# Wireless Infrared Networking in The Duke Paperless Classroom

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During the spring semesters of 1994 and 1995, freshmen in Duke University's Department of Biomedical Engineering participated in the first full-scale classroom test of diffuse infrared (IR) networking. The experiment was known as "The Duke Paperless Classroom" and the subject of the course was introductory computer programming and numerical methods. Reported in numerous mainstream press publications (see sidebar), it's one example of cutting-edge learning environments afforded by new technologies.

This article names the products used and reports on how classroom dynamics were (and were not) changed, and which instructional strategies proved most effective in this environment.

The project used an IR networking device from Photonics called the Cooperative Transceiver. A total of 72 student volunteers purchased Macintosh PowerBooks (Models 165c and 520, in the two successive years) and carried them into the classroom twice a week. The IR devices were used to form a LocalTalk network in the classroom.

The teacher's PowerBook was attached to computer graphics projector (ViewFrame SpectraC) projected on a big screen in front of the class, replacing the chalkboard and traditional slide projectors.

Farallon's Timbuktu Pro software was utilized as it allowed the teacher to project the screen of any student's computer over the IR network onto the big screen, and also to functionally take over and control that student's keyboard and trackball. The teacher could, in effect, lean over any shoulder with the rest of the class watching. In addition, individual students could take turns operating the teacher's computer via Timbuktu as well, allowing the whole class to work together on joint projects using a single computer. No physical alteration was required to the classroom itself.

This article reports on how classroom dynamics were (and were not) changed.

## What is Diffuse Infrared Communications?

Computer clusters on campus have been connected by networks for decades, but portable computers offer new challenges to networking technologies. Wireless communications provides distinct advantages here, including the ability to:

- Provide local area networks without physically altering the classroom or limiting service to specific locations; and
- Provide access to printers or the Internet for students within large public spaces such as the library or common room, while preserving local mobility within such spaces.

The Photonics device is the first commercially available embodiment of a new wireless technology based on diffuse infrared light.[1] The device is about the size of a computer mouse and plugs into the back of a Mac PowerBook, from which it derives power. The transceiver uses the same sensor and emitter elements found in television remote controls. However, unlike line-of-site devices which must be pointed *at* each other, the diffuse IR transceiver is sensitive enough to capture reflections from ceilings and walls. This permits a large number of transceivers in a typical lecture hall to be connected simply by pointing them at the same general area of the ceiling (we tested up to 41 at once). Unlike radio devices, there is no interference from neighboring rooms.

The speed of the present IR network between Mac PowerBooks is the same as that for wired LocalTalk connections, about 230 kilobits per second (kbps). In fact, the IR hardware is completely transparent to networking and printer software, including the software built into every Macintosh. Any two Macintosh computers equipped with infrared devices may share files peer-to-peer without additional software or set-up. A similar IR device, from Photonics, inserts into a PCMCIA slot of any IBM compatible,



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and runs at approximately 1 megabit per second (Mbps). These speeds are roughly 10-40 times slower than typical Ethernet, which operates at 10 Mbps. Nonetheless, diffuse IR is fast enough to support certain important in-classroom functions, in particular, screen sharing and remote control between the teacher and a single student.

The long-range promise of diffuse IR includes higher speeds, perhaps as fast as 100 Mbps, but such systems are still experimental, expensive and power-hungry. The Photonics device is available today and only drains the battery of the notebook computer a small amount. We found Photonics' estimate of a half-hour reduction in battery life to be accurate. In our experience the devices were 100% reliable, even after being carried in freshmen knapsacks for two semesters. The current U.S. educational price for the Cooperative Transceiver is about $100.

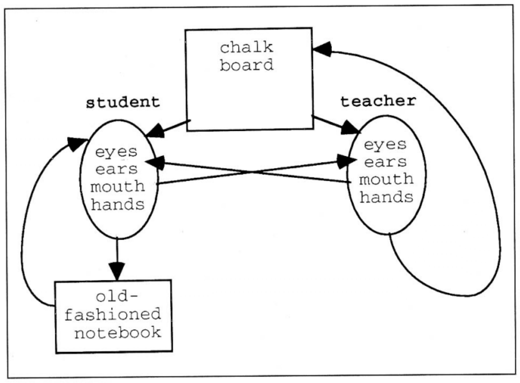


**Figure 1.** Diagram of Information Flow in the Standard Classroom

## Why Use Notebook Computers?

Student-owned computers offer the students important advantages over university-maintained clusters, including:

- Increased accessibility, and
- Greater pride and responsibility of ownership.

