so used to using computers in everything they do that they will continue to use them without thinking about it. In the *ubicom* environment people don’t consciously think, “I’m going to use a computer for that.” Instead they naturally take advantage of the computers in their environment to accomplish their daily tasks.

According to Weiser, ubiquitous computing is the next logical step in the progression of computer use (Weiser & Brown, 1996). The first mainframe computers were large and expensive and therefore one computer was shared by many users. Then personal computers became more affordable and portable and enabled each person to have his or her own computer to store all personal files and programs. Weiser imagined the next step to be for each person to have control over many computers or devices, all able to communicate seamlessly with one another and with their user. This way, whereas most of the time such devices would be available but able to disappear into the periphery, when one was needed, the user could easily bring it into the center of his or her attention.

What Is Not Ubiquitous Computing?

Today, it would seem that Weiser’s prediction of one person having control over many computerized devices might be beginning to come true. Many people do have their own personal collection of devices, including a laptop, cell phone, mp3 player, PDA, GPS, etc. These devices can be brought and used anywhere, even connected to the Internet almost everywhere, and as a result, many people see them as ubiquitous. However, according to Weiser’s vision, labeling these mobile technologies as ubiquitous technologies is a misuse of the term.

First of all, these devices are not connected to each other and do not communicate with each other, which is one of *ubicom*’s important characteristics. Many gadgets we use can be hooked up to a personal computer, but doing this is a separate action taken by the user, not an inherent function of the device itself. Second, these devices are all quite personal and must be carried with someone if they want to use them somewhere else. An important principle of *ubicom* is that the computers are ubiquitous because they are part of the environment and as a result the same

information can be accessed from the home, school, office, car, or perhaps many other places, without having to carry an entire laptop around. Third, each of the devices we currently use still requires the user to focus attention on the screen of one device at a time, preventing them from being available in the user's peripheral attention, as Weiser and Brown (1995) had envisioned.

How Will Ubicomp's Features Fit into an Educational Environment?

The concept of ubiquitous computing has many different features, including natural interfaces, context-awareness, and capture and access capabilities (Abowd & Mynatt, 2000). When imagining how it might work in various settings, such as offices, homes, communities, or in our case schools and education, it is important to consider each of these features and how they could affect that environment and the activities people are doing.

We must consider what infrastructure must already be in place for a classroom to utilize ubiquitous computing technology. The electronics in the classroom, such as any computers, TVs, or clocks, would be much the same, but all would have the capability to communicate with other devices. In addition, many other items, like chairs, blocks, or flashcards, would also have small computers embedded in them. Still other items, for example, books, paper, and blackboards, might be replaced by digital versions that serve the same purpose but with increased functionality. Also, surveillance cameras, microphones, sensors, and other monitoring devices not usually found in classrooms might be added so that the computers could collect information about what is happening. Finally, "tangible interfaces," methods of interacting with a computer by manipulating physical objects (Ishii & Ullmer, 1997), and "smart objects," things that know about their surroundings, would become very useful in a learning environment as well. These various types of devices would know what the other devices in the room were doing, and they would also be connected to other classrooms, other schools, parents' offices, and potentially anywhere else with a ubicomp system connected to the Internet.

How Have Aspects of Ubicomp Been Used in Education?

Because true ubicomp technology does not exist yet, as described in Weiser's original vision, we have not seen how it would work in an educational setting. Crawford's vision of classroom teaching with mobile devices for every student (Crawford, 2007) and Lin's examples of informal mobile learning in museums and developing countries (Lin, 2007) provide an interesting look at what might be coming in the near future. However, the fact that the learners in these situations are necessarily tied to their handheld devices instead of using interfaces built into the environment illustrates the difference between mobile devices and true ubiquitous computing.

Apart from these more reachable scenarios, a number of

experiments have introduced elements of truly ubiquitous computing into a classroom setting. One interesting initiative is the Smart Kindergarten project at UCLA (Chen *et al.*, 2002), in which researchers are developing a smart classroom that can monitor interactions between students, teachers, and objects, and can also capture speech, using unobtrusive sensor technology. The teacher can tell the system to watch for certain things, such as pronunciation or grammar, in certain students, record their speech, and review it later to assess their progress. If implemented well, a smart kindergarten classroom could provide the teacher with many new capabilities, such as tracking students' speech, time spent in certain areas, and interactions with other students. Though such a classroom has potential, it has yet to be seen whether this type of ubicomp function would really improve a teacher's ability to teach, or whether it would simply bring about information overload.

The Ambient Wood project takes the ubiquitous computing concept outdoors to a woodland augmented with sensors that detect when students are near and provide them with timely information (Rogers *et al.*, 2005). Students use tools to gather data and test their hypotheses, and this data is simultaneously compiled into a visual display. Since the network is aware of various locations in the wood, locations of students, readings made with tools, and other information, students can simultaneously explore the wood and reflect on what they have found, instead of waiting to return to the classroom. This type of learning experience may broaden children's understandings and help them make more connections between the world and the classroom.

Besides use in the classroom, ubiquitous computing elements have also been used in informal educational settings, such as the "Re-tracing the Past" exhibit at the Hunt Museum in Limerick, Ireland (Hall & Bannon, 2006). In the exhibit, various sensor and RFID technologies let children handle objects that provided relevant information about themselves and their history. Visitors could also record their own thoughts and add them to the exhibit. Students learned well through being able to handle the objects and bring them to different locations to find information, and from the ability to collaborate and discuss what they were seeing. This is an interesting use of ubiquitous technology components because it combines the advantages of experiential learning and tactual interaction with those of a computer's information storage and multimedia capabilities.

