Chapter 18: Computer Science: Pen-enabled Computers for the "Ubiquitous Teacher"

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What ubiquity means

The deepest and most difficult kinds of learning require a teacher who understands the student's struggle to learn. The teacher engages with the student in a beneficial feedback loop, continually probing the student's progress and adjusting her teaching to the student's needs. While computers and the internet make information ubiquitous, they cannot do the same for teachers – there are not enough of them to go around. Making learning truly ubiquitous requires that we *make teachers ubiquitous*. Our research is aimed at using two technologies – pen-enabled computers (specifically, Tablet PCs) and computer networks – to restore the essential feedback loop that is at the heart of the best teaching – not only for online courses, but for large in-person classes as well.

To understand this odd phrase – *making teachers ubiquitous* – consider why one-on-one teaching is so effective (Cohen, Kulik and Kulik 1982). In this mode, the teacher develops a keen sense of the student: what he knows, what he is capable of absorbing at any moment, how fast he can absorb it, and how best to present it. From the student's point of view, the individual tutor is "ubiquitous" in the sense that the student never feels her absence: no sooner does a question come to the student's mind than it is answered; no sooner does he learn one concept than he is presented with another.

By contrast, a teacher in a large class – such as one commonly finds in a university – is barely present to the student, even during a lecture. And her absence is keenly felt: questions go unasked; misconceptions go uncorrected; new subjects are introduced before old ones are mastered. A teacher in an online course, even a synchronous one, is at an even greater disadvantage, as are, accordingly, her students.

Being ubiquitous in a class – online or in-person – means the teacher knows each student, not just in general, but *right now*. She can sense the student's confusion, misunderstandings, lack of confidence, and disengagement, and counteract them. It is essential to the learning process that the student experience confusion and uncertainty, tries solving problems at the edge of his knowledge and abilities, and formulates questions based on these efforts. The importance of the teacher is in not letting these periods of uncertainty last longer than is helpful. Teaching is a dialectical process: The teacher explores the student's understanding and provides instruction of a kind and at a pace appropriate to that student; the student attempts to perform as the teacher wishes, expressing, in word or deed, how well the teacher is succeeding; these expressions in turn inform the teacher's next interaction with the student. Over the course of a lesson, the student becomes a better student and the teacher becomes a better teacher.

Chapter 18 in W. Cope (ed.), **Ubiquitous Learning**, U. of Illinois Press, 2008.

The employment of educational technology – more specifically, networked computers – is an attempt to raise the effective "ubiquity" of the teacher. We provide several examples below. But to set the stage a bit more, we consider how teachers in non-computerized classrooms enhance their presence to the students.

In traditional classrooms, many techniques have been developed to, in effect, emulate the dialectical process between student and tutor described above. The simplest and most common is the in-class exercise, which can range from a simple question put to the class with a request for a show of hands (a "poll") to a written problem to be handed in and graded. With in-class exercises, the teacher is attempting to give the students a task they can do, or can *almost* do, and is hoping in turn to gauge what the students are learning. It is, then, an attempt to recover "ubiquity" in the classroom. However, it falls short of reaching this goal in several ways: The exercises will not be appropriate for all students; this is inevitable as long as there is more than one student present. More fundamentally, in this procedure, the loop is rarely closed: The teacher gets only a rough idea of whether students were able to do the exercise, and if not, why not. If the exercise is a simple multiple choice poll, the responses probably do not carry very much information (even if a majority of students "vote"); if it is more complicated, it is impractical to tally the answers in class. The exercise is worthwhile in giving the students practice, keeping them engaged, and possibly helping boost their confidence. However, the teacher is left largely in the dark.

In our research, we have explored how Tablet PCs connected by a network can increase the teacher's sense of a class (what Chen 2003 called the "pulse of the classroom"), and the class's sense of the teacher's presence. Here we mean "class" in the sense of a synchronous, though possibly geographically distributed, group of students, with a human teacher. The following cases give some idea of how computers can do this. The first two represent older or less powerful technology than Tablet PCs, but still offer interesting lessons concerning this notion of ubiquity. The third is representative of our own recent work with Tablet PCs. Our research also has implications for more conventional notions of spatial and temporal ubiquity.

