Technology and Teaching: Learning in a High-Tech Environment Revisited

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Abstract

This paper discusses the use of computer educational technologies for teaching economic principles courses and considers the effect on student learning. Dakota State University has recently completed the integration of a trio of teaching technology initiatives into the general education curriculum, which include the economic principles courses offered by the university. These three teaching technologies are (a) the WebCT course management system, (b) a campus-wide wireless network added on top of our existing wired backbone network, and (c) a laptop initiative requiring the use of a digital pen-enabled laptop computer and digital ink-enabled software by first- and second-year students. In addition, P. Romer's Aplia course support system was also used in the author's courses.

This paper describes these technologies and their integration into the classroom. In addition to an overview of issues encountered during implementation, this study also offers a discussion of preliminary evidence as to the effectiveness of various technologies based on end-of-semester surveys. This survey data is then used to motivate the the construction of a model to provide insights into how future empirical work can better capture the impact of technological innovations in teaching on student learning, engagement, and attitude.

Therefore, the paper's other contribution to the literature is the development a theoretical model of student learning behavior. The model posits that students behave as cost-minimizers when it comes to learning, seeking enough learning to achieve their expected or desired grade in a course and then pursuing the least-cost strategy of teaching tool usage to obtain that level of learning. Therefore innovations in teaching technology change the opportunity cost, the relative price, of those teaching tools and induce changes in student behavior with respect to time on task using various tools and the optimal level of learning.

I. Introduction

This paper discusses a range of techniques and technologies that have become available to enhance the teaching of economics at the introductory level. In contrast to other recent work, this paper focuses in large measure on changes in computer hardware, especially mobile wireless computers, which have occurred in recent years. While the focus of the paper is to provide some guidance and suggestions for instructors interested in enhancing their courses with these various technologies, the author is also interested in informally evaluating the relative benefits to the students of their implementation in the future.

Dakota State University has recently completed the integration of a trio of teaching technology initiatives into the general education curriculum, which includes the economic principles courses offered by the university. These three teaching technologies are (a) the WebCT course management system, (b) a campus-wide wireless network added on top of our existing wired backbone network, and (c) the required use of a digital pen-enabled laptop computer and digital ink-enabled software (largely the Microsoft Windows operating system for tablet PCs and Office 2003 which is now digital ink-enabled and backwards-compatible). In addition, the use by this instructor of P. Romer's Aplia course support system--a commercial, Internet-based, instructional resource site with course management features designed to enhance principles of economics courses—resulted in fuller integration of Aplia's resources into these classes.

In courses taught in 2004, students in Principles of Microeconomics were exposed to an array of computer educational technologies including: Internet-based course material accessible over the wireless network (syllabus, grade reports, homework assignments via Aplia, sample problems and solutions) and made available to the class via the WebCT classroom management system, chapter reading quizzes taken over the Internet, the use of Aplia to participate in classroom experiments, and the required use of a Gateway M275 digital pen-enabled Laptop-Tablet PC hybrid computer.

The paper describes these technologies and how they were integrated into the courses. In addition to an overview of issues encountered, this study also offers a discussion of preliminary evidence as to the effectiveness of various technologies based on an informal comparison of end-of-semester surveys of the students. The conclusions drawn by this survey data analysis are then used to motivate the construction of a model to provide insights into how future empirical work can better capture the impact of technological innovations in teaching on student learning, engagement, and attitude.

This paper next offers a simple model of student learning behavior based on the idea that students employ a cost-minimization approach to learning in their courses. Stated simply, students will put in the least amount of time and effort to achieve a desired grade, ceteris paribus, and if grades are correlated with learning then by extension students are said to employ a cost-minimization approach to learning. The model suggests that educational technologies that reduce the opportunity cost of learning in a manner that advantages actives learning techniques will thereby change the trade-offs involved in achieving a desired grade and may either (a) increase student satisfaction with the course but not their overall level of learning by allowing them to achieve the desired grade at a slightly lower cost in time and effort, (b) increase both student satisfaction and overall level of learning in the course by lowering costs sufficiently to result in the achievement of a higher grade and therefore a higher level of learning, or (c) achieve an ambiguous result with respect to student satisfaction if students opt to work harder to achieve a now more easily attainable higher grade.

An experimental research methodology to test the predictions of the model is presented, i.e. to test that the use of computer educational resources changes the incentives to learn and can lead to enhanced student learning under the right conditions. The data will be collected in courses taught in 2005, pending approval by the dean and the university. Areas of exploration will be suggested and data collected for use in evaluating evidence that the role of the instructor changes in hybrid classes that have a significant technology component that involves active learning. One way to measure this is to categorize teaching technologies into essentially one of two classes:

(1) Technologies that essentially replicate elements of traditional lecture-based classroom economics instruction that largely represent passive learning instructional strategies (electronic textbook, streaming video lectures, etc.);

(2) Technologies that offer the student the opportunity to perform a task, complete an assessment, or access information that is not normally performed in a traditional

lecture-based environment and tend towards more active learning strategies (online experiments, web-based assignments and group work, etc.).

By focusing on the latter set of technologies and incorporating self-assessment tools and techniques for the both the instructor and the students, it is expected that significant benefits will arise in the measurement of student learning, engagement, and attitude.

This paper is therefore organized as follows. Section II provides a brief review of the current literature on teaching with technology. Section III describes the distinct attributes of the university computing environment and the technologies that were employed in the author's courses in 2004 with some comments on the experience. Section IV develops a stylized cost minimization model of student learning behavior and considers the implication to those incorporating technology to enhance learning. Section V discusses the results from student attitude surveys to provide a rough gauge of the effectiveness of the educational technologies employed in the author's courses this past year.[1] Section VI concludes with a brief summary.

II. Literature Review

The research on the use of computer technology to improve student learning seems to be evolving toward a consensus that, with appropriate use, educational computer technology can have a significant positive effects on student learning and attitude toward economics. Many reasons have been advanced to explain why that the use of computer technology in the teaching of economics is an area of significant potential benefit. For example, augmenting a class to include educational uses of the Internet has long been noted as one such area. Becker (2000, p. 113) identifies pedagogy involving the use of the Internet as one of two types that "seem especially well-suited to the teaching of economics." Becker then comments on the Internet's potential to involve distance learners interactively in the educational process. Indeed, the Internet's potential benefits are not limited to distance education--face-to-face learners in the classroom/lecture

[1] The surveys were conducted by the instructor via WebCT. Although the students were told they were anonymous and would not have an impact on their grade, these are not the official end-of-semester student evaluation instruments. Student course and instructor evaluation data, called Student Opinion Surveys at DSU, are not yet available for 2004 as of this writing.

environment can also benefit substantially from use of the Internet. The ability to access up-to-date data, news, and analysis on current events (oil price shocks, Fed interest rate hikes, etc.) and recurring themes of economic interest, such as deficit reduction, funding Social Security, the increasing share of health-related expenditures, the declining U.S. savings rate, and the ever-expanding trade deficit to name but a few, cannot help but spark the interest of the students and empower them to explore these issues outside the classroom at minimal effort. This provides an effective pedagogical "boost" to the effectiveness of the lecture, the dominant teaching method in economics (Becker and Watts, 1996,1998).

The use of the Web[2] to promote interest in economics is well recognized in the literature. Simkins (1999) provides a concise characterization of the primary benefits of the Web as a rich source of economic news, data and information, that can be presented in a variety of formats (video news clips, audio speeches, and primary source written material) and as a method of broadening the education experience beyond traditional teaching methods through the use of student-authored Web-based magazines, online stock-market trading games, Web-based macro- and microeconomic simulations, and Internet-based tutorials. (See Porter, Riley, and Ruffer (2004) for an excellent summary of many such online resources, including their URLs as of mid-2004.) In addition, course web sites and e-mail can provide effective course information dissemination including information on grades and course standing, homework assignments and due dates, discussion forums among students for course topics, and opportunities for question and answer sessions with the faculty member outside of office and class meeting hours. All of these uses of the web have been described as exerting a positive influence on students' attitudes toward economics to some degree in the literature. (See Manning (1996), Agarwal and Day (1998) and Parks (1999) for examples of the use of these technologies, among others.) Therefore, there is solid evidence that students achieve relatively more satisfaction from Internet use in their courses. This largely holds for other uses of technology—today's relatively computer-savvy students enjoy employing computers for educational use in addition to more common non-educational uses.

[2] While acknowledging that the World Wide Web is a subset of the Internet, the terms "Internet" and "Web" are used interchangeably in this paper.

The effect of educational technology use on student learning tends to indicate smaller magnitude but significantly positive results in many cases, but this is far from universal. In the past, the most frequently sited comprehensive study (Russell (1997))--in a study that summarizes the results of nearly 250 research reports, studies and papers--found that the vast majority fail to refute the hypothesis that there is "no significant difference" between the learning achievement of traditional classroom education and those students who are taught using technology.[3]

However, these results should be qualified due to inherent problems with meta-analysis and other issues. (See Myles Boylan (2004) for a discussion.) Recently, in a well designed, comprehensive study of technology and non-technology instruction at 15 institutions over two semesters, Sosin, Blecha, Agarwal, Bartlett, and Daniel (2004) examine the efficiency of a variety of teaching technologies on student learning. They find a significant impact on student learning in aggregate. They also examine the impact on student learning of specific types of technology. Sosin et al. (2004, pg. 255) conclude, "Using institutional fixed-effects regressions, we find that technology usage, as measured by a dichotomous variable comparing classes using extensive technology to those using little technology, has a small but positive effect on student performance. More importantly, our results using separate variable for various types of technology use indicate that some uses enhance student performance and some do not. Likewise different uses have different effects for micro- and macroeconomic courses."

