Smart Classroom

for the Gates Center

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Introduction

The completion date of the Gates Center of Computer Science is expected to be in mid 2008. Its goal is to create home for a portion of the researchers and the undergraduate program of Carnegie Mellon University (CMU) School of Computer Science (SCS).

Because of the global presence of CMU SCS, the Gates Center should be a showcase of how pervasive technology can be used to enhance everyday life. This paper focuses on the context in classroom. A few technologies, both from literature review and personal observations are outlined. A scenario is provided to demonstrate some of the discussed technologies. Finally, a cost analysis section talks about how the technologies can be deployed economically and efficiently.
**The Gates Center**

According to the Gates Center Program Goals\(^1\), teaching and research spaces should be aesthetic, livable, and functional. The sense of excitement and vision that is commensurate with the reputation of CMU SCS should be portrayed. In particular, new information technology should be incorporated into the building that is easily adaptable and maintainable. Therefore, it is justified to have a discussion on how the information technology, especially pervasive or ubiquitous computing, can be utilized to augment activities happen in the classroom, where the undergraduate and graduate classes take place.

The completion date of the Gates Center of Computer Science is expected to be in mid 2008. As the price of computing equipment is declining over time, those which considered being high cost in today standard should be affordable by 2008. A convincing piece of evidence would be the rate of adoption of LCD monitors in recent years.

\(^1\) Available at The the Gates Center Design (Carnegie Mellon University), [http://www-2.cs.cmu.edu/~faculty/gatesBuilding/index.html](http://www-2.cs.cmu.edu/~faculty/gatesBuilding/index.html)
SmartBoard

Blackboard has long been used as a communication medium between the instructor and students in a classroom. By definition it is a reusable writing surface on which texts or drawings are made. Although computer presentation programs like Microsoft PowerPoint have become popular, the inconveniences of manual annotation and modification on the fly are its main disadvantages. Also, a lecture given in PowerPoint discourages student participation. Friendland, Knipping, Rojas and Tapia pointed out that one principal advantage of a chalkboard is that it slows the instructor, since diagrams or formulas have to be drawn. This provides time for students to digest the information and thus encourage feedback. Therefore, when adopting technology, the dynamics between teacher and students should be considered seriously.

During class

Not surprisingly, blackboard (or whiteboard) is the first thing to be modernized in a classroom (Figure 1). In fact, a number of research studies have been done on this most heavily used widget in the classroom. The electronic blackboard system, Zen, developed in Classroom 2000 project in 1997 allowed instructor to interact with the system in the same way as a traditional blackboard. Every pen stroke is time-stamped and stored in the digital format. Friedland et al. presented E-Chalk, a software system which transforms a large touch sensitive screen into a smart teaching tool. In addition to capturing

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handwriting into the digital form, E-Chalk also supports image pasting from websites and Java applet. In addition, it has an algebraic server which provides answers or graphical plots to any hand-written equations instantly using Mathematica and Maple.

![Image](image-url)

**Figure 1.** Blackboard is traditionally the main communication channel between the instructor and students

In the context of the Gates Center, being able to display images is very useful. For example, in the introductory course for computer science, showing a picture of the first mouse is more engaging and informative than sketching or verbal/textual description. Although instructors could still pass around a hardcopy of the picture or project images onto a screen using slides, both ways suffer from the time overhead. In the hardcopy case, only one student can see the picture at a time. In the projector case, time usually spent on setting up the projector or PowerPoint presentation. Integrating pictures seamlessly to the
blackboard with other materials greatly increases the efficiency of teaching. The instructor can annotate on the image conveniently.

Being able to run Java applet helps to convey dynamic ideas which cannot be captured by static texts or images. One example is a lecture about various sorting algorithms. An applet is capable of providing a strong and powerful visualization for each sorting method temporally.  

While showing image and running applet are very useful, they could already be archived by presentation programs nowadays already. What is not mentioned in the papers, however, is the instant communication that could be established by means of the SmartBoard. Suppose students will all have their laptops in class by 2008, a lot of interesting interactions can be established between the SmartBoard and the laptops. For example, voting can be carried out to have the result immediately shown on the SmartBoard. Also, student can share the SmartBoard with the instructors. Some sort of shared whiteboard application could be developed to connect students’ computers to the SmartBoard. This allows students’ responses to be directly posted on the SmartBoard, with the consent of the instructor.