Another element of ubiquitous technology is tangible interfaces which can be used on smart objects. One way to use this concept is in the creation of smart toys. Plowman and Luckin (2004) designed a computerized doll, with a limited vocabulary, which could talk to children, and interact with computer software which could be used at the same time. Although this particular smart toy was not found to be terribly successful, parents did see some educational value, and the dolls were observed to facilitate peer interaction. So we see that there is potential for smart

toys connected to a network to help scaffold children's learning of certain skills.

For the most part, these experiments have not reached any conclusions about how ubiquitous computing will benefit education, though they have uncovered some important guidelines in the design of these systems. It will not be possible to see its effect on teaching and learning until more teachers are teaching in ubicomp classrooms on a daily basis, which is probably far in the future. Although there have been some successful prototypes, it is unlikely that ubiquitous computing would be implemented in classrooms before it becomes widespread in other arenas, such as homes and businesses. In order to imagine what the future of technology in education might be, this article combines our knowledge of the original concept of ubiquitous computing with what we know to be possible from projects that have already been designed and implemented.

Imagining the Future of Educational Ubiquitous Computing

The first vignette, which takes place in a kindergarten classroom, shows how ubiquitous computing might be used with younger children. It could enhance manipulatives, increase student interaction, and assist the teacher with classroom management, although it also creates unique concerns about security and privacy.

The Ubicomp Kindergarten. Ms. Marks is in her kindergarten classroom as the children start to arrive. As the children come in, they take their badges out of their cubbies and Ms. Marks helps them pin them to their clothing. These badges have sensors in them so that the ubiquitous computing system in the classroom can keep track of each student. Once all the students are there, Ms. Marks has them sit on the rug together for story time. Instead of all the children trying to see one small storybook in the teacher's hands, the story is displayed on an electronic board on the wall, which is large enough for everyone to see easily. Today Ms. Marks is creating an interactive story with her students, which means the e-book contains the outline of the story, and the children will customize it.

Today's story is about Arthur, and the first step is to choose what he looks like. Ms. Marks calls on Sally. Sally stands up and says, "Arthur has a red shirt." On the board, Arthur's shirt changes to red. The sensor on Sally's badge is capturing her speech, and the story software processes it and updates the board display. Ms. Marks begins to read the story. "Arthur was dancing in the living room. Molly, show us how Arthur danced." Molly gets up and does a little dance, which makes the class giggle. Her movements are captured by the video cameras in the room and mapped to the image of Arthur, who imitates Molly's moves. All the children laugh louder. Ms. Marks goes through the whole story this way, calling on students to contribute pieces of it. At the end, she saves the story with the children's input. At the end of the day, she will read the story again, and the

students will see and hear what they have authored. Ms. Marks loves that with interactive stories her students are all eager for their turn to contribute, and she notices their ideas becoming more and more creative. Everyone is very proud of the masterpiece they have created as a team.

Now it's time for activities, and Ms. Marks has various areas available to the children. Jenny and Carl are playing with blocks. Each block has a sensor in it, so it knows its own shape and size as well as what other blocks it is touching. This information is sent to a nearby screen, which displays the current block formation. By touching the screen, children can experiment with adding or taking away blocks to see what would happen if they did that to their actual structure. When the actual structure eventually falls down, they can see a slow-motion replay of it on the screen, and they can go back and watch the progression of their building as they were building it. The block corner can tell which students are working there, and this information is all saved to the correct student's account. Today Ms. Marks has asked Jenny and Carl to build a bridge and find out how long they can possibly make it. Each time their bridge falls down, they try another one. At the end, Ms. Marks will look through the records of all their structures with them, and they will find out how long their longest bridge was and see if they can make it again.

On the other side of the room, Elena is using some animal flashcards. She picks up a card with a picture of a giraffe and says, "It's a giraffe." The card's light turns green because she correctly identified the animal. Next she picks up a sloth card. She has never seen this animal before but guesses that it might be a monkey. The light doesn't turn green, and Elena can't quite read the word on the card, so she takes it over to the electronic board. When she holds it near the board, it tells her this animal is called a sloth, some information about sloths is called up, and a short video plays.

A few other students notice the video and come over. They can't believe how slowly sloths move! Ms. Marks sees what they've discovered and talks to them about how different animals live different lifestyles. Then, after a little discussion, the students go back to their activities. Ms. Marks enjoys these impromptu lessons. She loves to see her students exploring and asking questions about things they have found on their own, and she is happy that they can find their own answers right away instead of having to wait for her to find time to plan a lesson around it.

At a table in the front of the room, several students are practicing writing their letters. Matt can write his name, but he has a hard time with letters that are not in his name. On the table in front of him is an electronic paper, which he writes on with an electronic pen. At the top of the paper are some letters Ms. Marks has written for him to practice. He writes these letters in a row on his paper. To help Matt through the letters on his own, the computer is constantly evaluating his writing and can later notify his teacher of which letters he may be having the most trouble with. However, this time Ms. Marks looks over and sees that he

has written some better than others. She uses her own pen to trace some of his letters, showing him which ones are good and which ones need improvement. The marks she makes with her pen are saved into a different layer of the document so that once she is done showing Matt, she can hide what she has written or fade it to be lighter than his writing. This way he can check how the teacher has written the letters if he needs to but he sees that his letters are still the most important ones on the paper.

At the end of the activity time, the students put away their materials and gather on the rug because it's almost time for their music teacher to arrive. Ms. Marks sits down at her desk to go through some of the large amounts of student data that are collected and stored throughout the day. As the music teacher comes in and starts singing with the class, utilizing their microphones to let them see a visualization of the rhythm, Ms. Marks thinks about how it is a very different atmosphere than when she was in school. The ubicomp system may not change everything about the way she teaches, but it does help the classroom run more smoothly and her students have a lot more resources at their fingertips.

The second vignette shows what kind of learning might be possible outside the classroom. The ubiquitous technology here encourages independent inquiry and discovery and helps make connections between topics in school and the real world. It also provides immediate access to many information sources.