The issue of different technologies having differing effects on learning is raised in another recent paper as well. Brown and Liedholm (2004) present a choice theory where students' cognitive strategies determine the selection and use of learning tools. They then develop a simple comparative advantage-based graphical model of learning gain using different technology-based and non-technology based tools and obtain the typical 'partial

[3] Some see this as a tacit endorsement of technology by arguing that essentially a "Hippocratic Oath" approach to education is acceptable; as long as we "do no harm," the use of technology in teaching can be supported. I continue to believe that economists do not find this line of reasoning convincing on two fundamental grounds: First, the additional costs involved in any investment in the use of technology must be justified by an expected future stream of benefits, even in education. Second, as any good econometrics student can tell you, failing to reject the null hypothesis of "no significant difference" does not imply we can accept it as true. Our test may merely not have enough power to reject the null in favor of the other tail, i.e. that the students are slightly worse off. It is especially important to remember that statistical tests are biased in *favor* of the null hypothesis.

specialization' result in the face of increasing opportunity cost: Students will tend to make use of a variety of teaching tools, but will specialize (partially) in those tools for which they have a comparative advantage. In their empirical examination of student use of technology tools used in the courses they study, they find that students made use of all the tools and in fact each tool was favored by at least some students. As they found no evidence of correlation between performance and tool choice, they conclude that there is no reason for instructors to favor the use of one tool over another. They conclude,

> In terms of course design, our suggestion is to include additional tools in a course rather than look for tools to exclude. But this advice should be tempered with the knowledge that the diversity of learning strategies calls for different kinds of tools. This suggests that the future of the hybrid course is especially bright. The hybrid allows the inclusion of many more learning tools compared with the traditional (non-technology) course while maintaining the comparative advantage of the lecture." (pg. 491)

It is interesting to note that the conclusions of these two papers hold somewhat different implications for course designers' approach to technology adoption. An implication of Sosin et al (2004) is that while technology is generally beneficial to student learning, certain teaching technologies (e.g. PowerPoint) appear to be detrimental to student learning and therefore use of these technologies should be minimized, or perhaps even avoided, in favor of other more effective technologies. Brown and Liedholm imply instead that new technologies should supplement the existing technologies already in use by the instructor because students optimally make choices of educational technologies over the set available to maximize learning. They note repeatedly that learning preferrence theory argues in favor of larger sets of educational technologies, even arguing in favor of keeping older non-computer-based technologies. They go so far as to declare "the demise of the textbook and the lecture have been greatly exaggerated." (pg. 491) In Section IV, a model is built to reconcile these conclusions that may appear at first to be inconsistent.

Another significant use of the Internet is to facilitate active learning through the use of economic experiments that are simulations of markets and other economic environments. Ball and Eckel (2004) provides an excellent summary of three sources of Internet-based classroom economic experiments: Paul Romer's commercial Aplia system, Veconlab designed by Charlie Holt, and a digital library under development by the University of Arizona called EconPort. The article focuses primarily on the first two systems. These systems are designed for both in-class and outside-of-class usage.

Aplia experiments are designed for synchronous usage, so that the students are playing with/against each other at the same time. But they do not actually have to be in the same room (or even the same country)—the Internet allows them to log in from different locations and a chat function allows the instructor and students to send messages to everyone. Aplia's experiments are very well designed to maximize ease of use by instructors, which is especially helpful for those without an extensive background in experimental economics. As a result, the outcomes usually result in what theory predicts and the Aplia experiments are well suited for use in principles courses. (There are relatively more micro-oriented experiments than macro, although a real interest rate experiment was incorporated for macroeconomics in 2004 and additional macro experiments are planned for Fall 2005.)

Aplia also receives mention in two other recent studies of teaching technology, Porter, Riley, and Ruffer (2004) and Boylan (2004). Boylan also highlights Aplia's success in overcoming the significant challenges of distribution and acceptance by gaining significant adoption in a relatively brief time period. The Aplia website claims 90,000 students at more than 290 institutions have used their materials (Boylan, pg. 419).[4]

In contrast, Veconlab offers more flexibility in the range and variation of the parameters that the instructor can set and more choices of experimental software, but does not incorporate focused problem sets or Aplia's course management system features. It is clearly intended for use by instructors with some expertise in designing and running classroom experiments and a number of experiments are available for both micro- and macroeconomics courses at all levels, principles and beyond.

An interesting solution to the difficulty of running experiments in classes with large class sizes is to make use of wireless Internet network. The wireless network hubs can be placed in or around traditional classrooms, often located above ceiling panels so as

[4] It is not mentioned if this refers specifically to the experiments. Aplia sells the experiments separately or bundled with its other course management services. From personal experience, I am aware that some instructors do not necessarily make full use of all of Aplia's functionality even when those functions are available to both instructor and students.

to be very unobtrusive. By having the participants in the experiment use a device with a wireless network card, like a laptop or handheld PDA instead of a desktop computer wired to a network, these wireless networks can be set up in the classroom removing the necessity to reserve one or more computer labs, making synchronous experiments like those described above much less time-consuming to conduct.

Bell and Eckel also discuss a wireless system developed at Virginia Tech called the Wireless Interactive Teaching System (WITS) which likely has additional features, but to my knowledge any wireless network would suffice. Ball and Eckel (2004) argue that the benefits to the students of "real-time, in-class, shared experience" (pg. 473) is important to the overall success of this pedagogical technique, enough so to warrant the adoption of the wireless methodology for large classes. Their empirical analysis of a comparison between a control group and an experiment group using the wireless in-class teaching system gave students "a stronger understanding of the core principles of economics and a greater ability to apply their understanding to new situations." (pg. 477).

Myles Boylan of the National Science Foundation recently released a comprehensive review of significant efforts, often with NSF support, in the past 15 years to incorporate various teaching technologies into courses. It is appropriate to conclude with this study since it encompasses all of the topics mentioned above. Without going into further detail, Boylan (2004) examines a wide range of innovations in economics instruction that have occurred over the years, discussing specific examples of innovations in the use of scientific instruments, course management systems, multimedia methods, online courses, PowerPoint, graphing, computational and data analysis tools (including spreadsheets and statistical software), online laboratories in the social sciences, spatial technology (GIS) in the social sciences, case studies, simulated economies, economic classroom experiments, and assessment practices and techniques. He provides a concise summary of the effectiveness of these particular development efforts: To paraphrase, while the most successful scholars successfully integrate their teaching and research, it has been their use of technology to do so that has often met with best results for student learning and engagement. In his own words,

> In my experience, the large majority of successful innovations for teaching and learning depend on (or are improved by) technology. For example, about 75% of the 27 Distinguished Teaching Scholars awards that NSF has made from 2001 to 2004 have been for computer-based (and mostly web-based) instructional technology. For the most part, these scholars did not create the basic technology they are using but, instead, employed it to good advantage to connect context with research, teaching, and learning. Thus, technological advances in instructional technology have raised the possibilities for making substantial improvements in student learning. (Pg. 406)

This study is a fairly accurate summary of the current state of knowledge of teaching with educational technology. In Section III, the educational computer technologies employed in principles courses at Dakota State University are discussed.

Section III A High Tech Teaching Environment

The focus of this study is on three principles of economics courses taught in the spring and fall of 2004 by the author. One macroeconomic principles course, hereafter referred to as the 'macro course', was taught in Spring 2004. Two sections of microeconomic principles, hereafter referred to as the 'micro courses', and by section number when necessary ('micro section 1' and 'micro section 2'), were taught in Fall 2004. Both courses can be considered hybrid courses, incorporating significant computer technology usage while retaining face-to-face lecture presentations to a significant extent.

The micro courses taught in the fall semester received progressively more substantial technology enhancements than the macro course taught in the spring. The macro course was Internet-enhanced, made use of a wireless network system installed the previous semester, and featured the use by the instructor of a slate-style tablet PC. (The students were not required to use a laptop in Spring 2004.) The Internet-enhancements took the form of extensive Internet-based course resources that were accessible via the campus WebCT course management system. The WebCT course website contained access to an announcements 'home' page; a dynamic syllabus (modified by class agreement if/when any exam dates were altered during the semester); a grade report option for all exams, homework, and Internet course assignments; a chapter-by-chapter lecture notes web page containing the links to <u>incomplete</u> chapter lecture notes created by the instructor in Microsoft Word format that allow the students to fill in key concepts, definitions, diagrams, and graphs and better follow the lecture; sample midterm and final exams (also Word format) and their answer keys; a complete set of streaming video lectures (three years out-of-date) covering the entire course and available from 'Day 1'; a link to the textbook publishers website where the students could find practice quizzes for each chapter; a link to Aplia where the weekly graded homework assignments and a matching ungraded practice assignment were assigned every one to two weeks (ten total graded assignments of varying points, low score dropped and average score used) and two online experiments conducted during the semester with graded follow-up problem sets; and lastly a links page to other sites with interesting economic content.

The two sections of microeconomics taught in the fall offered all of the Internet-based features of the macro course described above but with the following differences: The streaming videos were removed[5]; only one Aplia experiment was conducted during the semester; a WebCT-based course-specific email system was enabled for easy distribution of supplemental announcements and electronic materials to the class[6]; WebCT's quiz functionality was used to conduct two, ungraded, beginning-of-semester and end-of-semester surveys as well as to deliver graded, ten multiple-choice question, chapter reading quizzes for nine of the eleven chapters covered that semester with the low score dropped from average; a test bank provided by publisher was easily loaded into WebCT; and of course the introduction of Tablet PCs into all general education courses including principles of micro (and macro). I will describe these devices in more detail below.

However, before a more thorough presentation of the technologies is made, it is appropriate to provide some background about the general university environment in which these technologies were employed. Dakota State University is a small public university, one of six institutions of higher education in the South Dakota regental system, with a current enrollment of approximately 2000 students. In 1986, the institution underwent a mission change that transformed it from an institution focusing on teacher education to an academic environment with an emphasis on the integration of

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[5] The university unexpectedly moved from supporting Real Player format to Windows MediaPlayer format at the start of the semester and the old format was no longer supported, which was unfortunate since microeconomic video lectures recorded Summer 2003 could have been made easily available to the class.
[6] The intent was for the instructor (only) to use this email system on an 'emergency' basis, i.e. to distribute electronic files at the start of class to all students, so students were instructed to use the professor's university (non-WebCT) email account. Nonetheless, some students made use of it (because it was used in a few of their other classes), resulting in 'missing' assignments until I remembered to check.

technology throughout the curriculum. DSU's new legislated mission[7] has been and still is to focus on the implementation of computer technology programs and other related undergraduate and graduate programs. In particular, DSU was authorized to offer programs in business and information systems, focused on the application of computer technology to business, and was also mandated to integrate technology into all aspects of the curriculum.

