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Continuous Improvement in Undergraduate Education: A Possible Dream

Institutions of higher education in the United States steadfastly cling to their business model in the face of a tsunami of change that is redefining both the need for their services and the ways in which this need can be met. Demand for a higher education has soared because a college degree is as essential for achieving a middle-class income today as a high school degree was in the 1970s. Created to serve the uniform needs of an upper-class clientele, colleges now serve an enormously diverse student body. Whether measured by age, educational and cultural backgrounds, race, gender, or need, the diversity of the people served by the system has greatly expanded. Expectations have also grown sharply, as students demand a greater scope and depth of expertise and seek to acquire the complex constellation of talents needed to participate in a fast-paced knowledge economy. Pressures for change are mounting, as administrators struggle to find ways to meet these new demands in the face of constrained public funding and growing public concern over increasing tuition prices.

Even the best universities have reacted to these pressures by making incremental changes in class size and trying to better integrate research and instruction.[1] But these changes are costly and it is difficult to see how they can scale-up to meet the enormous demand. Most knowledge-intensive, service-producing industries have restructured their operations around new information technologies to improve productivity and deliver new, personalized services. For a variety of reasons, education, health care, and several other enterprises organized to meet both public and private needs have been slow to adopt these innovations, and higher education is no exception. But higher education must find a way to introduce the deep man-

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agement innovations needed to use the new technologies in order to meet new demands in ways that improve the quality of the educational services delivered while also controlling costs.

The absence of a strong process for managing innovation and change has made it all but impossible to suggest, let alone test, innovations that require more than minor adjustments to current practices. This inability to embrace transformational change is becoming a barrier to innovation-driven economic growth in the United States and to the prosperity of many Americans.

CHANGES IN DEMAND

Changes in the U.S. economy that are driven by globalization and new technology have dramatically reshaped U.S. labor markets.[2] Demand has grown for strong technical skills in mathematics, science, and written communications, and for the skills needed by the fast, flexible, highly productive teams essential in today's economy: expert thinking, non-routine cognitive skills, and complex communications.[3] Increased requirement for these skills has been driven by sharp growth, both in occupations that have traditionally required postsecondary education and by the fact that higher skills are now needed in occupations that traditionally required only a high school education.[4] Production and office jobs where tasks can be described in a set of rules or procedures are rapidly being lost to automation and global outsourcing. The unskilled jobs that survive are difficult to automate or outsource—janitorial services, nurses' aides, restaurant workers, and the building trades.

These changes are reflected in a rapid increase in the financial return for investment in education. Only college graduates have seen growth in real median weekly earnings since 1979, while high school dropouts have seen their earnings decline by about 22 percent.[5] In 2006, among workers 25 years and older, weekly earnings for full-time wage and salary workers were almost two and a half times more for people with a college degree than for those who had not completed high school. Median weekly earnings for high school graduates were $595, compared to $1,039 for those with a bachelor's degree or higher.[6]

This hasn't gone unnoticed. In 2000, two-thirds of Americans polled by the National Center for Public Policy and Higher Education agreed with the statement that "there are many ways to succeed in today's work world without a college education." By 2007, fewer than half held this belief.[7] The evidence of growth in the demand for higher education is unambiguous: while demographic factors could slow growth in the coming decade, college enrollment has grown 50 percent faster than the population since 1975 and nearly three times as fast since 2000.[8] Over half of the U.S. population has some college experience—57 percent of Americans between the ages of 25 and 29 and nearly one in ten Americans between the ages of 18 and 64 are currently enrolled in higher education of some kind.[9] Worldwide, the potential demand for higher education is enormous, and there will be no slowing of this demand. Nearly two billion people worldwide are between the ages of 5 and 20, and there are half a billion people aged between 20 and 25.[10] Any strategy for providing even a fraction of these people access to quality higher education must include being able to scale up to these levels.

The sharp growth in postsecondary enrollment reflects rising rates for both young people leaving high school and older people seeking to acquire new skills needed for changing work environments. One result is that enrollment is no longer dominated by a largely homogeneous and financially dependent student body that enters college directly after leaving secondary school, matriculates on a full-time basis, and graduates four years later. Today, more than a third of the student body is older than 24, nearly 40 percent are enrolled part-time,[11] and many adult learners work and have responsibilities that compete for their time, energy, and financial resources. Only 3 percent of the baccalaureate degrees earned in 2004 were granted in liberal arts and sciences, general studies, and humanities.[12] The vast majority of degrees were given in business, communications, and other fields driven by particular employment requirements, as many students are interested in acquiring specific skills at the lowest possible cost.