Informal Learning. Annie is 12 years old, and she is out running errands with her mom. They are at the grocery store, and as always her mom said she would be quick, just picking up a few things, but she is taking "forever." Annie is reading the labels of different things on the shelf. She is in the soda aisle and wonders how they make diet soda different from regular. She picks up diet Coke and reads the ingredients. There are a few words she doesn't recognize, so she reaches into her pocket and takes out a gadget that looks something like a small pen. She scans the tip of the pen over the unknown word, and the word is displayed on the screen on the side of the pen. The pen then connects to its database through wireless signal, which is pretty much everywhere these days, and it finds the pronunciation and definition of the word. It shows the definition on a slightly larger screen which Annie pulls out from the pen, and it plays an audio clip of the word: Aspartame. Annie finds out that it's an artificial sweetener, which answers her question. She also reads that aspartame is 200 times sweeter than sugar and it got its name because it was found in asparagus. Gross. This little gadget always tells her random facts like that. So, she wonders, is this aspartame what makes diet soda diet? Must be. But she wants to check it out. She asks the pen to look for other products that have this ingredient in them. The pen connects to the supermarket's database, which keeps track of all the ingredients and other information about all the products in the store in order to

help customers find things easily. The shelf under each product has a small LED light, and some of the lights near Annie start flashing, indicating that those items contain aspartame. Sure enough, as she walks down the aisle, she sees that all the blinking products are diet this or diet that. Interesting discovery. Now all she has to do is convince her mom to buy her some of that soda.

Annie finds her mom one aisle over, but she's still not done with her shopping. Annie is starting to get bored, so her mom suggests she play one of the games from her digital pen. Annie thinks she has played them all but checks the games screen and finds that new games have appeared. There's one that looks like some kind of treasure hunt, and she reads the instructions for that one. It says she has two minutes to find as many things that are high in calcium as she can. To get a head start, she finds the milk before she starts the game. She knows that's got a lot of calcium. She presses the start button and two minutes start counting down. She scans her pen over the milk's bar code and gets 50 points! The digital pen is using the store's information about product bar codes together with its own information about calcium-rich foods. Next, Annie figures cheese is made from milk, so it must have lots of calcium too. She gets another 50 points. She goes through lots of things in the dairy section, but pretty soon she's run out. What else has calcium? She looks around and sees a carton of orange juice that says it has calcium on the label. Weird, she never noticed that orange juice had calcium before. She scans that one too. Now she's near the produce and she sees some whitish squash. She thinks it might be white because it has calcium so she scans its label. Oh no, minus 20 points, it's not right. What else? She looks around but is just not sure. After half a minute of no action, the pen starts to give her hints about which direction to move. She thinks its pointing her towards the carrots so she scans them. No luck. Next to that is the broccoli, she figures it's worth a try. 30 points! Who knew broccoli was full of calcium? The pen makes a buzzing sound and time is up. Annie thinks she can do better and gets ready to try again. She's going to learn all the calcium-rich foods and next time she comes with her older brother she'll race him and win!

After another round or two, her mom finds her and says it's time to go. They check out and walk out to the car. After a short drive, they arrive at the bank. There is a line for the teller and her mom stands at the end of it. Annie circles around the room but there is nothing interesting here. Suddenly her digital pen starts making a beeping sound. She checks it and sees that it says it has found something she might be interested in. Yeah right, like there's anything interesting in here. Each item in the room contains digital data about its contents, and the pen has scanned this information and found an object that matches either something Annie has learned in school or something else she is interested in. It guides her to a table in the middle of the room with pamphlets on it. It is pointing to one in particular about interest rates. Annie thinks, who cares, but picks it up and flips through it. Hey, wait a

minute! She realizes that it's talking about interest that is compounded monthly or annually and remembers that her math teacher, Mr. Finkel, was talking about that just last week. He made them all calculate these stupid equations about interest that made no sense and were totally useless. Annie didn't see what it was for then, but now she wonders if she could actually use that formula to find out how much interest her mom is getting from this bank. Maybe Mr. Finkel was talking about something useful—after all, knowing how much free money you can get could come in handy.

Her mom has just finished up with the teller, and when she comes over, Annie tells her about her latest discovery. She is proud that she knows what interest rates are and how to calculate the interest and everything. Her mom is very impressed, since Annie doesn't usually bring up things she's learning in school on her own, and she knows that if she herself had tried to get Annie to read something like this, the only result would be a big roll of her eyes. She sees many ways that this digital pen is really helping her daughter explore the world on her own, by making discoveries and connections that she can be proud of.

Analysis and Conclusion

After reviewing the research being done on ubiquitous computing for educational purposes and exploring what ubicomp learning might look like in the future, the question to be answered is what would this technology bring to learning and teaching? Clearly, some aspects of the classroom environment would be transformed, but the basic views and methods of teaching may still remain (Pausch, 2002). Some noticeable advantages are seen in the scenarios presented. For example, computers are everywhere and they provide natural interfaces for interaction which make it much easier for both teachers and students to take advantage of the technology. Natural interfaces, which are present in the electronic paper and pen, the digital blocks, and many other objects, make it simple for everyone to access the computers and incorporate them into everyday classroom activities. The ubiquity of the computers and the information they can access enable students to find their own answers to their questions, wherever they are. Like the girl in the supermarket, this will encourage and motivate people to explore and learn on their own.

Assessment is another broad area where ubicomp classrooms can be very useful. Because of ubicomp's "capture and access" capabilities, all student work and even their actions can be recorded for later reference. Of course, this can be both a blessing and a curse because teachers may not have the time to look through all of their data. However, if sophisticated software could be developed to recognize trends in the students' work and summarize these for the teacher, this could be a very powerful tool.