Thus, the environment at Dakota State is heavily oriented toward the use of technology. All students have e-mail accounts and space for personal websites, all dorm rooms have access to both a wired network with multiple access ports for multiple residents and a wireless network system, so each student can connect their computer to the university network whether it is a desktop or laptop. We are in the first year of a three-year phase in of a Tablet PC initiative that will eventually result in nearly all students being required to own a wireless tablet/laptop hybrid computer.

The Gateway M275 is a notebook tablet PC with a screen that can swivel 180 degrees and fold down and lock so be operated as a flat slate-style tablet PC where, instead of a mouse, the pointer is controlled by a stylus (digitizer pen). The screen is tapped to left-click and a depressible button on the stylus can be depressed to tap a right-click. Although larger than the typical pure-tablet slate-style PC, it is light enough to carry while lecturing.

All freshmen and sophomore students were required to lease one at an additional cost of $275 each term. Junior and senior students were given the option to 'opt-in' at the same cost, and a significant portion did so. In addition, freshmen students were required to take a three-semester-hour introductory course in the use of these computers that includes training in the use of e-mail, the Internet, and the Microsoft Office suite of software (Word, Excel, Access, PowerPoint, and FrontPage) in addition to learning all about the M275's various features, e.g. how to pivot the screen in any direction, and thus gaining some comfort with the new computer and the writing, analysis, database, presentation, and web design tools that they will be exposed to in their courses at the university. Moreover, all students are required to take a second three-semester-hour

[7] See South Dakota House Bill 1357, as enacted February 29, 1984, by the legislature of the State of South Dakota for the specifics of the mission change.

computer principles course that teaches them a programming language. Both courses are usually completed in the freshman year and generally prior to enrolling in a principles of economics course (both micro- and macroeconomics partially satisfy social science general education requirements). Of course, the Intro to Computers course with Tablet training was offered for the first time in Fall 2004.

The faculty throughout all three colleges (Arts and Sciences, Business & Information Systems, and Education) are very computer literate and have been provided incentives to make innovative use of technology in their courses. Dakota State University has been nationally recognized in the past for its integration of computer technology into all aspects of its curriculum based upon annual surveys that examined both the *facilities* and the *use* of computer technology by a university. Distance education courses have been offered since 1996 at DSU and this author has taught Internet-only distance education courses in microeconomic principles to both undergraduates and masters students since 2000.

It should be made plain at this point that, although the university could be characterized as a high-technology environment, the students that come to Dakota State are not necessarily the most highly computer literate. Entrance examinations clearly illustrate that the representative DSU freshman student is not much different in background from freshmen at the other state universities in South Dakota.[8] While the integration of technology into the K-12 environment is ongoing, most DSU students are graduates from small, rural high schools in South & North Dakota, Minnesota, Iowa, and Nebraska and may have had little experience with computer technology.

However, in my own experience and from discussions with colleagues, the main difference between students that attend DSU and those who do not is that DSU students are more willing to be exposed to new uses of technology. An expectation of, or at least a tolerance for, experimentation with new technology in their courses is common among the students. And since many have not attended another college, they soon adapt to the technological environment. Indeed, they sometimes forget that not everyone routinely checks their e-mail and can respond within the same day, let alone the same hour!

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[8] Information about the six public universities, including data on entering freshman class characteristics, can be found at the South Dakota Board of Regents web site: *http://www.sdbor.edu/publications/*.

This discussion is therefore intended to serve as a warning to those reviewing the fairly substantial list of technologies already incorporated and to be incorporated into these courses—the courses at DSU are designed for students who do not demand to be coddled in their exposure to technology. Students are expected to know how to use their new computers (in fact, most freshmen now know more than the faculty), to find material on the web and on the WebCT course websites, to use computers to complete their work, to submit their work using WebCT and to communicate routinely using e-mail. An accurate description of the teaching technologies as set up for use in my classes is that they are functional in their objective--easy to use but not overly sophisticated in their construction. It is quite possible that this mix of technologies may not be appropriate in an institution with students of different technology interests and aptitudes.

I would now like to address some features, benefits and concerns regarding the use of the M275 in the fall 2004 micro courses. This discussion will focus only on the fall, since they incorporated the most advanced uses to date.[9] The instructor used his M275 for every lecture in all three courses. The typical lecture begins with the instructor connecting wirelessly to the DSU network and then running a program, called AirProjector, that allows his computer to wireless connect to any projector configured for wireless use, which was the vast majority of classrooms in his college.[10] This allows the faculty member to take the computer from his office to the classroom. The computer can essentially be pre-configured prior to coming to any lecture by opening the programs, documents, and browser windows before class and taking the computer to class in a 'hibernate' mode. Both the student and the faculty software configurations on the M275 computers have the AirProjector software installed and any wireless laptop can use the program if the projector is available. This also enables the faculty member to 'share' the projector with students, allowing them to project if the instructor releases the projector. Whatever is displayed on their computer screen is projected for the class to view.

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[9] Although a slate was used in the spring macro section, it was far more limited. The slate also did not have any peripherals to speak of—no internal DVD or even CD player, no disk drives, and of course, no keyboard. (These peripherals were available through a docking station in my office. I also use a docking station with my M275.)

[10] There are fewer classrooms equipped with wireless projectors in the other two colleges, but almost all classrooms have ceiling mounted projection systems tied to a dedicated desktop computer, our previous generation of classroom projection technology.

Office 2003 is digital ink-enabled, which means that any Word document, Excel spreadsheet, or PowerPoint presentation can be annotated and the annotations saved. The digital ink is backward-compatible, so users with older versions of the Office suite can still see the digital ink (although they could not write). The ability to write and draw in Word allows me to distribute chapter lecture notes in Word document format and then to use the exact same files as my ‘lecture overheads’ allowing the students to complete them as I work through the same materials. It is believed that this is superior to annotating PowerPoint files. The students can choose to type or handwrite. The students can draw graphs and diagrams on the fly and can add more ‘room’ to the incomplete lecture notes easily by hitting ‘enter’ a few times. The instructor has the same ability during lecture.

The wireless tablet environment also provides full-time access to the Internet. While there are some definite advantages to having the Internet available in the classroom, including walking the students through the WebCT and Aplia websites, reviewing quiz and exam results and questions electronically, and accessing and displaying information from the Internet. Unfortunately, full-time classroom Internet access was also the source of perhaps the most severe disruption from the use of the wireless network: Access to browsing, games, email and instant messaging.

This is worth dwelling upon in more detail. There was a widespread belief among the faculty teaching general education courses that performance on exams was slipping. It was felt that the students were allowing themselves to be distracted by inappropriate web and e-messaging. They send email and instant messages to friends who are either in the same class or in a different classroom entirely. The ability to ‘talk to your neighbor’ not only proved distracting for those engaged in it, but also proved to be a negative externality for the students in the vicinity who could observe their classmates engaging in this behavior. Although the few upperclassmen who take principles strongly disapproved of this behavior, they were neither numerous enough nor vocal enough for peer pressure to dissuade the offending behavior. For the instructor, it is very distracting to suddenly have a student who appears to be typing furiously and apparently taking notes, suddenly break into a broad grin or nod when nothing humorous has been said for awhile and no question requiring an affirmative response has been asked.

Although some instructors were able to control this behavior by (a) designing assignments and activities each class period to keep the students on task or (b) monitoring what was on students' screens by lecturing from the back of the room (more effective with small class sizes), the midterm examinations in some courses, including principles, did indicate lower than average results. As a result, the general faculty agreed to raise this issue in all general education courses and emphasize the potential harm to their education and GPAs. I raised the issue in the context of the discussion of externalities in the two micro sections I was teaching. However, I did not attempt to police the students and as a result both the second exam--I give two exams, one at midterm and one approximately three weeks prior to the end of the course—and the comprehensive final exam exhibited lower than average results. This is an issue I plan to address early and often in future courses and, as will be apparent in the survey results, some students are even willing to sacrifice some of their freedom of Internet access during the lecture to avoid this problem. (Others whom I suspect are upperclassmen suggested that only the freshmen should be told to 'turn off their wireless' during lecture.)

With this one drawback, it appears the use of the Tablet and wireless projection in class was otherwise quite successful in a number of areas. The instructor was able to seamlessly integrate the use of the computer into daily activities. The ability to 'zoom' or magnify a diagram is a substantial improvement over a whiteboard or chalkboard. And it is easy to change to any of a multitude of ink colors (something I plan to do more of in future courses) and to move and resize lines, groups of lines or entire diagrams. (No more 'running out of room' on the whiteboard and trying to squeeze that last word in the definition in anyway.) The computer also has the ability to manipulate previous diagrams, correcting mistakes and removing careless marks swiftly with the eraser. (It can remove entire strokes instantly, rather than requiring the user to 'rub out' all marks manually like a pencil, white- or chalkboard eraser. This is very efficient—and dangerous if you are not careful.) In addition, it is easy to change from 'ballpoint' (thin line) pen to 'felt tip' (fat line) pen to highlighter, all with the special toolbar at the top of the screen. All of these elements—and the bonus of never having to turn your back to your class—has made a distinct improvement in the accuracy and efficiency of my 'chalk and talk' lectures.

Some additional features of the M275 are also worth noting. Although I rarely used it in class, there is also a handwriting-to-text conversion which is frankly the best I have ever seen. My handwriting is hardly good—a student once wryly asked me to 'write in English, please'—and the character recognition program has what I estimate to be approximately an 85- 90% accuracy even though I rarely use it. With use, I am told by other faculty that accuracy can improve to 95%, or even better with commonly used words, letters and characters.

The tablet also has a speech recognition ability that is most impressive. The speech recognition can be trained to recognize your particular dialect and pronunciation, thereby making it also very accurate. I experimented with classroom use--why write definitions when you can read them to your computer and let it write it in Word?—but unfortunately speech recognition needs a quiet environment and a relatively normal voice level, two elements not typically present in classroom lectures in large, echoing lecture halls. I therefore mainly use speech recognition in my office, but I am not yet a 'power-user' like some DSU English department faculty.