Students learn to use computers through their fingers, much the way musicians learn to play their instruments, or soldiers learn to use their guns. They master the equipment by learning not only how to operate it, but also to maintain and upgrade it. Many students already own computers, mostly for use in their dorm room for word processing, entertainment, and increasingly, for network access. Many colleges including Duke supply dorm rooms with connections to the Internet, and there is little doubt that students benefit from such dedicated and convenient access.

One basic choice for a student buying a computer is whether to get a desktop or notebook model. Desktop models are cheaper, faster, have better displays, more options, and fewer problems with theft and breakage. So why choose a notebook? We contend that students are a nomadic people, hunter-gatherers of education. There is still no replacement for exploring the classrooms, libraries and laboratories that comprise the physical campus. Carrying a notebook PC on this quest offers the student truly unlimited access to their own individual environment, and the ability to participate in special classrooms designed for notebook computers, if such courses are included in the curriculum.

Our primary goal was to enhance the existing human network within the classroom, while doing no harm.

## The Classroom Network

A recent article in *The New York Times* reviewing various experimental classrooms, including our own, was entitled "No Talking in Class",[2] suggesting that speech was being replaced. This was far from the truth in our class, although the teacher did find himself in some cases competing for attention with the students' computers.

Where once students who were bored with the lecture would have been doodling in the margins, instead they could be doing useful work on their computers. A certain etiquette was established to discourage the playing of games or sending "paperless airplanes" over the network to other students during class.

Our primary goal was to enhance the existing human network within the classroom, while doing no harm. Socrates had a perfectly good wireless network, functional and reliable, and it survived to the present day. This network, as shown in Figure 1, is based on the human auditory and visual systems, as well as the chalk, pencil or pen held in the human hand. Each arrow represents a channel of information.

How then should we add a computer network without detracting from the existing system? First, we decided to keep the idea of the chalk board, only in the form of the big-screen projector. Maintaining audience cohesion is best achieved by focusing people's attention on a common spot in full view. The big screen showed whatever was on the teacher's computer, and by using screen-sharing software (Timbuktu Pro) this could also include the screen of any computer in the room. In fact, several students' screens could be projected at once on a split-screen display. Plus, the teacher could control any student's computer or any student could control the teacher's machine (with the teacher's permission).

At the beginning of each class, as students walked in and opened their machines, their names were automatically added to a growing menu on the teacher's screen, from which he could choose a student simply by pointing and clicking. To assist the teacher in identifying students, their names were physically pasted in large white letters on the lids of their computers, where they could be easily seen from the front of the room.

The information flow in our classroom is shown in Figure 2. Note that none of the basic pathways in Figure 1 has been removed. Notebook computers with their small tiltable screens and minimal noise are relatively unobtrusive compared to a typical workstation cluster. A significant increase in bandwidth over the traditional classroom occurred, especially in information flowing from an individual student to the teacher and onto the big screen. Now students didn't just *ask* a question, they *showed* a question, and everyone in the class could see it.

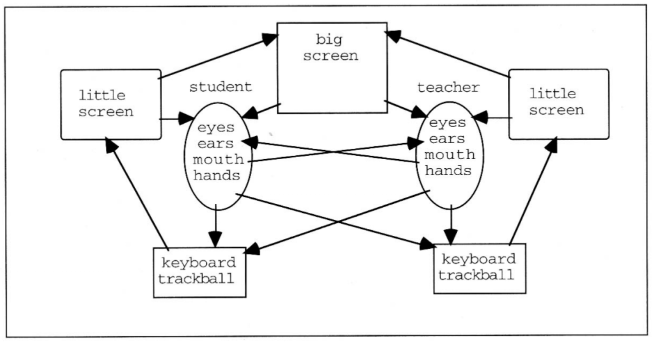


**Figure 2.** Diagram of Information Flow in the Paperless Classroom

Computer audio channels are not shown (and were not used in our experiment), although audio inputs and outputs came standard on our PowerBooks. Sporadic sound effects were, in fact, a short-lived source of amusement, and students were quickly encouraged to disable their sound effects. However, when properly integrated, audio output could actually be useful in a number of ways: to teach music, a foreign language, or even demonstrate concepts in signal processing. Audio input may be useful as well, especially as speech recognition improves.

## ■ Classroom Dynamics: Four Modes

In our two semesters of practical experience with the infrared network we have identified a number of useful teaching techniques. They may be grouped into the following four modes of operations: standard lecture, solving students' problems, building a shared project, and student demonstrations.