Aside from these main areas, many of the advantages ubicomp provides fall under the category of convenience. Kids can look things up wherever they go, teachers get help

with discipline, and everyone will be assisted in other similar ways. Like any new technology, this can take some of the workload from humans, doing things more efficiently and letting them concentrate on more complex tasks.

Naturally, there are also some significant disadvantages to learning in a ubicomp world. Accessibility was not discussed here, but in reality it will certainly be a pressing issue. The theory is that as computers and devices become less and less expensive, ubicomp environments will be able to be implemented in any setting. However, inevitably there will be certain people or places that do not have the resources to install and maintain such a system. Considering that ubicomp's most important characteristic is that it is ubiquitous, and many of its functions are designed based on this assumption, anyone who does not have access to these tools and this network could be at a serious disadvantage. In addition, even for those with access, no technology works perfectly all the time, and if ubicomp is so "invisible" that people use it constantly without thinking, then any breakdown in the system would cause a significant disturbance. Greenfield (2004) addresses this danger with his guidelines for the design of a socially usable ubicomp system.

Perhaps the greatest concerns, not addressed explicitly here but discussed in more detail by Langheinrich (2001), are those of privacy and security. As we saw in the kindergarten classroom, the ubiquitous sensors, cameras, and computers can practically capture a student's every move and store them indefinitely. While children normally have nothing to hide, having everything networked and frequently storing and passing personal information creates a danger of it being hacked into, stolen, or modified. For many even a secure system may seem like an infringement on their privacy and therefore inappropriate for their children's classrooms, and the added security risk may make the technology unacceptable. Unfortunately, the nature of ubicomp's capabilities makes it likely that the future will present us with this type of dilemma. Once ubicomp becomes a reality, there will be solutions to many of these issues, but they are valid concerns and certainly could prevent widespread adoption of ubiquitous computing systems even once they are fully developed. As with any new technology, users and society will have to weigh the benefits against the risks as it emerges.

In conclusion, a ubicomp world, as we have imagined it, would certainly add a lot of convenience to schools and learning, but it would not intrinsically add value. Assessment may become easier and more accurate, administrative tasks would not take up class time, and there would be easier access to information and resources. However, these capabilities in and of themselves do not necessarily make teachers teach better or students learn more deeply. Taking advantage of the opportunities ubicomp provides to create educational activities would still be up to the teacher. The technology-infused environment is a tool that can be leveraged to teach skills

not often taught and give more power and opportunities to the learners, but on its own it does not change the way we teach or learn. Ultimately, like any emerging technology, ubiquitous computing has great potential, but requires a great teacher to realize that potential. □

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Things to Say: Future Applications of Smart Objects in Learning

Kevin Preis

Smart object technology allows users to know something in real time about the physical objects in their presence. Each object, from cereal boxes to skyscrapers, becomes a source of information with which users can interact. Through a series of usage scenarios, the article explores the potential impact of smart objects on learning in formal and informal settings.

Introduction

The labeling of Internet data is a growing phenomenon among online users, with 28% of American adults having “tagged” content as of December 2006 (Rainie, 2007). Tagging is a way of categorizing the massive amount of online data in ways that make it meaningful to individuals. Millions of (online) objects gain context through the actions of these users, from photos to videos to Websites.

This model of learning through labeling is similar to the design of smart objects, a developing technology. Stated broadly, smart objects offer the ability to know something in real time about a physical item that is in the user's presence (E. Klopfer, personal communication, March 5, 2007; A. Ganz, personal communication, March 5, 2007). Instead of labeling online content, a smart object is created when an item—a painting, a building, a box of cereal—is “tagged” with an electronic device. For example, as noted in the Introduction by Dede, a tree in Harvard Yard might be tagged with information about its botanical characteristics. The tree might also offer to show a historic image of Harvard Yard at the time of its planting.

Information about the object is available through its electronic tag, making the object meaningful to other users. While smart objects have been implemented only in limited settings to date, one day, they might allow people to reference information about purchases directly from the products themselves, get data about their environment from the places they go, and learn about the world, from the smallest garden to the largest monument, by asking it questions. *These “things” will have things to say.*

A user connects to a smart object through a handheld

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device in a relationship Rukzio *et al.* (2006) describe as “physical mobile interaction.” When the user encounters the smart object, he or she draws an identifier from it to the handheld, and the identifier determines what information the handheld will exhibit through its interface. This information does not necessarily need to be stored on the tag. Siegemund, Floerkemeier, and Vogt (2005) suggest that the handheld can draw information wirelessly from a background infrastructure, such as an online database. As mobile devices grow in power and sophistication, smart objects could trigger handhelds to show online sites, movie clips, and other media. Another new type of application not discussed here that builds on this capability is “augmented reality”; an example developed by Dede and his colleagues is presented at <http://isites.harvard.edu/icb/icb.do?keyword=harp>. Also, because of their own complexities, context-aware sensors, automation, and object manipulation fall outside of the scope of this analysis and its definition of smart objects.

Instead, this article employs usage scenarios to demonstrate how the technology lends itself to education. The “future world” in which these usage scenarios take place is based on present-day smart objects. The benefits and limitations of current technology are considered, as are the conditions necessary for wide-spread adoption of smart objects.

Technologies

As used above, the term “handheld” is meant to describe an all-in-one mobile device that has telephone, Web, and other capabilities, in addition to being able to communicate with smart objects. In the future, users might connect their handhelds with smart objects in several ways; Rukzio *et al.* (2006) explore touching, pointing, and scanning. With touching and pointing, a user brings a handheld into contact with the tag on a smart object, or aims the device at the smart object, and information is transferred. With scanning, the user’s handheld displays smart objects within a particular area, and the user chooses from among them.