I should also add that using Aplia to conduct synchronous Internet-based experiments is extremely convenient when every student has a wireless laptop. There is no need to reserve one or more computer labs. The Aplia experiments are designed to minimize bandwidth usage (to accommodate huge sections of principles classes) and as a result there is little danger of overloading the wireless hubs in the classroom due to mass simultaneous use by students and the instructor, at least with class sizes of 100 or fewer. I am pleased to report that in both sections of micro the experiments went off without any major technical difficulties at all. In fact, the few times the students were not able to log in merely required a refreshing of the browser, essentially a second try, and then they met with success. I had no reports of any problems after the students logged in—and we ran experiments wirelessly and almost continuously for the entire 50 minutes and 75 minutes. (One class met three times a week; the other, twice a week respectively.) Ball and Eckel (2004) also report being similarly impressed by both the "foolproof" performance of the system and the excellent technical support provided by Aplia.

Overall, I believe there is considerable room for additional uses of the M275 in the classroom. I did not have my students do any in-class group work this semester.

With the ability to find data on the Internet and project answers to questions from the instructor, there are considerable opportunities for more active learning sessions, rather than the traditional chalk-and-talk. In an email circulated on the ‘tch-econ’ listserve, Talley (2004) writes:

> “For example, consider creating assignments for small groups of students, where they use the web to visit (the same or different) websites to answer specific instructor-authored questions and present the results of their analysis to the class. Or running Aplia-style Internet-based market simulations with follow-up questions answered by the groups--perhaps with each group projecting an answer to a question or set of questions for class discussion. Or going to a macroeconomics simulation website and giving each group a different set of starting parameters and exogenous 'shocks' to analyze in class. By making the class more hands-on and interactive, I hope to effectively integrate more active learning classroom teaching strategies while using the computer to full extent as a teaching tool. (*tch-econ* listserve, posted by Dan Talley on Thursday, May 20, 2004)

I look forward to pursing opportunities to augment my course with more active learning techniques and assess the effect on student learning and attitude towards economics in the future. This could include formative assessment feedback in the form of a WebCT accessible ‘one-minute paper’, where students identify the key point they learned that day as well as the ‘muddiest point’, as described in Chizmar and Ostrosky (1998) or perhaps incorporating elements of Just in Time Teaching as discussed in Simkins and Maier (2004) to have students provide electronic, i.e. email or WebCT-based feedback on assigned chapter readings just prior to class in order to better tailor my topics of discussion to areas of greatest benefit to the class. Combined with reading quizzes due prior to the start of the chapter, this could provide valuable information about areas of confusion in the class. Clearly, in many ways I am just scratching the surface of possible teaching techniques that the wireless laptop/tablet PC platform could better accommodate or enhance. Of course, the assessment of these experiments is critical to determining the effective use of this teaching tool.

At this point, it is appropriate to review the results of the end of course surveys wherein the students evaluated features of each course. Each of the three courses was surveyed in an effort to evaluate the four teaching technologies that were integrated into the macro and microeconomic principles courses (WebCT, Wireless Networking, Tablet PC, Aplia). In general any conclusions supported by this survey evidence must be tempered by the small sample size and the informal nature of the analysis.

Table 1
Student Perception of Course Technology Effectiveness

Number / Percentage of Students Responding Positively (Strongly Agree or Agree)

	WebCT Course Materials Evaluation Statement	Spring 2004 Macro (n = 22)	Fall 2004 Section 1 (n = 16)	Fall 2004 Section 2 (n = 24)
	All statements below end with "...on WebCT contributed to my success in the course."	# / %	# / %	# / %
1	The Instructor's Prepared Course Lecture Notes…	**19 / 86%**	**14 / 88%**	19 / 79%
2	The Syllabus…	12 / 55%	9 / 56%	11 / 46%
3	Sample Exams and Answer Keys…	16 / 73%	12 / 75%	15 / 63%
4	Streaming Video Lectures from 2001…	6 / 27%	n/a	n/a
5	Practice Homework Assignments…	15 / 68%	**13 / 81%**	17 / 71%
6	Updated Grade Reports…	**18 / 82%**	**14 / 88%**	18 / 75%
7	Textbook's Website…	17 / 77%	8 / 50%	9 / 38%
8	Aplia Homework Assignments…	**18 / 82%**	**13 / 81%**	**21 / 88%**
9	Aplia Experiments (Supply and Demand, Real Interest Rate (Macro only))…	**20 / 91%**	**15 / 94%**	**22 / 92%**
	Course Technology Evaluation Section			
10	The instructor should use the tablet vs. the whiteboard during class.	**19 / 86%**	n/a	n/a
11	The $28 fee for Aplia reasonable given the use made of it in the class.	14 / 64%	9 / 56%	11 / 46%
12	The use of wireless tablet computing improved the overall quality of the class.	n/a	9 / 56%	16 / 67%
13	The use of wireless tablet computing improved my homework scores.	n/a	**13 / 81%**	**21 / 88%**
14	Appropriate use of wireless tablet computing was made for this course.	n/a	10 / 63%	17 / 71%
15	Wireless tablet use should be restricted when it is not necessary for class.	n/a	2 / 13%	6 / 25%
16	Quality of instruction was increased through use of wireless tablet computing.	n/a	**13 / 81%**	18 / 75%
17	I used Digital Inking in Windows Journal at least once a week or more.	n/a	3 / 19%	7 / 29%
18	I used Digital Inking in Office 2003 (Word, etc.) at least once a week or more.	n/a	10 / 63%	16 / 67%
19	I used the Handwriting-to-Text Conversion at least once a week or more.	n/a	6 / 38%	8 / 33%
20	I used Voice Input at least once a week or more.*	n/a	0 / 0%	1 / 4%*

* One student was visually impaired.

Student performance in the macro section was not systematically measured although the exam and homework averages were consistent with past courses. 30 students began the semester, 1 dropped and 2 failed the course. The macro section was given a pen-and-paper survey at the end of the course to measure student attitude. 22 students completed the survey. Each student was asked about their amount of use of a subset of WebCT course site features and their attitude, in the form of ranking the usefulness of the features from highest (most useful) to lowest (least useful) and overall satisfaction with the information provided by the instructor on the site. The only use of the wireless network and the tablet PC (slate) was by the instructor, so the students were asked whether they preferred the slate-projection or a whiteboard. The tablet initiative was not present in the macro section, so there were no other tablet PC-related questions. Three questions discussed the use of Aplia in class: Did the Aplia experiments and homework assignments improve your understanding of economics and was the $28 charge for Aplia reasonable given the uses of it this semester?

The results are presented in Table 1 on page 19. There is generally a favorable majority, with 60-75% typically responding affirmatively to questions of usefulness of the various WebCT features, instructor resources and features of Aplia. Clearly the favorite resources were the incomplete lecture notes and the Aplia experiments. They also rated highly when ranked against the other technology tools available in the class (not reported), typically in the top three features of the course. In particular, the question regarding the instructor's use of wireless projection feature of the tablet was affirming. Although it was theoretically possible that the students would prefer to look at the back of my head as I wrote lecture notes on a whiteboard, the instructor was pleased and relieved that the students too preferred that the instructor face the class.

The results for the two microeconomics courses in Fall 2004 were generally consistent with the macro course, although micro section 2 seems to rate the course features consistently less highly than the macro section or micro section 1. The only significant difference between the courses was that section 1 met three times a week and section 2 only twice. Perhaps section 2 had less opportunity to absorb the beginning of class announcements and reminders about assignments, exams, and good practice, but there is no evidence to support this supposition. All three sections show a strong preference for the Aplia interactive problem sets and the Aplia experiments. And there is significant agreement across the three courses that the incomplete course lecture notes in Word format and the frequently updated grades report, posting their scores on all assignments, quizzes, and exams and computing a current estimated grade, were all useful features of the course website.

The two micro sections did answer questions about the use of the Tablet PC and the relevant software and tools. There was significant agreement in the two courses that the wireless tablets had a positive effect on homework scores. This may be a function of the wireless devices email and instant messaging features allowing for better communication or it may reflect the ability to view the Aplia assignments anywhere wireless access is available. It may also be yet another student testament to the quality of the Aplia website itself and have little to do with the PC technology.

The only other area where there was (almost) significant agreement is with the item that asks about the "quality of instruction" in utilizing the tablet. Several students in written and verbal comments noted that they thought the instructor did a relatively better job of integrating Tablet use into the course compared to other general education courses at the university. Giving them Word documents to complete, experiments to run, occasional websites to visit during class, and walking them though the course WebCT and Aplia websites at the start of class to review all assignments and quizzes may indeed have left the impression that the tablets were used well in this course.

One last item is worth noting. We have already discussed the distraction factor that the instructor believes had a deleterious effect on exams. Although the responses agreeing to the statement about restricting the tablets were not very numerous, there were approximately double that many written comments discussing the distracting nature of the tablets when students surf the web, play games, chat, IM, and email during class. I believe this is an issue that will need to be addressed across the campus. Expectations for in class behavior using the tablets will need to better instilled. In addition, a software solution is being considered that would require students to 'log in' at the beginning of class and allow the instructor to view (and project!) any and all student computer screens. Overall however, it appears that despite the typical 'learning curve' by both the instructor and the students of using a new teaching tool, that there was general satisfaction by the students, and in specific instances some genuine enthusiasm and appreciation for having them available.

The next step is to assess the effectiveness of these innovative new technologies on student learning. However, the literature clearly shows that this is not an easy task. In the next section, I build a theoretical model to possibly explain some of the sources of difficulty of determining that the integration of technology has resulted in significantly positive effects.

Section IV A Cost Minimization Model of Student Response to Innovations

In this section an ad hoc cost minimization model of student learning is constructed. The goal of this exercise is to arrive at a model that may demonstrate how students optimally choose between various learning tools and to suggest a mechanism by which those choices may change when those tools become available electronically or online. A secondary goal is to develop a model that might explain some of the empirical puzzles of the literature regarding the evaluation of the effectiveness of the use of computer technology.

Sosin et al. (2004) note this empirical puzzle in their introduction:

> "Economists typically analyze the impact of instructional innovations by testing for significant differences in student performances between a test and control corse using a production function explaining student performance. Using this approach, one set of findings shows that some uses of technology perform as well or better than conventional methods (Richard Hannah, 1996, Linda Manning 1996; Rajshree Agarwal and A. Edward Day, 1998). Another set suggests that the benefits of technology may not be uniform across student abilities, course levels, course types or gender (Margaret A. Ray and Paul W. Grimes, 1992; Barlett and Susan Feiner, 1992; N.Scott Cardell et al., 1996; M. O. Borg and H. A. Stranahan, 2002; Byron Brown and Carl E. Liedholm 2002).