### Mode 1: Standard Lecture

Many times in class it was important simply to "broadcast" information to the students, a mode analogous to the standard lecture. This did not require the IR network, but relied heavily on the projection system.

Instead of using presentation software that is commonplace in the corporate world, we used the C++ compiler which the students were learning anyway as part of the course. This allowed the lecture to include the creation and modification of actual programs, demonstrating the entire act of programming as well as general use of the computer. The students could try it, right there and then.

The standard on-screen arrow controlled by the mouse served as a pointer, and highlighting blocks of text helped focus students' attention. This mode also brought new meaning to the phrase "last minute preparation," since it allowed the teacher basically to improvise from scratch.

Because this mode did not need to use the network, it allowed for "handouts" to be distributed and homework to be collected over the IR network in the background. A student in the front row was recruited so as not to tie up the teacher's machine. Timbuktu simplified the procedures by automatically distributing handouts to multiple destinations and by labeling incoming homework assignments by date and sender. Since the files in our case remained relatively small (mostly source code) the network had plenty of bandwidth for these operations.

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### Mode 2: Solving Student's Problems

It was very helpful, especially as we got things working at first, for a student to be able to raise his or her hand with a problem. The teacher then picked the student's name from the menu, and in a few seconds the student's screen appeared on the big screen. The student could then show the problem. Taking control of the student's PowerBook, the teacher (hopefully) could solve the problem, often with the help of others in the class. The student's keyboard remained active as well, sometimes leading to confusion (a situation known as "mouse wars") until the etiquette of shared control was established.

A major advantage of such *communal debugging* was that each lesson had to be taught only once, in contrast to the traditional method of the teacher walking up and down aisles solving the same bug repeatedly for many students. Communal debugging allowed the class as a whole to lean over one virtual shoulder and participate in finding and fixing the bug.

The sudden variation from one student's environment to the next was at times disconcerting, but overall, this mode was effective in helping students learn the basics. However, as the class progressed into learning the skills of programming, there was insufficient time to debug everyone's program and another mode was needed.

### Mode 3: Building a Shared Project

In the next phase, students were "volunteered" to take over the teacher's computer one at a time, and to develop new programs together as a class. This mode seemed to focus the attention of everyone by presenting a more cohesive and long-term task, and also because people knew they could be next.

The "hot seat," as it was called, had to be used with sensitivity for the potential embarrassment of unprepared students. But, in that respect it was not much worse than calling on random students in the traditional classroom. An added advantage was that students in the hot seat could try software that resided only on the teacher's machine.

**Mode 4: Student Demonstrations**

In final mode, students showed off their successes. *Show-and-Tell* was an entertaining and effortless way to come up with new material. The student authors were at hand to explain their work and receive both glory as well as constructive criticism on the finer points of programming and documentation, which even the most advanced students could use.

Show-and-Tell was useful primarily during the final month in the course. Our students had created video games with a custom software library called *reality.c*, which provides building blocks for real-time interactive simulations using spaceships, planets, suns, etc. With *reality.c* the students produced interactive graphical environments while learning about physics, mathematics and numerical methods. Although examining students' source code and documentation in this mode was very useful, the IR network sometimes had trouble keeping up with the rapidly changing graphical output of the programs, when they were actually run on the students' machines.

## Conclusions

While computer programming was an appropriate subject for our experiment, it is clear that the Paperless Classroom could also serve well for any subject in which human-computer interactions capture the intellectual or creative process. These already include such endeavors as writing, architecture, music composition, and the visual arts, where computers are well established tools of the profession. In addition, more conceptual and information-based subjects such as mathematics, history and geology are rapidly undergoing a revolution in computer-based education, and whatever software is created to replace textbooks can be shared effectively in the Paperless Classroom.

Present diffuse IR technology demonstrates sufficient bandwidth to allow remote screen projection and keyboard/trackball control of notebook computers, except perhaps in the case of rapidly changing graphics or video. Even with its speed limitations, infrared technology offers an overriding advantage to schools in terms of flexibility and financial savings, by requiring no physical alteration of the classroom itself. ■

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Timbuktu Pro; Farallon, Inc., Alameda, CA, (510) 814-5000
*reality.c*, (for Mac, MS Windows & UNIX) Zwitter Press, Chapel Hill, NC, (919) 967-6374
ViewFrame Spectra C projector; *n*VIEW, Inc., Newport News, VA, (804) 873-1354