The U.S. system of higher education was developed to respond to a far different set of demands than those driving today's markets. Originally designed to serve an elite minority, the system must now serve dramatically expanded expectations. New approaches to management are needed to ensure that these diverse new demands can be met while still improving the quality of education. It is not possible to do this by simply expanding the existing system, and the extraordinary power that new information technologies have demonstrated in all other areas of the economy makes it impossible to argue that there are no alternatives. What has been missing is a management process capable of embracing change in ways that ensure continuous improvement in the way learning is provided.

MANAGEMENT RESPONSE

Much of the growth in productivity over the last decade has come from the seemingly impossible—growth in services driven by investment in both hardware and software.[13] For years, the heavy investment service industries were making in computers, software, high-speed communications, and other information technology (IT) had been something of a puzzle, as statistics showed no real change in productivity resulting from the investment. But the situation suddenly changed in the 1990s. The average productivity of 22 service industries (weighted by value added), which had grown 1.1 percent annually between 1977 and 1995, grew 3.0 percent yearly between 1995 and 2000.[14]

The use of IT in service and knowledge-based industries has enabled:

- Improved productivity and quality
- Reduced costs
- Radical shifts in the cost structures of service provision
- Customization of service offerings
- Dramatically enhanced service features

• New ways to reach out to customers

The digital revolution created a unique set of opportunities that took years to understand and capture. While initial efforts to use IT typically involved attempts to automate existing processes, it soon became apparent that new technology allowed firms to meet entirely new markets and interact with customers in entirely new ways by personalizing services and meeting the largely unfulfilled needs of the "long tail."[15] But, as Federal Reserve chairman Ben Bernanke points out, "Taking full advantage of new information and communication technologies may require extensive reorganization of work practices, the reassignment and retraining of workers, and ultimately some reallocation of labor among firms and industries."[16]

It's clear that this difficult process has not even begun in education. Despite the tremendous pressure for change, a recent analysis by the Organization for Economic Co-operation and Development (OECD) found that "the education sector has not yet reinvented itself in ways that other professions have done to improve outcomes and raise productivity. Indeed, the evidence suggests the reverse, namely that productivity in education has generally declined because the quality of schooling has broadly remained constant while the price of the inputs has markedly increased."[17] For example, U.S. spending on colleges and universities rose from $233 billion in 1995 to $340 billion in 2005.[18]

Labor productivity in U.S. service industries increased an average of 2.6 percent per year between 1995 and 2001, but education services apparently had negative labor productivity growth.[19] This was certainly not because these institutions failed to invest in information technology—85 percent of all college students reported using computers in 2003—but because they have not been able to engage in the difficult task of understanding how these new tools can be used effectively.

ARE PRODUCTIVITY GAINS POSSIBLE IN HIGHER EDUCATION?

There is compelling evidence from both theory and practice that new approaches can lead to major gains in the rate of learning, retention, and transfer of knowledge mastered for performance in subsequent courses and employment. What has changed with the unfolding digital revolution is that it's now possible to use these new approaches on a massive scale because technology has made them affordable.[20]

Experts in learning have long recognized that it's possible to master complex subject matter much faster than is possible in conventional classrooms by providing individual tutoring for each learner, allowing constant opportunities to ask questions, using highly motivating problems and challenges that help learners recognize the power of the ideas, presenting regular opportunities for practice, and providing many chances to refresh older skills in new contexts.[21] In a landmark series of studies, Bloom demonstrated that one-on-one tutoring improved student achievement by two standard deviations over group instruction, the equivalent of improving the performance of students in the 50th to the 98th percentile.[22]

While cognitive science research has demonstrated that learning improves when students ask questions, classroom environments are set up for teacher monologues rather than classroom dialogues. It is well documented that most learning environments do not stimulate many student questions. According to one research study, a typical student asks 17 questions per hour in a conventional classroom and 27 questions per hour in one-on-one tutoring.[23]

There is significant interest in personalized learning and in how technology can be used to tailor education to the individual and his or her pace of progress. Technology can offer continuous monitoring of progress, provide immediate feedback, use this information to diagnose performance, and adjust instruction to the learner's level of mastery. The technology also has unlimited patience.

A skillfully designed series of challenges accepted as authentic by a learner can get an individual into a "flow," making them willing to spend hours mastering the skills needed to achieve the goal.[24] Flow is a state of high interest and sustained motivation to achieve an objective and continue to make progress. Maintaining this state requires developing a series of compelling goals that allows players/learners to advance at a rate that is not too fast to create anxiety and frustration and not so slow that it leads to boredom. This is extremely difficult to achieve in a conventional classroom environment. The most compelling computer games, however, make effective use of this method to capture and hold a player's attention. One interesting feature of this flow is that the learner is, in effect, constantly being tested but accepting the measurement as a valid test of skill. The key is an ability to keep learning and keep trying until mastery is achieved.[25] This ability to fail, learn, and try again is the essence of successful computer games[26]—people are willing to spend hundreds of hours mastering obscure and usually useless skills.