It has already been noted in Section II of this paper that Brown and Liedholm (2004), citing differences in performance between different learners with different learning preferences, feel that technological innovations in teaching can yield considerably different benefits and costs for different individuals. And this only refers to differences in performance and learning. These differences also occur in attitude and they are far from consistent. For example, several studies note improvement in student attitude toward the subject of economics and the instructor even when gains are absent or significant decreases in performance result.

The motivation for the model in this paper began with a presentation in 2003 and two papers in 2004. Paul Romer presented a keynote address at the Midwest Conference on Student Learning in Economics: Innovation, Assessment and Classroom Research hosted by the University of Akron on Nov. 7, 2003. In this address, he challenged the audience by relating his experience with Stanford MBA students over the years. His *a priori* expectation was that, given the resources that are now available to students online and the potential learning opportunities that await his students, they should prefer as little structure to the course as possible. What he found instead was that they preferred a more structured course to an unstructured one. They wanted to know what the instructor's performance expectations were and they wanted to know up front how they would be assessed.

This behavior contrasts with a large body of microeconomic optimization models that typically imply that decision-makers are better off when they face unconstrained choices. The imposition of constraints typically worsens welfare. Romer (2004) followed this line of reasoning and offers a possible explanation by formally positing that learning economics is a source of disutility for students—whereas it is likely a source of positive utility for their instructors. In his model, students must be enticed to become 'addicted' to learning by placing them in (classroom) environments with other potential addicts and providing incentives in the form of assignments and exams for 'positive' feedback that could lead to the class becoming addicted to learning together. (Or perhaps at least to taking classes together, which for a university is an equally profitable outcome.) Regardless, one arrives at the conclusion that perhaps the characterization of learning as hard and sometimes unpleasant work is an apt description of the situation facing students.

The other paper that motivated this model to an important extent is Brown and Liedholm (2004). As already noted, they use a modified comparative advantage model to capture the idea that a student will not completely specialize in one teaching technology, or tool in their usage, even when the student has a comparative advantage in using that teaching technology to learn. They therefore argue in favor of offering students multiple tools for learning in the same course, including a mix of non-technology and technology tools.

By building on these ideas and combining them with a result from the education literature that active learning tools typically yield more effective learning than passive learning tools (see Boylan (2004) pgs. 406-7), it appears appropriate to characterize student classroom learning as a cost-minimization problem. Learning imposes costs on students. But students do not seek to maximize learning subject to these costs, but instead seek to minimize these costs to achieve a specific amount of learning sufficient to achieve the goal of a specific performance result, a grade in the simplest sense. Since performance as measured by grades is (or should be) correlated with learning, students will seek that amount learning that they believe will be sufficient to earn a desired grade (A, B, or C, perhaps) at the minimum cost possible. Therefore, they may be considered cost-minimizers when it comes to learning.

To be somewhat more formal, consider the simple case of a student who has a choice of two learning tools to assist in learning a subject. Suppose one of those tools is assumed to be an active learning tool, which we shall call Experiments, and another tool is assumed to be a passive learning tool, which we shall call Textbook. Initially, both of these tools are available to the student in a non-technology enhanced form. For example, the experiments are done in the classroom using a chalkboard, slips of paper, and other props and the textbook is published in paperback format.

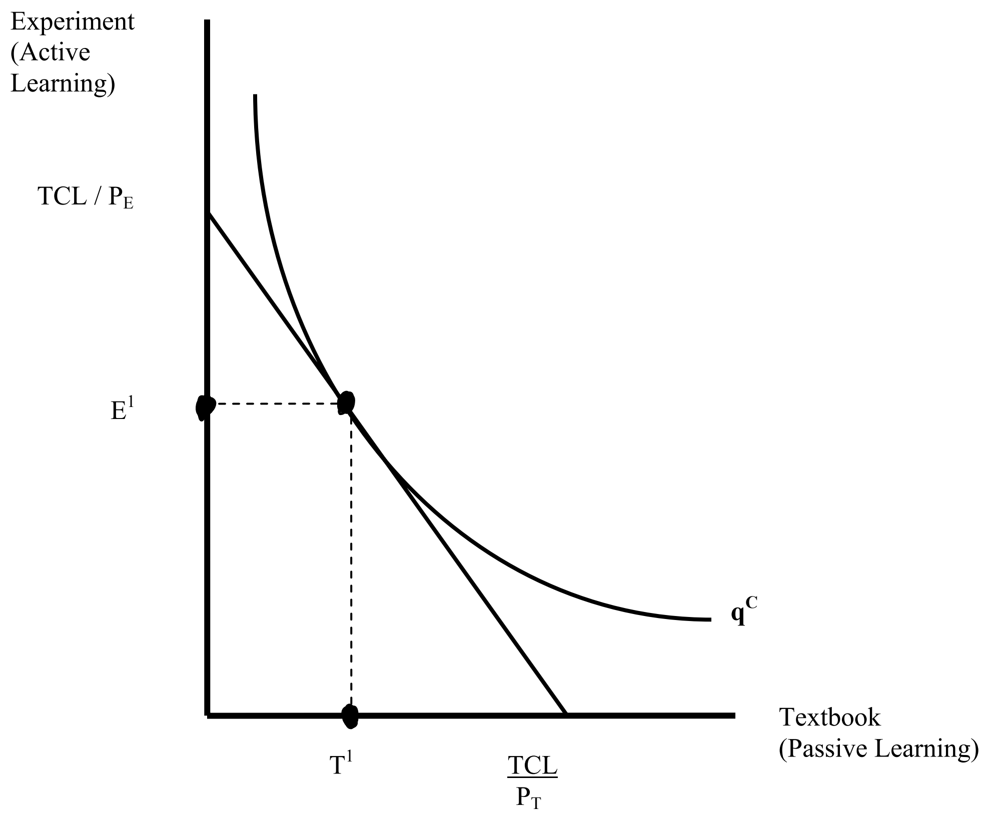
If the production of an amount of Learning (q) is a function of the amount of time spent using of these learning tools, Experiments (E) and the Textbook (T), then the production function could be expressed as Equation (1):

$$(1) \qquad q = f\,(E, T)$$

Let us assume that this production function satisfies the usual convexity requirements. (As this is an ad hoc model it is not necessary to posit a specific functional form, but the author suspects that a typical constant returns Cobb-Douglas specification would likely suffice. As long as the isoquants are convex, the conclusions should be independent of the specific functional form.) Now suppose that the use of each of these tools entails some form of positive opportunity cost. Under the assumption of constant opportunity costs for both tools, the opportunity cost of an hour of experiments can be represented as the constant price P_E and similarly the opportunity cost of an hour of textbook usage can be represented as the constant price, P_T. Assuming no fixed costs, the total opportunity cost of the production of a given amount of learning (TCL) can be stated as Equation (2):

$$(2) \qquad TCL = P_E \times E \;+\; P_T \times T$$

Figure 1



It is therefore possible to construct the optimization equation for a cost-minimizing student in Equation (3):

$$\text{(3)} \quad \text{Min TCL} = \text{TCL} = P_E \text{ x } E \; + \; P_T \text{ x } T \;\; \text{subject to } q_0 = f\,(E, T)$$

where q_0 represents the minimum amount of learning necessary, in the student's view, to obtain the desired grade in the course. Hereon, let the subscript on q denote the desired grade, i.e. a student hoping to pass a class with a 'C' grade would seek to learn amount q_C, the minimum amount of learning required to earn a 'C' in the course.[11]

[11] It is assumed here that the student's expectations regarding the necessary amount of learning to achieve a specific grade is completely accurate. It is of course entirely possible that a student may have incomplete information or inaccurate expectations of the amount of learning necessary to earn a desired grade in a

Figure 1 on page 25 illustrates the operation of the basic model. The student in Figure 1 desires a 'C' grade. Therefore the student will minimize the total opportunity cost of obtaining a 'C' grade in the course by seeking the minimum amount of learning that will yield a 'C' grade, q_C. Given the trade-offs embodied in the relative 'prices' or rather opportunity costs of employing the two techniques, the cost minimizing student will choose to employ E^1 hours engaging in, reflecting upon, and completing assessments of her knowledge on Experiments and T^1 hours reading, reflecting upon, and completing assessments of her knowledge on the information in the Textbook. The result that E^1 appears greater than T^1 in Figure 1 is entirely arbitrary, since this depends upon the specific relative prices (the Marginal Rate of Transformation as depicted by the slope of the cost function) and the relative learning ability of the student with respect to the two teaching tools (the Marginal Rate of Substitution, as depicted by the changing slope of the learning production function), as expected. Note that rewriting Equation (2) first solving for E to obtain the y-intercept and then solving for T to obtain the x-intercept, yields the y-intercept, (TCL / P_E), and the x-intercept (TCL / P_T).

To carry the analysis farther, we need to incorporate innovations in teaching technology into the model. Let the variable C represent the discrete 'state of nature' regarding technology. C = 1 will designate the state of nature where the teaching tools are being employed without technology, as depicted in Figure 1. C = 2 will designate the state of nature where an innovation in teaching technology has occurred, i.e. the class is being taught with online technology tools. For example, suppose the experiments are now being conducted online (say using Aplia) and the textbook is now only available in an electronic format (CD or Internet-based). It is appropriate to assume that C is a completely exogenous variable since, *from the student's perspective*, the choice of instructional technology tool is made by the instructor, typically before the class starts and will typically remain fixed once the course has begun and the student finally has an opportunity to provide input to the instructor.