The connections between the smart object’s tag, the handheld, and the background infrastructure might be made up of a variety of components. However, this interaction faces similar issues that Duff *et al.* (2005) raise about positioning technologies: cost, expense, power consumption, and form factors. Location-aware systems have utilized technologies that could be applied to smart objects, including Bluetooth, GSM, GPS, WiFi, ultrasound, and infrared (Benford *et al.*, 2005; Madhavapeddy & Tse, 2005; Otsason, Varshavsky, LaMarca, & de Lara, 2005).

Radio-frequency identification (RFID) has been used in several smart object implementations because of its advantages along some of these dimensions (Rukzio *et al.*, 2006; Siegemund, Floerkemeier, & Vogt, 2005; Want, 2003.) In addition, Nokia, Philips, and Sony are exploring Near Field Communication, which allows for the exchange of information between devices over the range of a few centimeters (NFC Forum, 2007; Portable Design, 2004). Each technology offers its own specific limitations, such as specialized infrastructure, network instability, and range.

Still, there is the potential for these systems to work in collaboration. For example, absolute positioning may be more valuable than relative positioning at times, suggesting the use of a GPS-type system in conjunction with Bluetooth and RFID (Benford *et al.*, 2005).

Necessary Conditions

It is difficult to establish a time by which the “future world” of the usage scenarios will become “now.” Product-based factors, cultural shifts, and elements beyond the scope of this analysis all play a role. The assumptions below do not underestimate these challenges. However, understanding what is required technically, socially, and financially helps in knowing how close (or far away) educational applications are.

Three assumptions are made about this future. First, tagging equipment is standard, scalable, simple, and affordable. The system envisioned requires no modification of tags and can grow to thousands of objects, an issue described in Liu, Corner, and Shenoy’s work on RFID (2006). The equipment’s low cost allows users to tag objects informally and without concern for expense. Tags operate with a standard protocol, and they are easy enough for users with only moderate technology backgrounds to employ. A parallel can be drawn with Norris, Shin, and Soloway’s (2007) examination of mobile devices in the classroom; they emphasize the importance of avoiding steep learning curves in technology.

The second assumption is that tags and handhelds are designed with appropriate security. However, certain functions have been offloaded to the handhelds so that they stand in proxy for the user. Siegemund *et al.* (2005) speak to the issue of authorization in present-day technology, and their work suggests that there could be consequences for users who have saved access codes if a handheld device were to be lost. On the other end of this relationship are rights permitted by a tag’s designer. Security measures are in place in the future so that a smart object tag cannot be removed or destroyed easily. Want (2003) points out that RFID tags can use encryption and other techniques to make them difficult to forge. This idea is extended to the usage scenarios: one tag cannot “spoof” another, authentic tag.

The third assumption is that cultural and legal norms exist to allay privacy concerns. Currently, privacy is a major issue, and one could expect it to be no less important in the future (Want, 2003). The European Union Information Society Technologies Programme created a set of guidelines related to privacy; one of its tenets holds that everything that is unnecessary for providing a service to a user should be eliminated from the interaction (Lahlou, Langheinrich, & Röcker, 2005). It is assumed, then, that similar guidelines, laws, and technological safeguards have been implemented in these scenarios to make smart object technology palatable to users.

Usage Scenarios

In these scenarios, users represent a variety of education

levels, socio-economic statuses, settings (formal and informal), academic subjects, engagement levels, and preferred styles of learning. This allows for a discussion of issues faced by learners, teachers, and designers of smart objects.

K–2nd Grades. Ms. Sue, as she was known by her class, instructed the 25 first-grade students to organize on the meeting carpet. The kids were looking at objects placed around the classroom. Some were pieces of paper with drawings on them. Others were dolls, toys, and plastic animal shapes. All of these objects had individual smart tags, attached with adhesive backings.

“Today,” Ms. Sue told them, “we’re going to learn about homophones.”

She repeated the word, and then had the class say “homophones” back to her.

Ms. Sue defined the word, telling them, “Homophones are words that sound the same but have different meanings and usually have different spellings.”

She held up a piece of plastic modeled to look like a steak. On the desk next to her were a rubber-encased scanner and a screen, which were attached to one another via a wireless connection. Ms. Sue picked up the handheld scanner and brought the plastic steak close to it so that the scanner could read its smart tag. The screen displayed the word “MEAT” in broad letters and speakers in the screen said, “MEAT.”

“This is meat,” Ms. Sue said. “Can someone use a sentence with ‘meat’?”

A few students volunteered. Ms. Sue chose a girl named Shira.

“I like to eat meat with dinner,” Shira said.

“Great!” Ms. Sue replied. She took a few more volunteers, and then held up a sketch of two people shaking hands so that all of the students could see. She scanned the tag attached to the picture, and the screen displayed the word “MEET” in broad letters. Speakers in the screen said, “MEET.”

“See how these two people meet?” Ms. Sue asked. “They’re saying hello for the first time. Can someone use a sentence with ‘meet’?”

More students offered to say their sentences. Ms. Sue provided suggestions to the class so that they understood the word in different contexts and helped them see their difference in spelling.

“Okay!” she announced. “Now, we’re going to learn in groups.”

The class had split up this way before. Group 1 would meet with Ms. Sue so that she could work through reading and vocabulary exercises with a small number of students. This way, she could gauge which of them required extra attention. Groups 2 and 3 would take turns with the scanner and screen. They would create original sentences with the tagged objects. Since some of the objects were unfamiliar, the scanner could help them to learn what ideas they represented. The handheld’s size, weight, and build were all kid-friendly and durable. Hearing the words spoken by

the screen and then seeing the words in big letters assisted students in remembering them.