Case 1: PLATO

The notion that computers might be helpful in education goes back many years (Alessi and Trollip 1985). Its first major incarnation was the PLATO system developed on this campus (Woolley 1994). Its intended use was as an "intelligent tutor," giving routine drill-type instruction. It also developed into a substantial "social" network, a precursor to the modern internet. The system was not "networked" in the technical sense, but there were many terminals around campus connected to a mainframe computer, thereby giving the same effect. The community of users was large enough to develop "newsgroups" on various topics, an instant messaging system, and early versions of multiplayer online games. PLATO was eventually used in many courses on the U of I campus. It was purchased by Control Data Corporation in 1974, but continued to be used at the U of I and many other locations; running on a large mainframe computer, it was gradually displaced by the newer technologies of PCs and the internet.

When using the PLATO system, the student had no live teacher to consult. But the system itself was very much an attempt to personalize instruction – that is, to give the student the feeling of

having an ever-present teacher. Lessons were designed so that the student could not stray far from the correct path, as every question was instantaneously graded. For each question, lesson writers attempted to anticipate misconceptions and build in answers that would reveal them, so as to guide students down the most helpful instructional paths. The dream of the PLATLO developers was to provide the kind of teaching that normally comes only with a personal tutor, but both geographically and temporally ubiquitous, and at much lower cost.

PLATO-type programmed instruction now has many incarnations in a variety of fields. It is, however, little used on this campus. It is hardly surprising that it is very difficult to replace a live teacher with a machine. But some interesting lessons were learned:

- Developing lessons for a computerized tutoring system is very difficult and time-consuming. For this reason, these systems are only usable in high-volume learning situations, and, more importantly, in situations in which the subject matter is very stable. At least at the college level, courses are remarkably unstable: even when the content of the subject does not change, teaching approaches do, and lessons designed to fit into a specific course structure may become useless when that structure changes. In short, it is not clear that, when the cost of lesson *development and maintenance* is taken into account, there is actually any cost savings to be had.
- The keyboard was a limitation on the students' interaction with PLATO. The developers ended up inventing a new technology to overcome this: the computer touch screen. Input modalities are extremely important. The Tablet PC is the logical conclusion of the development of computers with natural input modalities.

Research on "intelligent tutoring systems" continues (Graesser, Chipman, Haynes and Olney 2005). Interestingly, some of this work is attempting to make the computer better emulate a human teacher, by using various observations (including biometric measurements) to deduce the pupil's state of mind (D'Mello, Craig, Gholson, Franklin, Picard and Graesser 2005; Kapoor and Picard 2005). Tablet PCs are a far richer input device than keyboards or touch screen; it is reasonable to surmise that the characteristics of a student's writing might better reveal such information.

Case 2: "Clickers"

Classroom "clickers" have recently become quite popular (Caldwell 2007), in part due to their being promoted by textbook publishers. These are devices that resemble TV remote controls and can be used in class to allow students to respond to teachers' poll questions (in-class exercises with multiple-choice answers). Recall our earlier discussion about the disadvantages of in-class exercises in which students answer by raising their hands. Because the answers provided by clickers are recorded, students tend to participate (the choice of whether to count these responses in the students' final grades is, of course, the teacher's); and because the teacher gets quantifiable results, coming from nearly all the students, she can form a clearer picture of the students' knowledge.

Though it is impossible to provide personalized instruction in the classroom, this technology does provide a better emulation of the "ubiquitous teacher" to more students than can be obtained without it.