To introduce C into the model, we will assume that the technological state of nature, C, affects the opportunity cost of the technology tools, potentially both P_E and P_T

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course. Risk-averse students would likely seek to learn somewhat more than the minimum amount of learning to earn a desired grade to account for this uncertainty, but this is an extension left to another paper.

for the student. Further, it is posited that the use of technology-based tools will lower the opportunity cost of the active learning technology relatively more than the passive learning technology. For illustration let us assume that in fact there is no effect on the opportunity cost of the passive learning technology. This is a strong assumption, but it seems reasonable. Students tend to enjoy using new technologies, typically being some of the earliest adopters. Moreover, it seems reasonable that the more involved and engaging active learning tools would benefit relatively more than converting a passive technology like a book from paper to CD. Reading a book on a computer screen is hardly more engaging than reading it on paper—and in fact many might argue that reading on the computer screen is less engaging. Nonetheless, we can formally express these assumptions in Equations (4) and (5):

(4a) $P_E = f(C)$

(4b) $P_T = f(C)$

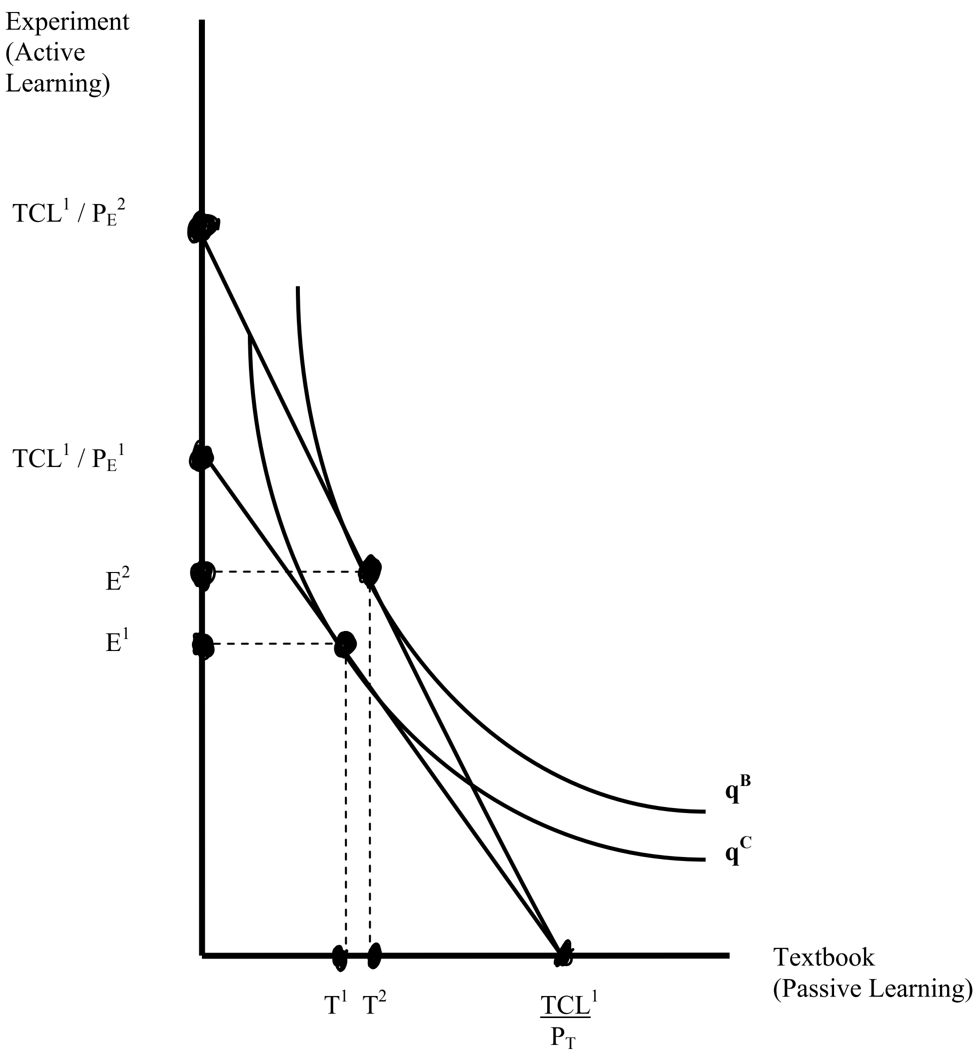
(5a) $(d\,P_E / d\,C) < 0$

(5b) $(d\,P_T / d\,C) = 0$

It would no doubt be preferable to model the opportunity cost parameters, P_E and P_T, more formally with a specific functional form, but for this ad hoc model this characterization will suffice.

A logical question to pose at this point is why not let the teaching technology variable appear as a shock to the production function. It seems reasonable at first blush to assume that an increase in technology would shift the production function of learning up and to the right for all levels of inputs E and T. However, the predictions from such a model would not make sense: A technology innovation would cause an increase in the total opportunity cost of learning as the cost function would also have to shift up and to the right to achieve the same amount of learning as prior to the innovation. I do not believe students would be happy about technological innovations to teaching tools that consistently increased the cost of learning to them. This model would contradict study after study that has shown that student satisfaction (with both the course and the

Figure 2



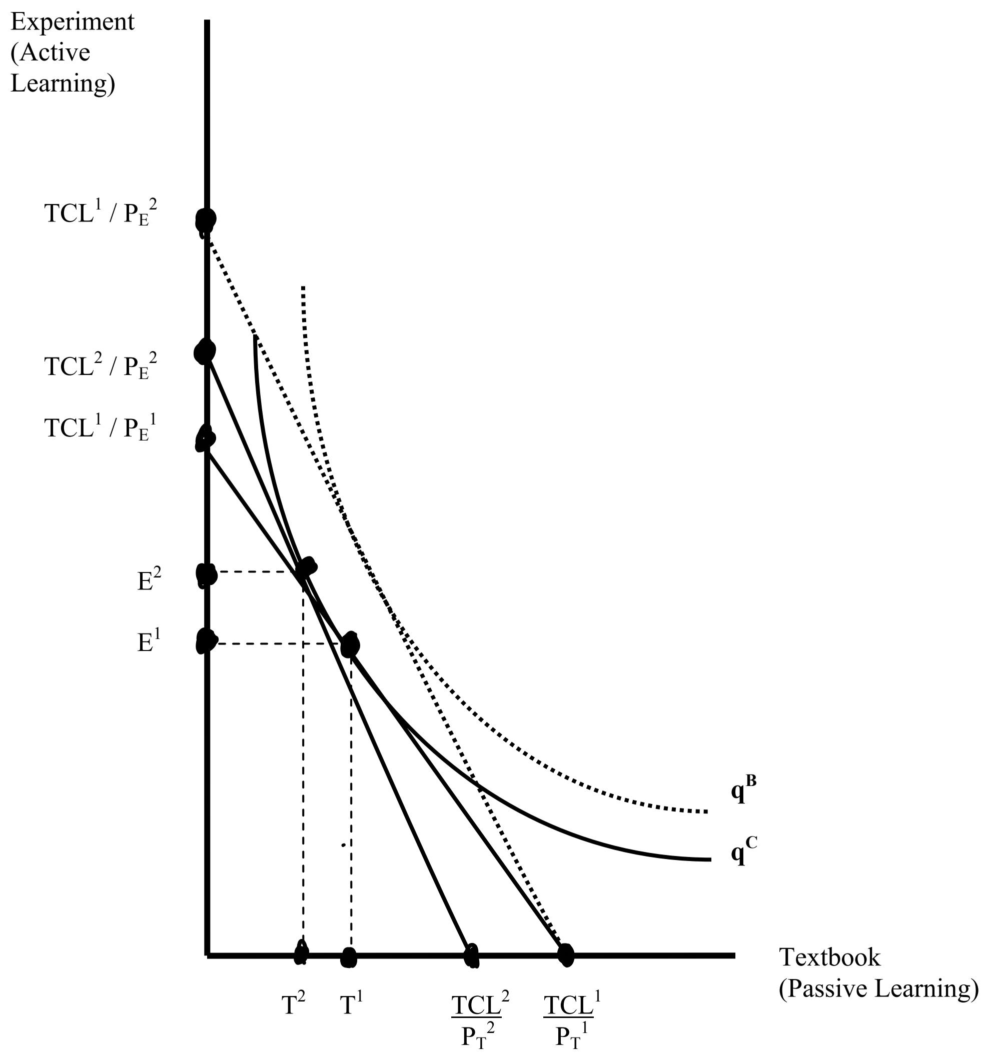
instructor) tends to increase with the use of technology. Therefore, I am satisfied that the model is correctly specified and that technological innovations to teaching tools are best represented as a reduction in the opportunity cost of employing that tool. This conforms to personal experience: I am not able to read a book any faster because it is in electronic format, but I can comfortably experience accelerated progress through an experiment (as a student) as a result of the computer handling the logistics, rather than bearing the traditional method's transaction costs, for example passing out and retrieving paper, playing cards, etc., and moving around the classroom to interact with different peers.

Ball and Eckel (2004) make a similar point when discussing the purpose technology serves in running an experiment. In an example of a simple experiment administered to a large class, Ball and Eckel state "Because the published exercise calls for 15 periods, the instructor ends up getting a real workout even in this simple-to-administer exercise. If a subset of the class is used in the exercise (the authors recommend groups for large classes), the ratio of students *doing something to waiting for something to happen* is too low. Boredom and confusion set in, and students lose interest in the exercise thus defeating its purpose." (pg. 470; emphasis is original) I believe this conclusion can be generalized, at least weakly, to many such active learning teaching tools, at least when compared to passive learning teaching tools, to conclude that a technological innovation to a tool will have a stronger effect on the relative opportunity cost of the use of an active learning tool relative to a passive learning tool. For purpose of illustration only, the strong form expressed in Equations (4) and (5) will continue to be used.

Figure 2 on page 28 illustrates one possible outcome of an innovation in the technology of teaching on both tools. Starting with P_E^1, an innovation in the technology of teaching for both tools causes P_E to fall to P_E^2, where $P_E^2 < P_E^1$. This causes the y-intercept to shift, but the x-intercept to stay the same, given Equation (5a) and (5b). The innovation in technology makes it possible for this student to improve her performance *at the same perceived opportunity cost*. She is now able to earn a B in the class thanks to the lower relative opportunity cost of the Experiment. Note that her optimal response is to increase both the amount of time she spends engaging in, assessing her understanding of, and reflecting on the Experiments in which she participates, as $E^2 > E^1$, and the amount of time she spends engaging in reading, assessing her understanding of, and reflecting on the information in the Textbook, as $T^2 > T^1$.