Groups 4 and 5 would each go to one table on the opposite side of the classroom. Both tables had objects representing different homophone pairs: “flour” and “flower,” “hair” and “hare,” and so forth. A set of paper labels had been taped to the tables. The students would work together to place the objects under corresponding labels. Every few minutes, these groups would switch activities, allowing students exposure to the words in several contexts.

In a classroom across the hall, another teacher, Ms. Pam, was having her first-grade students work in pairs to create sentences using homophones. She could only pay half-attention to them as she was trying to fix a problem with the scanner. It was probably just as well, as she had not had time to set up the smart tags (her class before this period had run late). Also, while her colleague, Ms. Sue, had worked with the technology previously, it had been some time since the professional development day in which the scanner had been introduced, and now Ms. Pam was unfamiliar with it and the administrative software that controlled it. To make matters worse, the software’s designer had not made functions of the scanner and tags clear, and she found it hard to use. Instead, she caught herself returning to traditional methods of teaching.

Seventh Grade. For the past two weeks, Mr. Winderlich had been teaching his seventh grade math class at the Klein School in New Orleans about ratios and proportions. He worked to teach both symbolic math and ways that its concepts connected to real-life uses. The curriculum he had designed utilized smart objects, a technology that was part of the students’ daily lives from the products they consumed to the promotional campaigns to which they were exposed. In addition to math, Mr. Winderlich pushed students to think about how they used smart objects and to question the messages with which they were surrounded.

Each week, he had assigned the class a different challenge. First, students had gone to the supermarket with a parent (or taken a food item from their pantry), used their handhelds to scan the tags that the food manufacturers had attached to their products, and drawn out serving information. The students had brought this information to class and tried to determine how many boxes of the food item would feed the class of 24 one serving each. For the next challenge, Mr. Winderlich had each student scan a different parked car to get information about its capabilities. Back in the classroom, students had used their individual car information to plan trips based on the miles-per-gallon that the vehicles provided.

Today, the class would learn about scale by modeling buildings. Students filed behind Mr. Winderlich as they were led into Marion Park, across the street from the school. It was lined with offices and shops, each of which was equipped with a smart tag. Tagging buildings was common among commercial property owners as visitors or passersby could scan these tags to learn more about the

occupants inside. They could transfer information to different functions of the handheld, such as making telephone calls to the businesses or receiving electronic coupons. A user chose contexts to define which tags the handheld would automatically read, the distance at which they would be read, and how the information would be sorted and presented. For some users, it was as though the entire world was speaking to them. This led to problems when information was not appropriately tagged or when it intruded onto the handheld despite security measures.

Before stepping outdoors, Mr. Winderlich had placed a block on the students' handhelds, which permitted them to use the Klein School's wireless network but restricted access to sites and programs. In this case, he had only allowed them to see information from the city's Department of Urban Planning, which let them view building specifications. As the class walked in a rectangle around the small park, they pointed their handheld devices at each structure. Instead of information about the businesses inside, details of their construction were relayed to the devices. Students decided which buildings they wanted to use for their assignment.

The modeling was an individual exercise, since everyone had a handheld. However, not all devices were equal. A student, Rajeev Singh, looked on as his classmate, a boy named Matt, showed a group how he could make the device play music from his favorite band. Apparently, he had found an unprotected wireless network to which he could connect. When Mr. Winderlich noticed the distraction, he pulled Matt aside and talked to him about his behavior. In truth, Mr. Winderlich was disappointed in himself for not emphasizing the rules. Sometimes, technology wasn't enough to change student behavior.

Rajeev's own handheld was several generations older than newer models like Matt's. He qualified for the free/reduced lunch program at school, but his mom knew that he needed things that would help him fit in with his friends. She had made sure he had gotten the handheld for his birthday two years ago. Still, the software that it ran didn't work with tags on some buildings. Mr. Winderlich told Rajeev that his classmates could help him by transferring building plans to his handheld. Rajeev kept to himself throughout the exercise. He hadn't really understood the mathematical principles when they were taught, even though Mr. Winderlich had sat with him a few times after class. He could work the ratios in symbolic form, but in the real-life scenarios that the class was presented, other students solved the challenges more easily than he did.

Back in the classroom, students used information they had gotten from the tags and began creating scale models of the buildings, drawing them on paper with rulers and pencils. They sent the ratio figures from their models and from the original buildings—widths, heights, and lengths—to Mr. Winderlich using their handhelds. His job of grading was made easier by software that converted the answers based on the students' measurements. Mr. Winderlich noticed that Rajeev had submitted answers that were

wrong. On inspection of his model sketch, he found that the dimensions of the building, the trees, and the other objects students had been asked to include in their drawings were incorrect. As he looked over Rajeev's shoulder, the teacher wondered where the disconnect was.

High School Freshmen. Tameka, 15 years old, sat on a bench in Fredrick City, Minnesota, watching over her younger brother. She had walked with him to Spencer Park, where he could meet up with his friends. The boys were playing football now, so Tameka withdrew her handheld from her purse and began sending messages. Her own friends were at another girl's home baking cookies for a school function; they didn't have time to chat online. Eventually, Tameka shut down her handheld and looked around the park, which had fallen into disrepair since she had been younger. Then again, she had grown up and changed as well. The space used to seem huge to her, but now it didn't feel all that big, and she wondered for a moment just how large the park was. Judging measurements was a skill she had never really needed. If she wanted to know the dimensions, that information was probably embedded in the tag she had seen at the entrance to the park.

Tameka smiled, thinking about the tags. Her dad had given her a hard time about them yesterday. She and her father had been sitting at a busy restaurant, and as people had come in and out, Tameka had said, "They must make a lot of money here."

Her father had replied, "Well, let's figure it out."

Tameka had pulled out her handheld and looked around the restaurant for a tag. Her father had covered the handheld's screen. "You don't need that!" he had said to her. "Just make guesses. How much do you think it costs each person to eat here? How many people come in an hour?"

