The Information Technology Revolution and Higher Education

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Abstract: *Higher education is under pressure from state legislatures and other clients to reduce costs. Two information technologies – increased computing power on the desktop and the World Wide Web – have shifted out the meta production function for instruction in higher education. The theory of induced innovation provides hypotheses about the kinds of educational practices that will attract technological change. Several sources of inefficiency in higher education are identified and likely technology-driven changes suggested. These innovations will provide the means to reduce costs in higher education.*

Key Words and Phrases: *Induced innovation, Learning technologies, World Wide Web.*

Two independent forces are at work to bring dramatic change to higher education. The first is rapid technological change in computers and software. At its initial public offering on August 9, 1995, Netscape Corporation stock sold for $29. In December, 1995, the stock was selling at five times its initial value. The largest stockholder (Netscape's CEO) was a paper billionaire. This explosive growth in Netscape's value symbolizes the market's early assessment of the commercial value of the software and hardware technologies embodied in the World Wide Web. Silicon Valley entrepreneurs are scrambling to respond. The head of Intel Corporation, Andrew Grove, reports "It's [the web] a new territory, and the cyber equivalent of the Oklahoma land rush is on," (quoted in Markoff).

The second force is the rapid growth in the costs of providing higher education. These costs have increased much faster than the consumer price index. In addition, much of higher education is funded by state legislatures faced with rapidly growing entitlement programs and rebellion against higher state taxes. As an example of how this pressure is translated into action, the president of Michigan State University promised the Michigan state legislature that tuition would not rise faster than the consumer price index.[1]

In this paper, I speculate on the consequences of the new computing and web technologies for higher education. The theory of induced innovation can be used to identify activities in higher education that are targets for change because of these innovations. Innovations based on computer technology and the web – the "new

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learning technologies" – will bring fundamental change in education at all levels, but soonest to higher education. The structure of costs in higher education and the availability of equipment and personnel in universities (computing centers, network infrastructure, skilled technicians) provide a ready laboratory for change.

The outcome will ultimately be higher quality education at lower cost. More people will take advantage of higher education than ever before. However, the bright future for web-based higher education does not mean it will be delivered by the institutions (colleges and universities) and their employees who are currently its major providers. Many elements of higher education use skilled labor very intensively. Some of its most common practices are prime targets for labor-saving technical change. The word "revolution" in the title is meant to suggest that stark options face both institutions of higher education and individuals in those institutions. Those who join the revolution will have successes like Henry Ford and Marc Andreesson, Netscape's primary developer. Those who do not join will find themselves in different jobs, as did the buggy whip makers that Ford made redundant.

Pressures to Reduce Cost and Technological Change

Two sets of technical change in information technology make it potentially possible to address the escalating cost of higher education. The first is the rapid increase in desktop computing power. The power of the Apple II computer released in 1980 is a fraction of today's Power PC or Pentium-based computer. Random access memory, hard disk space and modems are orders of magnitude more powerful than they were ten years ago, and cost the same, or less. The second set of technical changes is the development of the Internet and hardware and software that allows anyone to set up a way station on the web. The first widespread web browser, Mosaic, was released for public use by the National Center for Supercomputing Applications at the University of Illinois only in 1993. At that time, almost all Internet addresses ended in ".edu"; in other words, they were at educational institutions. Sometime in mid-1995, the number of ".com", or commercial, addresses surpassed the number of ".edu" addresses. The vast majority of these addresses were set up to provide web pages. The number of web addresses continues to expand at a rapid rate.