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4 A collection of applets showing different sorting algorithms is available at [http://www.cs.ubc.ca/spider/harrison/Java/sorting-demo.html](http://www.cs.ubc.ca/spider/harrison/Java/sorting-demo.html)
Figure 2. A plot of an energy function provided by Mathematica during a lecture

After class

As pointed out by Abowd, capture is meaningless without access. A good blackboard system should provide an easy and universal access to the captured class materials. Adowd regards HTML as a robust and universal platform for information access. He highlights the importance of searching within the captured record to hone in on a segment of interest.

In fact, some classes at CMU have already provided recorded class video online. In illustration, Mobile and Pervasive Commerce class offered by Dr. Norman Sadeh-Koniecpol in Spring 2005 semester hosted a streaming server providing videos integrated with Microsoft PowerPoint. However, there are some issues to do it in a traditional classroom:
1) A cameraman was present throughout the classes: This increased the running cost of the lectures. Also, having an outsider with a camera prominently located at the corner of the classroom might seem intrusive to some students, thus discouraged participation.

2) Equipment setup time: Significant time was spent in setting up the recording equipment. Since the classroom was not installed with recording infrastructure, the cameraman had to set up and clean up the equipment in every class.

3) Sometimes the recording equipment stopped running. This affected the flow of the class activities.

4) Platform dependent: the streaming server supported PC machines only. At CMU, there are a significant population using non-PC machines such as Linux and Macintosh. A survey done at the University of North Carolina at Asheville (UNC) has shown that 30% of the faculty and staff work on Macs. As a result, in their smart classroom project, file server accessible by both platforms (PC and Mac) was installed. The server was named “Unity” to further emphasize that they considered both operating systems equal. The percentage of Mac users at CMU is supposed to be similar to that of UNC. Therefore, the measure adopted at UNC is of high reference value.

After all, despite the above issues, making the course contents available online is a significant step towards the vision of smart classroom. So what has been accomplished in Mobile and Pervasive Commerce class should be highly appreciated. At the same time,

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5 Mike Honeycutt, Smart Classrooms: Doing it Cheaply, Doing it Quickly, SIGUCCS 2002
we can see that a majority of the problems can be solved should it be done in a smart classroom.

When more and more lecture materials are available online, there is a need to make sure only authorized parties can have access to them. One way of doing that is the use of password. However, there are drawbacks of using password, namely password leakage. Detailed discussion on security is not provided here since it is outside the scope of the paper.
Remote Student Tele-presence

CMU has been consistently ranked by places like the U.S. News & World Report as being among the top schools in the field for both graduate and undergraduate studies, especially in the field of computer science. In addition to the main campus here in Pittsburgh, another West Coast Campus is located in Mountain View, CA and yet another Qatar Campus in Doha, Qatar. An independent company called iCarnegie Inc., which offers curriculum powered by CMU, has delivered more than 65,000 course enrollments and nearly 1,000 professional iCarnegie certifications to students in 18 countries. As we can see, there is a great demand for CMU computer science training around the world.

Currently, distance education students are completely detached from the students who are attending school lectures. The learning materials for distance education students are usually distributed through online web portals or CDs/DVDs. In the best scenario they could post messages in the online bulletin boards and get comments from fellow students or the instructor.

StudentBoard

A group at Tsinghua University has demonstrated the idea of tele-presense in classroom activities. With the use of SmartBoard discussed in the previous section, it is straightforward to capture live pen strokes and images from the physical classroom and

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7 Shi, Xie, Xu, Shi, Chen, Mao, Liu. The Smart Classroom: Merging Technologies for Seamless Tele-Education. IEEE 2003
stream it to the remote students. The innovative aspect is the presentation of live video of remote students on a fixed amount of space on the wall called StudentBoard (Figures 3 and 4).

In their design of the StudentBoard interaction, laser pointers are used as interaction tools. Using a computer-vision-based module called Laser2Cursor in the classroom, the instructor selects a remote student by aiming the laser pointer at the student image, fixing the laser spot for a second and then circling the student. The remote student is then given the floor. The instructor can revoke it at will.

Distance education strives to provide a rich, near-classroom experience to non-classroom students. The learning experience of remote students can be improved if they could participate in classroom activities. By providing innovative distance education that blends into the physical classroom, the uniqueness and strengths of our SCS is reflected (Goal #4 for the Gates Center Program Goals). In fact, as the use of webcam and microphone becomes common, the input channels of computer are no longer just limited to typing and pointing actions. With the increase of Internet bandwidth, what is discussed here might not be far-fetched in 2008.