They had gone back and forth on the questions. After coming to an answer that had suited her father, he had gestured to the handheld and said, "What are you going to do someday if you don't have that thing and need to figure out stuff on your own?"

Tameka had shaken her head. "When is that going to happen?"

"It doesn't matter," he had told her. "You've got to be able to think."

It was like that sometimes, Tameka had found. Someone would ask a question and she wouldn't know the answer. Instead, she could find tools that would help to find the answer, and to her, she could accomplish the same goal.

Her eyes roved over the rest of the park. Spring was still a few months away, and instead of grass, the field was mostly compacted dirt. While looking down, she noticed that a tag had been placed at the base of the bench on which she sat.

Weird place to stick one, she thought. It was likely trash. If she scanned it, it would probably have information attached to it about the warranty for a coffee pot, completely out of context. Still, she was curious. She withdrew her handheld from her purse again and pointed it at the tag. It was called "My Park – Fredrick City."

Apparently, the tag's author was part of a nationwide effort by communities to add information to their own places. The organization, "My Place," worked with parents and teachers to develop and oversee tags in their area.

When Tameka selected the tag, a Website appeared on the handheld's screen, offering links to items called "Haley's Bench" and "Super-Fast Grass." Tameka selected "Haley's Bench" and her handheld showed her a second site with articles and photos. She learned that the seat on which she rested had been built by a high school class in honor of a parent, Mrs. Wiggin, who had passed away. Mrs. Wiggin's son had carved his initials in the back of the bench three years ago so that "a piece of him would always be with her." Tameka got up, walked behind the bench, and found the grooves of the initials. She ran her finger over them for a moment.

When she returned to her seat, she selected "Super-Fast Grass." Immediately, her handheld began blaring a pop song and showing a multimedia clip. It began with dirt like the field's, and as the music built to a crescendo, grass burst forth and pushed upwards in high speed. The movie seemed drawn from stock footage rather than shot at Spencer Park. Images showed the process by which grass developed in the soil. The movie was three minutes long, but by its end, she understood better when the field might grow again and under what conditions.

College Student and Post-College Adult. The bus that had picked up the tour group from their Israeli hotel jostled its way through a turn. The group heading for Jaffa Gate, one of several entrances to the Old City of Jerusalem. Among the passengers were David Martin and Mark Ernst. David was a nineteen-year-old college student traveling with friends on a trip organized through his university. Mark, 40 years old, and his wife, Lani, had introduced themselves to him at the hotel.

The bus pulled into a parking place near a falafel stand. Mark and Lani followed the touring students into the street and through the bustling Jaffa Gate. Their guide led them up to the nearby ramparts. These heights, formed in saffron-colored stone, allowed a view down onto the Old City. However, Mark was too far away to hear the guide's narration. He withdrew a tour book that had information about the Old City, but he found a good amount of opinion written into the so-called facts. Also, the book's section about the history of the ramparts was somewhat limited.

Mark looked over to David. The younger man was glancing from his handheld to the city scene below and then back again to the screen.

"What's up?" Mark asked.

David showed him his handheld. "There was a tag at the ramparts' entrance. Someone put together a simulation of an attack during the Crusades." On the screen, Mark saw animated soldiers overlaid onto the viewfinder's image of the city in front of them. Different structures, long gone from this place, were also simulated.

Mark said, "That's pretty impressive. I mainly use my handheld for work."

"Well," David replied, "there's a whole set of movies. Each location links to new scenarios. Some of them show clips of life at different time periods. Other links give the history of a particular street."

Mark held up his guide book. "This is pretty poor. I've got to read two or three books just to get an understanding of what's going on."

"Yeah," David said, walking along with the group. "I read the guidebooks too, but I try to use Fizznet when I look something up. It's a site that manages tagged information. It has the same rules as Wikipedia, so users have to be neutral when presenting information."

Mark smiled. "I guess Lani and I will have to tour ourselves."

Implications of Scenarios

Defining Knowledge. One of the key tensions that the scenarios explore is the difference between taking in information and being able to find and think through multiple sources to derive an answer. As they become more prevalent, smart objects may alter the cultural definition of knowledge. Dede (2005) relates to this idea in his description of neomillennial learning styles. He writes that "learning based on collectively seeking, sieving, and synthesizing experiences" will become more significant than learning through a single "best" source. This tension exists in the conversation Tameka, the high school freshman, has with her father. Technology has reached a point of such ubiquity for her that knowing pieces (perhaps large tracts) of information has become as unnecessary as knowing how to start a fire without a match. She would have to be on a deserted island to be removed from the resources that serve her needs. As a result, Tameka is very adept at identifying sources of information, but it is unclear from the scenario how well she is synthesizing these sources. Her father is concerned that she develops this skill, and he presses her to think through her daily experience.

Technology offers both benefits and challenges to learning, as in Tameka's case. The instructional framework and the guidance of parents and teachers can make the most of advantages and help limit disadvantages. As another example, Barkhuus and Dourish (2004) recognize that young people are often early adopters of digital media. This is one reason that students in the scenarios have heavy involvement with smart objects, and Mr. Winderlich uses this intrinsic motivation to teach math. Still, he insists that students question the texts with which they are surrounded, trying to develop the skill of synthesis. In informal settings, communities of practice might help to establish a baseline of trustworthy, authoritative knowledge, similar to the Fizznet system of which David Martin takes advantage.

Content and Experience. The scenarios represent a mix of media. From the math class' paper and pencils to the toys Ms. Sue uses, smart objects have not muscled out other representations of information. New technologies

must, as Barkhuus and Dourish (2004) state, “live alongside old ones.” Having fluency in a variety of media and an understanding and appreciation of how each empowers the user is one of the neomillennial skills Dede (2005) describes. In this respect, David Martin and Mark Ernst represent neomillennial and millennial skills. David seems to be comfortable in many media, including smart object technology for informal learning. Mark prefers a different format for his experience (tour books).