Why Education is Next – the Theory of Induced Innovation

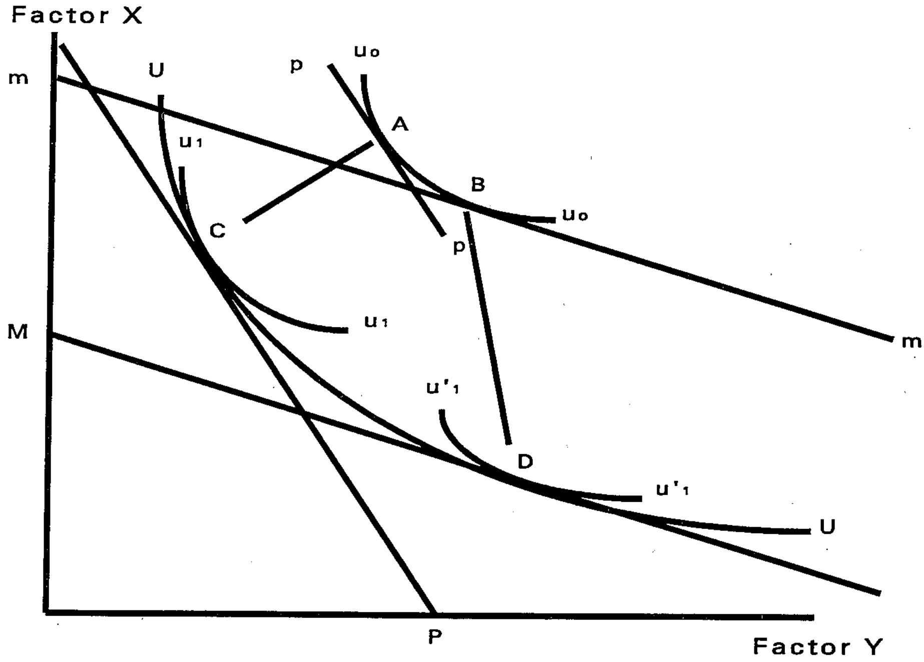
The theory of induced innovation applied to a labor-scarce economy like the United States can be used to explain why higher education is likely to see major technological change. The theory has two elements (see Hayami and Ruttan, 1985, for a recent exposition). The first is that basic research makes possible a large number of possible commercial technologies. This set of technologies is embodied in the meta production function – UU in Figure 1. This function represents the set of possible outcomes for applied research and innovation. With more basic research and innovation, the potential gains from applied research are enhanced (the distance between u_0u_0 and UU grows).

The second element of induced innovation theory is that applied research and innovation do not happen randomly; they are directed by market forces to develop technologies from the meta production function that reduce the use of the factor of production with the largest share in input costs. In Figure 1, if relative factor prices are pp, innovation moves the efficiency frontier from u_0u_0 to u_1u_1. On the other hand, if relative factor prices are mm, innovation moves the efficiency frontier from u_0u_0 to $u'_1u'_1$. The returns to innovation can be measured in terms of the reduction in input cost. For example, if factor prices are mm, the cost savings from innovation are equal to m-M, measured in terms of factor X.

A well-known example of induced innovation resulting in different kinds of commercial technologies is technology adoption in U.S. and Japanese agriculture in the late 1800s (see Hayami and Ruttan, 1970, for details). In both countries, a series of labor-saving innovations were developed and the nature of those innovations depended on relative factor costs. In the United States, land was abundant and labor scarce. Labor costs made up the largest share of agricultural production costs. First, horse-drawn threshers, then steam- and later diesel-driven implements substituted capital and land for expensive labor. Labor input per hectare was reduced substantially, but yields remained constant until the 1930s. In Japan, on the other hand, labor was relatively abundant and land scarce. Innovative activities were directed toward increasing yields to conserve land. Yields rose as did labor input.

In the United States, labor has historically been the scarce factor of production and technological change has reduced the labor content of U.S. output, targeting unskilled labor first, then semiskilled labor, and now more skilled labor. Basic research into the steam engine led to the industrial revolution in the 1750s. Basic chemistry research led to the chemical revolution that began in the 1930s. Both of these revolutions saved unskilled labor. Basic research in computing and semiconductors made possible the computer revolution. Early commercial applications targeted semiskilled labor. The first round of automation began in the 1950s and reduced the labor costs associated with simple services. Backroom accounting and the ATM are examples. The coming wave of labor-saving automation targets more complex services. For example, the most recent Boeing jet, the Boeing 777, was designed entirely on a computer, eliminating the need for skilled draftsmen (Sabbagh). When assembled for the first time, the pieces fit perfectly.

Figure 1.
Based on Figure 1 in Ruttan and Hayami



In higher education, 70 to 90 percent of costs are skilled labor. Induced innovation theory suggests that innovations in higher education will target the use of skilled labor.

An important, but misunderstood, point about technical change and induced innovation in labor-scarce economies is that it has not resulted in lower wages or increased unemployment generally. Past waves of technical change have been accompanied by rapid growth in employment opportunities. The number of people working today is larger than at any time in history. Those countries with the greatest rate of technical change also enjoy the highest standard of living in the world. Rather, innovation targets inefficient use of expensive factors of production. Firms that do not adopt the new innovations are put out of business and the resources transferred to more productive uses.