Therefore, under certain conditions, it is entirely possible that an innovation in technology does not result in a 'time saving' for the student—they may optimally choose to spend more 'time on task' and yet not perceive this as an increase in cost, when put into opportunity cost terms. Therefore, it would be a mistake to assume that innovations that do not result in students becoming more 'efficient' are 'ineffective' in this sense. For the student, she prefers to allocate time spent learning in a manner that is more enjoyable

Figure 3



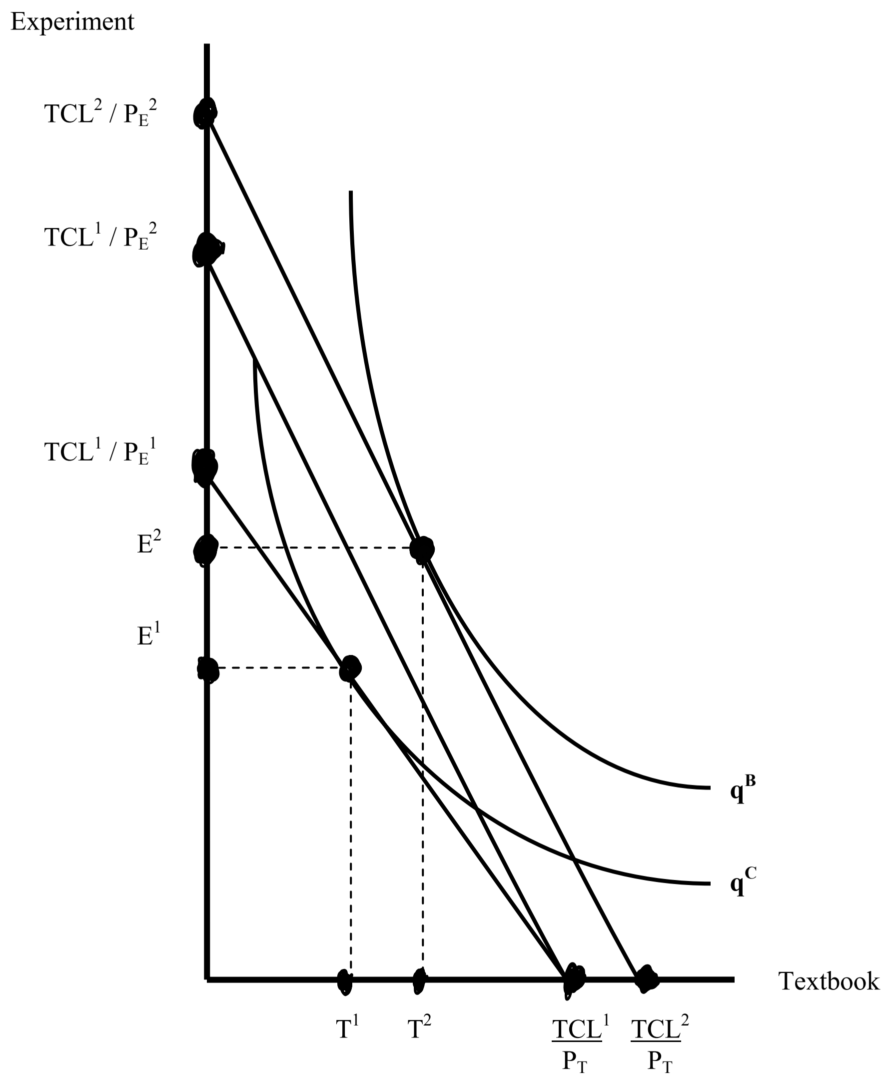
or more enlightening and therefore the time is better employed in this learning activity from her perspective. In fact, she would probably perceive a return to the traditional technology tool delivery mechanisms as making her worse off.

Of course this result hinges critically on the underlying, unspecified parameters underlying these general form equations. Figure 3 depicts another possible outcome. This is the same situation as shown in Figure 2, with the production function isoquant for q_B and the tangent isocost function to that isoquant from Figure 2 shown as dashed lines for comparison. But in this model, the student does not take advantage of the reduced opportunity cost to improve her grade. Instead she pivots along the isoquant for q_C, and choosing to minimize the cost of obtaining a 'C' grade instead of going for the 'B' grade. As a result, she chooses to ultimately earn the same performance by achieving the same level of learning after the innovation in technology, but she does so at lower cost since TCL^2 must be lower than TCL^1. By plotting TCL^1 / P_E^1 from Figure 2, we can be assured that her choice of isocost line, implicitly made by her choice of E^2 and T^2, results in a lower cost of learning.

Therefore under another set of (so-far unexplained) conditions, this student does not choose to enhance her performance in the class in the face of a technology innovation, but instead optimally chooses to earn the same grade she would with the old technology (chalk and paper). So which diagram is correct? Clearly, this model is not yet fully specified, as the decision as to whether to pursue a 'B' or stay with a 'C' is not modeled. In the classic cost-minimization model, the level of output, q, is a given. Here, the level of learning is dependent on the grade the student chooses to pursue. Yet the process of arriving at that decision is not modeled. This is purposeful, as I am only using this model to suggest different observed outcomes even when the innovation is having the desired effect of an improvement in efficiency in the sense of reducing the opportunity cost. I leave the specification of the endogenous decision as to which grade to achieve to a more formal theoretical analysis in a future paper.

But already the model is demonstrating exactly the results that were found in other empirical work. In response to an innovation in technology, a student may instead demonstrate no improvement in performance and yet express an increase in satisfaction with the course since she is now able to achieve her desired grade at a lower opportunity in the presence of the technological innovation to the active learning teaching tool. The fact that she is able to earn a 'C' by spending less time absorbing the learning benefits by engaging in, reflecting upon, and completing assessments of her knowledge on the information in the Textbook, as $T^2 < T^1$, and more time spent absorbing the learning benefits of the Experiments, as $E^2 > E^1$, is an optimal response by her given her objective. Indeed since this results in a lower opportunity cost she would likely express satisfaction

Figure 4



with the course compared to another with a higher opportunity cost as a result of not implementing the innovation in teaching technology.

So far we have examined a situation where, in response to an innovation to a technology used to deliver a teaching tool, one student responded by increasing her performance for the same opportunity cost and another student responded by choosing the same performance as she would have chosen previously, but at a lower opportunity cost, thereby likely enhancing her satisfaction with the course. Figure 4 depicts a situation similar to Figure 2 except that the technological innovation to the teaching tool is not sufficient to allow the student to achieve a higher grade at the same cost. However, for a marginally higher cost, the student will optimally choose to pursue the higher grade.

Once again, there is no formal mechanism that is currently part of the existing, but limited, underlying mathematical model of this paper to explain this behavior. But in the face of this diagram it seems reasonable to believe that some students may perceive the innovation in technology to be the marginal boost they need to justify their optimal response to put in the extra effort (bear the extra opportunity cost) to achieve a higher grade in the course.

Let's add one last wrinkle to better understand then what we may find when we survey students regarding their attitude. Suppose that the student's utility function underlying these choices reflects two facts: (A) Students care about what grade they receive in a class, with a higher grade resulting in higher satisfaction. (Let Grade = 5 if the student receives an A, Grade = 4 if a B, and so on until Grade = 1 if an F.) (B) Students prefer grades earned at lower opportunity cost than higher cost. In that case, the utility function and first order conditions could be specified generally as:

(6) $U^i = U^i(\text{Grade, TCL})$, where i is an index value denoting an individual student's preferences to allow them to differ from student to student.

(7a) $(d\,U / d\,\text{Grade}) > 0$

(7b) $(d\,U / d\,\text{TCL}) < 0$

If course evaluations depend in some sense upon overall student satisfaction as measured by this utility function, then we could end up with rather mixed results. Some students would be happier with the innovation, specifically those students for whom the effect of the grade on utility was larger than the opportunity cost, which represents the disutilty of the effort required to get that grade.

On the other hand, it is entirely reasonable to believe there would also be students in the same class for whom the effect of the grade on utility had less impact than the effect of the opportunity cost and that therefore they would be less satisfied by the presence of the innovation to get the (observed) grade that they received. These students would rationally choose to learn less than other students who are otherwise identical. (A figure depicting this outcome is not included in this paper.) This may potentially explain situations like that experienced by Brown and Liedholm (2004). On pg. 490, they find that "Whereas 21% of respondents said the thought they learned more than in face-to-face class, 25% thought they learned less." If the latter 25% are comparing their learning with what their peers did and achieved, instead of with what they would have chosen to do then they may reasonably be expected to provide such a response.

I believe this graphical presentation of the model has the potential to explain a wide range of observed outcomes where both student performance and student attitude do not both improve in the face of an innovation in the delivery method of a technology. Clearly, this model would need to be developed more fully, with specific functional forms and additional equations modeling the decision to seek a specific grade and therefore a specific level of learning, q. But the diagrams appear to replicate the behavior of students found in a number of studies. Because of the unobservable nature of the effect of the innovations on the student's optimum response, merely inferring the success or failure of an innovation based on the observable variables may in fact be misleading. In every figure, the innovation resulted in a reduction in the opportunity cost of using the active learning tool. This result I believe should motivate future research into innovations into classroom teaching.

Section V. Implications for Empirical Examinations of the Impact on Learning

In this section, the empirical implications of the cost-minimization model are considered as the evidence gathered in the past year of the effective use of the three technologies that were incorporated into the three courses taught. The examination of this evidence then motivates future classroom research into the effective use of these technologies.

A review of the two key assumptions underlying the model is warranted:

(1) *Innovations in the technology of teaching do not improve the student's mental production processes that create learning.*

Instead technological innovations reduce the (marginal) opportunity costs associated with the time needed to produce such learning. This is perhaps the most important conceptual departure point of this model of student learning from the standard intermediate theory cost-minimization model.

(2) *Innovations in the technology of teaching do not affect all teaching techniques (or tools) equally*.

Innovations in technology that focus on active learning teaching techniques are more likely to have an affect than innovations that focus on passive learning techniques.

The model in fact makes the very strong assumption that the innovation on the passive learning technique had no effect; essentially, as if there were no innovation at all. This is an extreme simplifying assumption, but the literature seems to favor the general conclusion that innovations in passive learning techniques are less likely to see reductions in the (marginal) opportunity cost associated with their use than innovations in active learning techniques. The consistent significant negative impact of PowerPoint on student learning in the Sosin et al (2004) study is one such example.