One issue might be the scalability of the StudentBoard. Especially for CMU which has a large population of distance education students, having all of them shown on the StudentBoard might not be possible. One solution could be to randomly show students in current connection. This closely resembles the situation in a physical classroom –
instructor will not be able to see all students at once but scan across the classroom randomly. A positive side effect is to keep distance education students alert during the lecture, as they may not know when their images will be shown on the StudentBoard.

**Figure 3.** Images of the remote students are displayed on a StudentBoard located on a side wall

**Figure 4.** A close view of the StudentBoard
Context-aware Classroom

For a classroom to be smart, it should be able to understand and support the user intents. More and more instructors have moved from the use of transparency slides to the use of presentation application e.g. PowerPoint. One drawback of using presentation application is the time to set up the computer and projector. Very often it involves connecting the projector to a laptop computer (Figure 5). The fact that a digital projector requires time to warm up (typically from 15 to 25 seconds) worsens the situation.

Furthermore, especially in a small room with temporary set up projector, it is difficult to archive an undistorted, properly sized image on the projection screen (Figure 6).

Figure 5. LCD projector requires connection to the computer
Figure 6. Projected image sometimes is distorted

**Wireless transfer of presentation files**

To solve the projector setup issue, we might be able to get some insight from the printing work model. At the moment, most of the public printers in Wean Hall and Newell-Simon Hall are listed in an open directory. When a user wants to print a document through a public printer, she only has to select the printer name from the open directory (Figure 7). Print job is sent to the printer server wirelessly. In the same principle, each projector in the Gates Center could be connected to a projector-serving machine. All projector-serving machines are named and listed in an open directory. Users could then send their presentation files wirelessly to any projector-serving machines just like what we do today for printing.
When a presentation file is received, the associated projector will be woken up, the lighting of the classroom in which the projector is located dims to prepare an environment suitable for projection viewing. If the user sends the file a few minutes before the actual presentation, the disturbing projector warm-up period can be avoided.

The above implementation can be easily extended to support Short Message Service (SMS) from cell phones. For example, when a professor knows that she would be late for class minutes before the class begins, she could send a message such as “Sorry, I would be late for 10 minutes, please stay in the classroom and wait for me” to the projector server in the classroom. Once the server receives the SMS message from the professor (validated from the caller ID), the message could be projected on the screen. In this case, the projector has become a remote announcement channel for instructors.

*Projection re-calibration*
Research has been done at CMU to tackle the projection calibration problem\(^8\). Light sensors can be embedded behind a projection target, e.g. whiteboard (Figure 8). Gray-coded binary light patterns are used to calibrate the projection to the pixel level. During the demonstration, the projection calibration took less than 3 seconds to reposition the projected image on a displaced screen (Figure 9).

Figure 8. Back side of a projection target with optical fibers at each corner and a USB sensor board

Figure 9. Projected image is re-calibrated when the screen is moved
**Scenario**

The previous sections have presented the technologies that are possible and would be affordable in 2008. Now, we will show how some of the technologies can work with each other through a scenario.

Dr. Smith is a professor who is teaching a computer science class at CMU in 2009. His class takes place in a smart classroom of the Gates Center.

Dr. Smith has created some slides for today class. While he is walking his way to the classroom, he transfers his slides to the projector server “Snoopy,” which is the server located in the classroom he will be teaching.
A dialog box shows up on his handheld computer. Dr. Smith can select a particular projector in the campus network from the drop down box. The slides are sent to the projector server wirelessly through the campus WiFi.

A few minutes later, Dr. Smith arrives at the classroom. The projector has already warmed up and the lighting of the room dims to prepare for his presentation.
Dr. Smith would like to get more space for the SmartBoard. Therefore, he shifts the projection screen a little bit. Since the projector has position calibration functionality, Dr. Smith does not need to bother about repositioning the projector.

Using the SmartBoard, Dr. Smith can put up a Java applet showing various sorting algorithms. A student wonders what the first mouse is look like, so Dr. Smith pastes an image of the mouse from the Internet to the SmartBoard. Furthermore, he uses Mathematica to instantly plot out a graph from the equation he has just written. All of these appear together on the SmartBoard. Again, all the contents are saved to a disk, which can be accessed online by students and professors after class.
Penny Jacob, a student from Dubai, is attending the class at the same time using his webcam. He has questions about the materials just presented by the professor. He requests the floor through his computer. His image in the StudentBoard is highlighted. Dr. Smith gives him the floor and talks to him in front of the class during the question period of the lecture.