Sources of Inefficiency in Higher Education

Higher education uses skilled labor very intensively, most of it in the form of instructors. The central question for "firms" (colleges and universities) delivering higher education is to identify the elements of instruction that are candidates for innovation with the new learning technologies. Successful institutions will innovate or adopt these innovations. Others will exit the industry.

We can use previous experience with technological change in the provision of information to speculate about the nature of innovation. Computers automate repetitive tasks. Early computer-based innovations targeted simple repetitive tasks such as those in bookkeeping. Three activities in higher education involve repetition – delivering information (lectures), providing training materials (workbooks, homework), and evaluating mastery (examinations). These three activities are repeated by an instructor every time a course is taught. The first courses targeted by new learning technologies will be those offered many times at many institutions.

Delivery. The most popular approach to delivery of concepts and facts is the lecture/textbook combination. WIn a typical lecture, a body of knowledge, including facts and concepts, is doled out in fifty-minute increments to a group of students by an instructor who talks for the vast majority of that period.[2] An excellent lecturer can make a difference in the performance of students, but most instructors have minimal training in the preparation and delivery of material orally. Even for the best public speakers, the lecture is an inefficient way to convey information. First, the instructor repeats the same lecture each time the course is taught (and instructors all over the country are giving variants on the lecture). Second, evidence from cognitive psychology demonstrates that retention of concepts presented in a lecture can be low, as indicated by the following quote from Gagné.

> H. Simon has estimated that each new bit of information takes ten seconds to encode....A typical speech rate for lectures is 150 words per minute. Let us assume that an average proposition is formed from five words. Therefore students are being bombarded with thirty propositions per minute.... Let us assume that only half of these propositions are new and important. Therefore the hope is that students will encode fifteen new propositions per minute. But H. Simon's work suggests that the new student will encode only six new propositions per minute. Furthermore, if students are actively elaborating on new propositions, this may slow them down to a rate of one proposition per minute! Thus it is no wonder that students sometime seem to forget what a teacher [even the best] has just stated (page 80).

To supplement the lecture, a textbook is often required. The textbook has the advantages that it can be reread and often contains exercises. But textbooks are expensive to produce so they are seldom revised and often do not contain up-to-date factual material. Furthermore, the exercises are not repeatable. If a student has done a problem once, a second repetition contributes much less to learning. The lecture/textbook combination does not address the need for repetition with variation.

Training Materials. To supplement the lecture and textbook, most instructors provide homework exercises. These exercises usually serve two purposes – to let the student practice with the material and to give early feedback on learning outcomes (this approach derives from the "active learning" literature, see Bonwell and Eison, for example). The ideal homework provides the interactive learner with the opportunity to experiment with concepts in a variety of settings. It provides repeated opportunities to use a concept in a framework designed to reinforce learning. It delivers immediate feedback on performance. Unfortunately, much homework is not ideal. It is static so the student has only limited opportunities to experiment. Furthermore, the instructor must grade the same exercise as many times as there are students. Finally, there are often substantial delays between the time the student works on the homework and when it is returned. The teachable moment, which usually comes in the midst of working on an exercise, is lost.

Evaluation of Learning Outcomes. The primary goal of examinations is measurement of a student's learning. Most examinations and homework today share many of the same characteristics (and faults). They require an instructor to grade them individually. More importantly, they provide only a one-time evaluation of the student's knowledge. It is possible, and probably quite common, that students cram for exams. Unfortunately, the long-term retention from cramming is small, so a one-time evaluation of performance can overstate learning.[3] In addition, examinations can never test for all the material covered in a class. Some students are skilled at discovering which materials will be included in the examination while others are not. So what is tested is not overall learning, but ability to "scope out" the test preparer.[4]

Learning Technology Solutions to Inefficiency in Higher Education

In this section, insights from the induced innovation model are used to identify areas in which learning technologies are likely to reduce instructor repetitions, increase efficiency and improve learning. Some possible forms the new learning technologies might take are also suggested.

The lecture is the most expensive repetitive element in the educational process. Efforts to reduce its cost are ancient. After the invention of paper and the printing press had shifted out the meta production function, the textbook innovation was developed in response to the cost (and inefficiency) of the lecture. It allowed a standard body of knowledge to be distributed widely and in a consistent format.

The textbook also changed the nature of the lecturer. Before the textbook, the lecturer was either the researcher who discovered the content of the lecture or was only one step removed. With the invention of the textbook, the role of lecturer was to deliver knowledge gathered by many researchers. The lecturer must no longer also be a researcher.