Case 3: An introductory programming class

Introductory programming classes in college suffer from a peculiar problem: Students come into them with very different pre-existing skill levels. It is not simply that they have different abilities; many of them already know how to program. Especially in the first half of the course, it has proven extremely difficult to find a balance between the needs of the less experienced and more experienced students. A large proportion of the class inevitably feels that they, in effect, have no teacher, in that the things the teacher is saying and doing are far removed from the student's needs.

This past semester (Spring 2007), we tried an experiment. We ran a section of the class in our laboratory classroom, equipped with about 35 Tablet PCs, wirelessly networked. We employed a class structure that could not be implemented without computers. It is a partially self-paced class, with occasional "synchronization" points. The teacher plans the class as a sequence of objectives, each with the same structure: pre-flight (a brief introduction), content presentation, self-assessment, and post-flight (brief recap). The class goes through the objectives together, but they may move at different rates within an objective; in practice, most students remain in synchrony with the teacher, while some go more quickly and others lag. This structure helps keep the more advanced students from getting bored too quickly, and at the same time allows them to contribute to the learning of the other students. (Since the computer prevents them from moving on to the next objective, they spend the time helping their classmates through the current one.)

This class also incorporates a window on the teacher's computer – which we call the "teacher's dashboard" – indicating how many students are at each point in the current objective. This is an example of "passive monitoring," which we discuss further below. The class alternates between lecture time and periods when the students are working on exercises, during which the teacher can consult the dashboard.

This experiment points the way toward new kinds of class structures. In these structures, students and teachers are engaged in a variety of concurrent activities, with part or all of the class synchronizing at specified points. These classes fall somewhere between pure self-paced, "programmed" instruction and traditional teacher-led instruction. In terms of "ubiquity," the teacher has an excellent picture of the class, as the dashboard tells her where each student is. The geographically remote student participates fully, with the teacher being almost as current with the student's progress as she is with the on-site students.

Research agenda

Two technologies that are now widely available can change the way learning is done: pen-enabled computers (of which the Tablet PC is the most popular, but not the only, example) and computer networks (especially wireless networks). They can help make learning ubiquitous in the usual sense of making it possible for students to engage in learning experiences at any time and in any place. They can also move us closer to the ideal of the "ubiquitous teacher."

We believe that, in the future, classroom equipped with pen-enabled computers will be so common that an observer entering a classroom *not* so equipped will be moved to ask, "How does the teacher know what the students are doing?" For the online class, they will be, if anything, even *more* essential, as there are fewer other clues for the teacher to rely on. In terms of the teacher's ability to assess the state of the class, pen and paper offer little. Computers – specifically, computers that students use in place of paper – offer a great deal.

The relative scarcity of fully computer-equipped classrooms, the difficulty of writing software for these devices, and technical issues associated with wireless networking have made it difficult to explore the many possibilities offered by these technologies. All of these are temporary problems that we expect will be overcome within the next decade. We list some of the possible uses of the technologies, as reported by various researchers (Anderson, Anderson., Simon, Wolfman, VanDeGrift and Yashuhara 2004; Anderson, Anderson, Davis, Linnell, Prince and Razmov 2007; Mock 2004; Peiper, Warden, Chan, Capitanu and Kamin 2005; Willis and Miertschin 2004):

- The basic capabilities of pen-enabled computers are the provisions for writing, erasing, changing pen colors, selecting and copying ink, and saving ink. All represent advantages over traditional chalkboard or pen and paper.
- In a lecture class, the professor may choose to send her ink annotations to students' tablet, ensuring that they have an accurate copy of the notes. The professor may, on the other hand, decline to do so, because of reported pedagogical benefits of note-taking. Some combination of the two – such as broadcasting skeletal slides – is also possible.
- The professor can send a poll to the students, requesting their answers on a question. This is, in effect, a formalized version of hand-raising, but is better in a number of ways, including the ability to easily count who voted and how.
- Ink on a tablet can be replayed, providing a simple recording of the class.
- Students can submit questions anonymously. To keep the instructor from being overwhelmed by questions, various mechanisms could be employed: have a teaching assistant, if available, respond to questions.
- When exams are taken on the computer, it can assist in grading, including providing grade averages on individual questions, information that is extremely useful but rarely calculated.
- The classroom structure can be changed to accommodate a certain amount of freedom for the students to pace themselves, as discussed above in case 3.