A central conclusion of the cost-minimization model is that innovations in technology to improve teaching and learning are not magic bullets. It is highly likely that you can turn an ‘F’ student into an ‘A’ student via any use of technology. What is apparent from the discussion in Section is that different students will demonstrate different optimal responses to the same positive innovation. For some students, the innovation will be enough (or almost enough) to enable the student to seek a higher grade and increase performance and learning at the same (or slightly higher) total opportunity cost. Other students will optimally(?) choose to ‘spend’ the benefits of a lower marginal opportunity cost by pursuing the same grade but with less effort and at less overall cost. This student will likely exhibit an increase in satisfaction with the course, if no different performance or learning. The model can also exhibit variations where students improve performance but suffer higher total opportunity costs, which would therefore make their response to a satisfaction survey ambiguous depending upon which affects utility more, the positive impact of the higher grade or the negative impact of the higher total opportunity cost.

An implication of this model therefore is that only those innovations that have a significantly large magnitude effect on the marginal opportunity cost, the cost per hour of study to be specific, of the teaching tool(s) affected by the innovation should expect to yield empirical results where a large enough fraction of the class will optimally select to learn more and spend more time on task with all tools, i.e. more time working on the class as a whole. Helpful but smaller magnitude innovations, although reducing the marginal cost to the student, may not produce performance and learning gains for every student. These innovations are therefore unlikely to yield significant results in statistical studies and, counter-intuitively, could in fact lead to empirical findings of less use of some tools, implying the students are spending less time on task in the class by some measures. Total 'time on task' could theoretically be unchanged, or change by such a small magnitude that the empirical analysis yields an insignificant effect. (Worse yet and as noted above, it is even theoretically possible to have a significant decline in the student's total 'time on task' for the course.) The empirical analysis will be dependent upon the distribution of the different types of students in the course.

Therefore, it is appropriate to conclude that one has to be very careful in interpreting the results of a comparison of control-treatment group tests of the effectiveness of teaching technology that examines student attitudes and student performance as indicators of effectiveness. Cost-reducing innovations in technology for teaching could produce empirical results that appear as failures of the technology to improve teaching and learning when the positive effect on teaching learning significantly affects too few students to be picked up by the statistics.

This model also suggests that there is a single consistent method to measure benefits of a new innovation in the technology of teaching. In all cases, time on task of the active learning technology increased as the student optimally responded to the reduction in the (marginal opportunity) cost by increasing the use of the tool, i.e. the lower cost increases the quantity demanded of that input in the production of learning. Therefore studies that measure the amount of time on task spent on that particular active learning tool offers the best empirical measure of capturing any significant effects from the innovation. Again, it is important to estimate the impact on the time spent on that tool, not total time spent on the course. And measuring student performance will not necessarily capture the impact of the innovation if students behave according to the cost-minimization model and chose favor lower total opportunity costs over better performance in the class.

The remainder of this section draws on these lessons. Pulling together the lessons of the model means that a focus on incorporating active learning techniques into courses that are expected to receive significant cost benefits from the incorporating the use of technology is most likely to lead to increases in student learning. These gains will be able to be empirically measured by comparing time spent on these active learning techniques before and after the innovation is introduced.[12] The following suggested areas of future research may therefore yield fruitful results.

There are two areas where principles of economics may usefully incorporate some technological teaching innovations that may yield measurable improvement, in the empirical sense described above. The two areas generally fall into the incorporation of additional active learning techniques and improving assessment.

In the area of active learning, the addition of experiments was clearly enjoyed by the students. There are several possible teaching techniques that may be employed in future courses and make good use of the wireless laptop/tablet hybrid computers:

- In-class, small group 'question and answer' assignments--students 'take control' of the classroom projector for presentations.
- Shift the lecture component of the course to streaming video. Use class time to discuss key concepts and work problems on practice and/or graded problem sets.
- Use externally-developed economics learning material on the Web. (Aplia, MERLOT, etc.)
- Use of classroom polling for in-class quizzing and response to questions. Everybody participates—results displayed immediately. Explore to see if there is a system that can make use of wireless laptop computers instead of proprietary devices.

In addition, there could be substantial improvements in formative assessment if additional substantial student self-assessment materials (Sample Exams and Answer Keys, Practice Quizzes) could be made available via the Internet to allow for constant drill and practice in class at the instructor's prompting and outside of class when students are studying. In addition, the instructor could implement the "One-minute paper" in WebCT (Chizmar

[12] An intriguing methodology for those who cannot use two course sections to perform control class-treatment class type experiments may be to introduce the innovation in the middle of the semester, perhaps after the first exam or the midterm. Measuring time spent on the task by all students in a week prior to that exam and then measuring time spent on task by all students in a week after the technology has been introduced may prove illuminating. If introducing the innovation at midterm, it is probably prudent to

and Ostrosky (1998)) to gain more timely information regarding the students progress and difficulties in the class, perhaps even implementing a Just-in-Time Teaching approach as advocated by Simkins and Maier (2004). These ideas represent exciting potential additions to the course.

It would be equally important to assess their effectiveness in the classroom. As the model built in Section IV clearly indicates, for those augmentations that represent students learning tools it would be necessary to measure their time on task when these technological innovations are provided in a traditional (non-technology) manner and then measure their use and time on task when the technological innovations are provided online instead. In this manner, we could best gauge the significance of their effectiveness.

Section VI. Conclusion

In courses taught in 2004, students in Principles of Microeconomics were exposed to an array of computer educational technologies including: Internet-based course material accessible over the wireless network (syllabus, grade reports, homework assignments via Aplia, sample problems and solutions) and made available to the class via the WebCT classroom management system, chapter reading quizzes taken over the Internet, the use of Aplia to participate in classroom experiments, and the required use of a Gateway M275 pen-enabled Laptop-Tablet PC hybrid computer for note taking.

This paper described the integration of these technologies into the principles classroom. In addition to an overview of issues encountered during implementation, this study also discussed preliminary evidence as to the effectiveness of various technologies based on end-of-semester student surveys. These conclusions motivated the construction of a model to provide insights into how future empirical work can better capture the impact of technological innovations in teaching on student learning, engagement, and attitude.

This paper next offers a simple model of student learning behavior based on the idea that students employ a cost-minimization approach to learning in their courses.

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choose one of the last few weeks to sample in order to allow time for students to learn how to get the full cost advantages from using the innovation.

Students put in the least amount of time and effort to achieve a desired grade, ceteris paribus, employing a cost-minimization approach to learning. The model found that educational technologies that reduce the opportunity cost in a manner that favors active learning techniques will thereby change the trade-offs involved in achieving a desired grade and may result in ambiguous results when the performance and attitude are used to measure the effectiveness of the technology.

An experimental research methodology to test the predictions of the model was presented that emphasized measuring time on task using the active learning technique before and after the technological innovation is introduced. It is believed this can result in an increased chance of finding significant effects if they indeed exist.

By focusing on technologies that offer the student the opportunity to perform a task, complete an assessment, or access information that is not normally performed in a traditional lecture-based environment and tend towards more active learning strategies (online experiments, web-based assignments and group work, etc.) while also incorporating self-assessment tools and techniques into the course, it is expected that significant benefits will be found in future research.

References

Agarwal, R., and A. E. Day. 1998. The impact of the Internet on economic education. *Journal of Economic Education* 29 (Spring): 99-110.

Aplia. 2004. *What is Aplia?* Retrieved June 5, 2004 from *http:/www.aplia.com/index.jsp*.

Ball, S. and C. Eckel. 2004. Using technology to facilitate active learning in economics through experiments. *Social Science Computer Review* 22 (Winter): 469-478.

Becker, W.E. 2000. Teaching economics in the 21st century. *Journal of Economic Perspectives* 14 (Winter): 109-119.

Becker, W. E. and M. Watts. 1996. Chalk and talk: A national survey on teaching undergraduate economics. *American Economic Review* 86 (May): 448-53.

Becker, W. E. and M. Watts., eds. 1998. *Teaching Economics to Undergraduates: Alternatives to Chalk and Talk.* Cheltenham UK: Edward Elgar.

Boylan, M. 2004. What have we leaerned from 15 years of supporting the development of innovative teaching technology? *Social Science Computer Review* 22 (Winter): 405-425.

Brown, B. and C. Liedholm. 2004. Student preferences in using online learning resources. *Social Science Computer Review* 22 (Winter): 479-492.

Chizmar, J. F., and A. Ostrosky. 1998. The one-minute paper: Some empirical findings *Journal of Economic Education* 29 (Winter): 3-10.

Daniel, J. 1999. Using the Web to improve computer-aided instruction in economics. *Journal of Economic Education* 30 (Summer): 225-43.

Fair R., 2003. FAIRMODEL, April 25 version. Available online at *http://fairmodel.econ.yale.edu/modver.htm*

Manning, L. 1996. Economics on the Internet: Electronic mail in the classroom. *Journal of Economic Education* 27 (Summer): 201-04.

Porter, T., T. Riley, and R. Ruffer. 2004. A review of the use of simulations in teaching economics. *Social Science Computer Review* 22 (Winter): 426-443.

Parks, R. P. 1999. Macro Principles, PowerPoint, and the Internet: Four Years of the Good, the Bad, and the Ugly. *Journal of Economic Education* 30 (Summer): 200-09.

Russell, T. 1997. The 'no significant difference' phenomenon, as reported in 248 research reports, summaries, and papers. Available online at *http://nt.media.hku.hk/no_sig_diff/phenom1.html*

Romer, P. 2004. Environmental consumption. Unpublished manuscript presented at the 2004 ASSA annual meetings. January 5, 2004.

Simkins, S. P. 1999. Promoting active-student learning using the World Wide Web in economics courses. *Journal of Economic Education* 30 (Summer): 278-87.

Simkins, S. and M. Maier. 2004. Using just-in-time teaching techniques in the principles of economics course. *Social Science Computer Review* 22 (Winter): 444-456.

Sosin, K., B. Blecha, R. Agarwal, R. Bartlett, and J. Daniel. 2004. Efficiency in the use of technology in economic education: Some preliminary results. *American Economic Review* 94 (May): 253-258.

South Dakota Board of Regents. 2004. *2004 Factbook*. Available online at *http://www.sdbor.edu/publications/*

Talley, D. 2004. RE: Blackboard vs Whiteboard. Email sent to tch-econ listserv on Thursday May 20. Archived online at *http://wueconb.wustl.edu/~tchecndg/archive/2002/0738.html*