The textbook did not eliminate the lecture. Instead it allowed a rapid growth in knowledge dissemination and allowed less expensive lecturers, i.e., someone other than the researcher, to convey the information. Today, the repetitive elements of the lecture are a likely target for technological change.

Multimedia Live Lectures. Multimedia live lectures are a first step in increasing lecture efficiency. Multimedia enhancements range from the use of transparencies to the development of full-blown multimedia experiences that include video clips and sound. The development of these materials incurs an up-front cost, but it is a capital investment that pays off by reducing preparation time in the future (through ease of updates) and improves retention (because of a cleaner, better-organized presentation). However, the multimedia lecture does not change the fact that the same or similar lectures are repeated many times. Nor does it give students the opportunity for review.

Multimedia Video Lectures. Multimedia video lectures use the multimedia elements of the multimedia live lecture, but replace the live lecturer with a video counterpart who has rehearsed the material and is trained in public speaking. Besides improving the quality of the average lecture, this material can be made available on demand and can be incorporated with interactive learning materials such as interactive textbooks (discussed below). Attempts to use a similar approach, videotaped lectures, have not had widespread acceptance for (at least) three reasons. First, delivery requires the availability of a single purpose technology (the videotape machine) wherever the lecture is presented (or student access to the tapes). Second, it relies on a technology (the videotape machine) that is otherwise not a central part of the educational process.[5] Third, the videotaped lecture has no interactivity. You cannot ask a videotape a question. However, if these lectures are digitized, and incorporated with other multimedia elements, they can provide an enhanced, interactive learning experience.

Interactive Textbooks with Exercises. Interactive textbooks take the content of traditional textbooks, add multimedia video lectures, and interactive learning tools. A well-designed interactive textbook has the following advantages – inexpensive repetition, interactivity, instantaneous feedback, and repeated evaluation of learning outcomes. For example, instead of using a static graph with a page of descriptive material to illustrate a concept, an interactive textbook has an interactive graph. The student steps through the construction of the graph and then changes parameters to see how the outcome changes. The exercises at the end of each paper chapter can be incorporated throughout the text and made interactive. A concept can be illustrated with a number of problems, each of which can be repeated with variation. The exercises can be graded and results made available to the student instantly. If the student has difficulty with a particular problem, he or she can be given hints or taken to the appropriate part of the text to review the concept.

Interactive textbooks are not yet widely used for a variety of reasons. The software and hardware to provide a truly interactive experience and to deliver video are only now becoming widespread. In addition, development costs are very high. The authors of an early (1990) interactive software package called "Good Graphs" estimated the development costs at $31,000 (Porter and Riley). Textbook companies have (until recently) viewed traditional textbooks as their profit centers and have been unwilling to invest large sums in software. Finally, distribution and platform issues present additional barriers. Many of these constraints to the development of interactive textbooks can be dealt with using a web-based solution as discussed below.

Interactive Mastery Exams. Interactive mastery exams look like a traditional exam, but have several advantages. Because they are administered by a computer, random numbers can be used to devise a unique test of each student. For quantitative questions, the values of variables can be changed. For qualitative questions, a random sample can be taken from a pool of questions. Furthermore, a student can take the test as many times as desired without the need for human grading. Frequently made errors, either by an individual or by a group of test takers, can be reported to the instructor or interactive textbook developer and used to change the presentation. Finally, instructors whose courses rely on a student's prior acquisition of certain concepts and skills can use a mastery exam to evaluate the knowledge base.

In addition to efficiency gains from reducing repetition by instructors, interactive learning materials directly address the needs of students with differing learning styles (Gregorc). The passive learner can listen to the video lecture or read the interactive text and proceed directly to the mastery exam. The active learner can experiment with the concepts in a variety of settings with immediate feedback on performance.

The Role of the World Wide Web. We are in the early stages of the birth of the World Wide Web. New tools appear almost daily. The only statement one can make with complete confidence is that web uses in higher education will expand as rapidly as in other parts of the economy. Nevertheless we can use the ideas presented above to speculate about what uses will become widespread.

The web has several important advantages for the preparation and delivery of interactive instructional software that will reduce the share of labor in the expense of delivering education.

Cross-platform delivery – Because web browsers are available on all types of computers, software developers do not need to develop multiple versions.

Interactivity – With the soon-to-be-universal incorporation of Java and plug-in capability in all web browsers, it is possible to deliver interactive content on the web. Results of online exercises and tests can be stored on the server for evaluation by the instructor.[6]

Maintenance – Because web-based software is stored on a single computer (the web server), revisions are easily incorporated into existing material. Once incorporated they are available to all users.