A possibility we are especially excited by is "passive monitoring." The record created by students writing on their computers can be transmitted in real time to the teacher, and displayed in various ways. One use is for the teacher to quickly review the students' notes, although there is rarely time for this in class. (The technology makes it simple for the teacher to obtain the notes of all students for review after class.) Another use is to provide a summary picture of the class's writing behavior (who is writing, and how much), but this may not be very useful in itself. Perhaps the computer can find unusual or anomalous behaviors and highlight those for the teacher. In the long run, we are interested to see if the computer can analyze the data in a deeper way, using the ink to determine, for example, which students are engaged with the material and which are bored or tired.

The technology we have described can be applied to any synchronous class, but remote classes, by increasing the potential number of students, can offer even more fertile ground for innovation and investigation. At large sizes, two things happen: First, it becomes much more difficult for the teacher to know what the class is thinking, and that makes the role of passive monitoring that much more important. Chen (2003) monitored relatively small online classes using video cameras on each student, with some automated visual analysis, and that technology might also be useful here.) Second, large-scale social forces within the class begin to have an effect. Students could share their notes in real time – during the class – and answer each other's questions. A voting mechanism, such as is used on websites like Slashdot (www.slashdot.com) could be established whereby the students choose what questions are "popular" enough to get the attention of the teacher. Davis et al. (Davis 2007) describe an in-person class where a small number of students were designated as live bloggers; using Tablet PCs, they would write annotations on the lecturer's notes that the other students could view on ordinary laptops. In short, the students can form an online community *during the class*.

The asynchronous case – providing temporal ubiquity – is more challenging. It is difficult to see how a teacher can be ubiquitous if she is not even present. Yet a certain kind of ubiquity might be obtained via post hoc analysis of the student's writing. (Recall that the teacher can *play back* the student's writing, not just view the final result.) The student will not feel the teacher's presence immediately, but may feel afterwards as if the teacher must have been there to have the insights the computer has helped provide.

With all these possibilities to explore, we are currently engaged in software development and data analysis. Finding ways to develop software quickly for educational uses would be a boon to teachers and researchers alike. Given the ability to develop this software, these are the research questions that seem to us most interesting:

- How, and how much, can the technology increase the teacher's "presence" in the class – her sense of the class, and the class's sense of her?
- What kind of information about the students' state of mind can be extracted from the student's ink?
- What class structures and teaching methods work best when using this technology?
- How can the technology help education *researchers*? For example, the passive monitoring data that can be provided to the teacher might prove very useful to researchers.
- What differences arise between in-class learning, synchronous online learning, and asynchronous learning?
- What device/form factor/user interface is best for exploiting the technology?
- How do teachers and students use the computer, and how does it affect the student-teacher relationship?
- How are educational outcomes affected by this technology?
- What kind of social processes will be created in a large-scale, geographically distributed class where hundreds or thousands of students are taking notes, and how can these processes yield educational value?

Readings and References

There is now an annual meeting, Workshop on the Impact of Pen-enabled Technology on Education (WIPTE, www.purdue.edu/wipte), devoted to the use of Tablet PCs in education; proceedings of the inaugural workshop in 2006 are available in book form (Prey, Berque, and Reed 2006). Papers on this topic also appear in the annual SIGCSE (Special Interest Group on Computer Science Education) and ITiCSE (Innovation and Technology in Computer Science Education) conferences; both can be obtained from www.acm.org. The reader may also want to read http://tabletpceducation.blogspot.com/, a weblog devoted to Tablet PCs in education. The annual Eurographics Workshop on Sketch-Based Interfaces and Modeling (http://www.eg.org/sbm) is devoted to technical issues in the use of pen-enabled computers, but often with a strong education component.

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