Because of the time constraint, no user studies have been done for the proposed scenario. A useful next step would be sharing the scenario with stakeholders, in this case instructors and students, in a focus group and eliciting their comments about the interactions.
Cost and efficiency

The implementation of most of the systems mentioned in this paper does not cost much. The projector remote access service just needs additional projector servers, and they can be any low-end computers which have decent hard-disk space and network connection. Since old computers in SCS are phased out constantly due to the improvement in technology, the computers phased out can be used as the projector servers. Therefore, the cost incurred is negligible.

The projector re-calibration function only requires the use of light sensors. A light sensor can be bought at price under $50.9

As mentioned before, the price of computing equipment drops consistently. Therefore, by 2008, most of the equipment which sounds expensive now should be affordable then. Besides, for a premium research institute like CMU, price should not be the first consideration provided that the resulting environment can foster innovation and reflect the school’s uniqueness and strength in the field. The following is a brief discussion about the costs of some of the components.

The price of the Webcam is already quite competitive nowadays. For instance, Logitech QuickCam Pro 4000, with price under US$8010, provides 640x480 live video resolution, zooming capability and easy USB hookup. It is not hard to imagine each computer will

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9 Price reference from http://www.vernier.com
be equipped with a webcam in the near future, just like microphone nowadays. This makes the tele-presense of remote students not a scientific fiction.

Most smart boards in the market only offer to save the pen strokes as a computer file such as portable document format (pdf). Such devices, for example the interactive whiteboard produced by Projected Image\textsuperscript{11} in UK, cost under US$5000 for the whole setup\textsuperscript{12}. Since the SmartBoard presented in the previous section has more functionalities like image display and Java applet support, one implementation would be using touch sensitive LCD. For an LCD with similar size as a conventional whiteboard, its price is still soaring. As a reference, a 45” LCD TV costs about US$5000\textsuperscript{13}. The one with size comparable to a whiteboard is expected to cost much more than this. However, it is predicted that the price of LCD will drop steadily in the future.

Mike Honeycutt\textsuperscript{14} has mentioned how to construct a smart classroom cheaply and quickly. Some useful comments are as follows:

1) When decide which room to convert to a smart classroom, rooms with the greatest usage should go first.

2) Buying in bulk decreases the cost because most computer suppliers provide discount for big buyer.

3) Standardization can simplify the inventory maintenance for a variety of products in a smart classroom.

\textsuperscript{11} Projected Image SMART boards, \url{http://www.projected.co.uk/smartboard.htm}

\textsuperscript{12} includes the SMART board, floor stand, wireless module, soft stylus, round eraser and USB cable

\textsuperscript{13} Sharp LC-45GD4U 45” AQUOS Flat-Panel LCD TV with Integrated HDTV Tuner

\textsuperscript{14} Mike Honeycutt. Smart Classrooms: Doing it Cheaply, Doing it Quickly. SIGUCCS 2002
4) “Limit the number of buttons” approach means there are fewer ways a class can be interrupted by the technology.

5) Computers should be restored to their original specifications after each reboot. This gives users the latitude to make changes to the operating systems without having to worry about restoring the settings after class. The paper mentioned a program called Deep Freeze from Hyper Technologies.

6) Macintosh users should be able to use PCs without regard for the operating system differences. Conversions Plus from Dataviz was used to let PC read and write Macintosh files.
Conclusion

This report discusses some of the technologies that can be used to augment classroom activities, namely:

1) SmartBoard: Communication between the instructor and students can be more dynamic because of the instant feedback. Lecture materials can be captured and available conveniently online.

2) Remote student tele-presence: The consolidation of the learning experiences of distance education students and traditional students enhances the overall environment. If it is done right, the innovative and prestigious image of CMU SCS can be strengthened.

3) Context-aware classroom: Building the classroom in a way that it understands and supports user intents can be very beneficial. This paper uses the projector case to illustrate how pervasive computing can save a lot of headache, and provide a new communication channel between the instructor and students.

A scenario has shown how the teaching cycle can be streamlined with some of the discussed technologies. This paper also points out that a lot of the proposed systems can be done cheaply. Even for those appear to be expensive in nowadays standard, they are expected to be affordable by 2008.

~ End of Paper ~