Access to additional information – The web makes it possible to incorporate much more factual material into the educational process. Instead of a trek to the library to check out a reference (only to find that the last copy of the book has just been checked out), the student can click on a hotlink to the relevant material or use an Internet search engine to find new sources.[7] When a factual question arises, it is possible to "surf" the web in class and get an answer immediately.

Place-bound nature – Finally, the new learning technologies have the potential to revolutionize higher education in another dimension – its place-bound nature. The infrastructure needed to support current institutions of higher education is expensive. Furthermore, for students with jobs or families, the opportunity cost of earning a degree can be prohibitively high. If the educational materials have been computerized, they can be made available for distance learning. Students can use the materials on their schedule and at their pace. The premier advantages of the web over previous distance learning technologies are the degree of standardization and widespread (and growing) availability.

Challenges for Higher Education

Perhaps the greatest challenge facing existing higher education institutions is to distinguish the activities that can take best advantage of the new learning technologies from those that cannot be replaced in the foreseeable future. I have argued above that repetitive parts of lectures, homework and examinations will be early targets for cost savings. The rewards for entrepreneurship in this area are large. For example, textbook companies pay well-known economists large (six digit) "signing bonuses" to author a new principles-of-economics textbook. Revenue streams that support this kind of payment are not yet available for applications of the new learning technologies, but the mechanisms to support them are already in place (charging for password access to web sites, software to provide secure transactions over the web). Early innovators are likely to capture these revenues; early adopters are likely to benefit from them.

What then are the activities that cannot be replaced with the new learning technologies? The most important of these is the ability of an instructor is to facilitate creative intuition (see Bonwell and Eison on active learning). A well-timed answer to a question about a puzzling concept can never be fully automated. The insights gathered in the back-and-forth interaction of a guided discussion cannot be captured when the student interacts solely with a computer. But, even here, new technologies are enhancing the efficiency of these exchanges. Instead of student contact with the instructor being limited to the instructor's office during office hours, questions can be posed on line, either with an e-mail message to the instructor or in a conferencing system. These asynchronous learning methods allow much more rapid feedback to problems. They also make it possible for the instructor to capture the exchange and make it available to other students. Conferencing systems can also facilitate student interaction, from getting help on problems sets to enhancing communication on group projects.

The new technologies will revolutionize the role of the instructor and the educational institution as much as the textbook did. Universities that help instructors successfully incorporate the new learning technologies into their activities will greatly expand their reach. My crystal ball is murky about details of this change, but I offer the following speculations. The home campus will serve as engine, a home for technology, and to capture synergies in research and teaching. Traditional libraries will remain to service the old stock of books and materials, but increasingly they will be electronic repositories and there will be fewer of them. The private sector may take over the delivery of much of the instruction that was formerly the purview of the large lecture or the introductory class. Class structure might change. Instead of a regular meeting for a fixed time period, classes might meet irregularly and consist of all-day retreats or special presentations. Instructors will no longer deliver the same lecture many times, or rewrite old exams. Instead the instructor of the future will be a facilitator – a guide to knowledge sources, a discussion leader, and may play several roles probably not yet thought of.

Notes

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1. Alan Blinder observed in 1991, "We all know that college tuition cannot keep rising 4 percentage points faster than the consumer price index forever.... I believe things will come to a head in the 1990s...."

2. Some instructors use their lecture time in other ways, in particular to foster active learning. This discussion does not refer to those lecturers.
3. The earliest, and still widely cited, research in this area by Ebbinghaus suggested that retention drops to 30 percent after two days for some kinds of oral presentations.
4. One reviewer pointed out that ability to understand what a superior is looking for can be important later in life. However, it is probably better to teach it directly than to rely on this indirect approach.
5. Not everyone agrees with this assessment. The Teaching Company distributes its "Greatest Lectures by America's SuperStar Teachers" on audio- and videotape.
6. An example of the interactive power of Java is useful. A programmer at the University of Illinois created a prototype supply-demand graph Java applet in a couple of days. The graph is drawn on a web page. The user can "grab" the demand curve and move it around. As the curve moves, equilibrium price and quantity are both plotted on the graph and entered into a table below the graph.
7. In preparing this paper, I searched the web for references to memory retention, cramming and Ebbinghaus. The AltaVista search engine found "about 300" documents that contained references to Ebbinghaus. Examples include several student reports on his experiments, syllabi from cognitive psychology courses, and collections of references on memory and retention.

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