David’s handheld device does have obvious advantages. It allows him to access a vastly larger set of resources, and he can get these resources just-in-time. This strategy of learning while doing is in line with Gee’s 27th learning principle (2003), the “Explicit Information On-Demand and Just-in-Time Principle.” The learner receives information when he or she needs it or just at the point where the information can be best understood and used. In David’s case, the Crusades video shows the power of being in the right place with information as it is needed.

Pedagogy. Despite taking place in the future, the scenarios’ classroom exercises retain methods from current instruction. Ms. Sue teaches her first-grade class in the same way as many successful teachers of present-day, using repetition, integration, meaningful use, and rich instruction (Beck, McKeown, & Kucan, 2002; Nagy, 1988). She utilizes visual cues so that students can learn new vocabulary and word pairs in context (Higgins & Cocks, 1999; Rice & Woodsmall, 1988). The ability to hold objects that represent words assists students in learning in the usage scenario, and the scanner and screen give them more individual time with the content.

From the educator’s perspective, smart objects offer a great deal of promise, but there remain questions as to whether the value of the technology outweighs costs of implementation. Recognizing the specific advantages of a new technology is important. If schools adopted smart objects as a panacea for all challenges, teachers and students might find themselves achieving fewer, not greater, learning gains. Dede (2004) writes: “Intellectual, emotional, and social support is essential for ‘unlearning’ and for transformational re-learning that can lead to deeper behavioral changes to create next-generation educational practices.” Developing lesson plans like Ms. Sue’s, instilling classroom norms, and scaffolding independent student activity requires a new way of teaching.

Depending on the expectations of a school, it may also require new methods for evaluating teacher performance. For those schools more interested in seeing students quietly listening to a teacher’s lecture, the experience of active participation could be jarring. Tomasino, Doubek, and Ormiston’s (2007) analysis of mobile devices in schools demonstrates this concern. Also, Ms. Sue and Ms. Pam differ in their exposure to the technology, which changes their need for professional development. In many institutions, professional development is scarcely provided or ineffectual, leaving teachers without strategies for

successful pedagogy (Elmore, 2004; Hunt & Carroll, 2003). This is the case with Ms. Pam, who is unable to close the knowledge gap she has in using features of the software.

In addition to time and training constraints, financial and administrative concerns are not going to disappear. The supplies Ms. Sue needs for her homophone exercise—dolls, pieces of paper, and other toys—are likely part of her classroom budget. While screens and scanners might be supplied through a grant or careful investment, the ability to structure lesson plans with limited resources is important. The central role that standards and accountability play in U.S. public schools may also affect smart object adoption. Mr. Winderlich appears to have navigated this concern, focusing the technology on core mathematical skills.

Finally, organizations in these scenarios can influence informal education through smart objects. The “My Place” program that Tameka discovers is an example. One might imagine classrooms, youth leagues, non-profit groups, and technology developers working together to enrich community spaces. With infrastructure to protect privacy and to ensure appropriate content, educational programs like this could be scalable and low-cost.

Conclusion

As the future becomes the present, it seems clear that consumer technology will advance towards ubiquitous information access. The potential benefits of smart objects are an interactive educational experience, student engagement in learning both in and out of school, and the development of critical skills that can be applied in authentic settings. Just as significant (but perhaps not as transparent) is the pitfall of relying on smart-object technology to do what only people can. This means understanding learners’ needs, making choices that take into consideration the end user, protecting against rogue actors, and keeping the onus for education on human beings rather than technology. These decisions fall into the realm of those who would see smart-object ubiquity become a reality. If successful, the world that learners inhabit will become exceedingly more complex and rich with information. Rather than being manipulated by it, they will enter it empowered and informed. □

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Afterword

Now that you have read these two visions of what ubiquitous computing might mean for education, I want to add a few closing thoughts. Learning is a human activity quite diverse in its manifestations from person to person (Dede, in press*).

Consider three activities in which all humans engage: sleeping, eating, and bonding. One can arrange these in a continuum from simple to complex, with sleeping towards the simple end of the continuum, eating in the middle, and bonding on the complex side of this scale. People sleep in roughly similar ways; if one is designing hotel rooms as settings for sleep, while styles of decor and artifacts vary somewhat, everyone needs more or less the same conditions to foster slumber.

Eating is more diverse in nature. Individuals like to eat different foods and often seek out a range of quite disparate cuisines. People also vary considerably in the conditions under which they prefer to dine, as the broad spectrum of restaurant types attests. Bonding as a human activity is more complex still. People bond to pets, to sports teams, to individuals of the same gender and of the other gender. They bond sexually or platonically, to others similar or opposite in nature, for short or long periods of time, to a single partner or to large groups. Fostering bonding and understanding its nature are incredibly complicated activities.

Educational research strongly suggests that individual learning is as diverse and as complex as bonding, or certainly as eating. Yet theories of learning and philosophies about how to use ICT for instruction tend to treat learning like sleeping, as a simple activity relatively invariant across people, subject areas, and educational objectives. Current, widely used instructional technology applications have less variety in approach than a low-end fast-food restaurant.

What we need to succeed with all students is very interactive, individualized pedagogical strategies under some loose umbrella that allows students to navigate to what they need and helps teachers to guide learners to reach the next level of educational performance. The technological infrastructure for this is rapidly approaching. Hopefully, we as a society will have the wisdom to use ubiquitous computing to its full educational potential.

—Chris Dede

* Dede, C. (in press) Theoretical perspectives influencing the use of information technology in teaching and learning. In J. Voogt & G. Knezek, Eds., *International handbook of information technology in primary and secondary education*. New York: Springer.