The new IT tools make it practical and affordable to deliver the kinds of personalized learning experiences and practical problem-solving that learning theorists have championed for many years.

Military Training

There are clear cases where IT has been successfully used in formal education and training. The experience of military training is unequivocal—new technologies can increase both the rate at which expertise is mastered and the rate at which skills demonstrated during instruction are transferred to skills that prove of practical value in the field. A recent survey of results indicated that the current generation of instructional technology can cut either training time or cut costs by a third.[27]

The U.S. Department of Defense has led the world in using advanced instructional technology—including games—for decades. The most visible early example is the flight simulator that has consistently proven its ability to provide productivity gains and high levels of expertise, including expertise in dealing with dangerous situations that could not be practiced in any other way. Multiple studies demonstrate that 60 minutes using a flight simulator is worth 30 minutes flying an airplane in terms of training efficacy.[28] Simulators can be used to build expertise in using and maintaining many different kinds of equipment, from tanks to sonar devices. Simulated war games are now being played by teams who build not only technical skills but the communication, trust, and interpersonal skills essential for effective team operations.

The U.S. Navy has undertaken a systematic reorganization of its training with startling results. In one well-studied example, they took a course that had a fixed "seat-time" requirement and converted it into a series of computer-mediated instructional modules with a clear performance-based test. The result was that instead of having everyone take the same time to master the subject, the time different students took to meet the performance goal fell into a Gaussian distribution. Some took longer than the previously fixed course time but, strikingly, the average student achieved mastery in half the previously prescribed time and some achieved mastery in 5-10 percent of the time.[29]

Reacting to the clear impact of the innovative instructional methods, the Deputy Secretary of Defense issued a directive, "Implementing the Strategic Plan for Transforming DoD Training," instructing the directors of all defense agencies to implement technology training as quickly as possible.

Led in part by military medical training, technology-based instruction has demonstrated major successes in training surgeons, anesthesiologists, first responders, nurses, and other medical professionals.[30] Simulators can authentically reproduce much of what a surgeon must do in such procedures and provide a valid measure of skill.[31,32] The economic advantages of increasing the productivity and effectiveness of medical training are clear because of the high price of conventional training methods and the expense of medical errors, which kill as many as 93,000 Americans and cost the health care system $37-$50 billion annually.[33,34]

Examples in Higher Education

The most common opposition to using these examples as evidence that progress in higher education is possible is that they provide only tools for training and not the kinds of expansive knowledge expected of a college education. There are, however, several answers to these objections. First, the level of expertise that must be acquired by pilots of advanced aircraft, people trained to repair sophisticated electronic equipment, endoscopic surgeons, and other medical professionals is extremely high. Likewise, the combination of physiological and procedural knowledge needed to successfully complete an operation experiencing unexpected complications is also extremely high. In addition, there are numerous technical disciplines in the sciences, engineering, business, and information technology in which technology-based simulations are promising. For example, an artificial tutor system built by Carnegie Mellon and commercialized by Carnegie Learning demonstrates a nearly threefold gain in solving complex algebra and geometry problems.[35]

By applying new technologies and reengineering methods, significant improvements have been demonstrated in higher educational settings. The

National Center for Academic Transformation (NCAT) has worked with 30 two- and four-year colleges to demonstrate that a course redesign methodology could achieve significant improvements in quality while reducing costs in higher education. Large-enrollment introductory courses were redesigned and supported with online tutorials and course management; automated assessment of exercises, quizzes, and tests; continuous computer-based assessment and feedback; course delivery via the Internet; and the replacement of duplicative lectures, homework, and tests with collaboratively developed online material. The NCAT approaches reduced the time faculty and instructional personnel spent on non-academic tasks. According to NCAT, 25 of 30 course redesign projects showed significant increases in student learning while the other five showed learning outcomes equivalent to traditional formats. Among the 30 institutions, costs were reduced by 37 percent on average, with cost savings ranging from 20 percent to 70 percent.

MANAGING CHANGE

Despite the evidence of successful IT integration into service industries, higher education has resisted making the structural changes needed to exploit technology in innovative ways. The traditional model of education has been called an industrial or mass-production model. Former U.S. Deputy Secretary of Education Eugene Hickok said, "As an institution, the schooling system we have is almost perfectly organized. It's evolved over time, almost perfectly organized to sustain and maintain itself. The way it is put together makes it very difficult to encourage the kinds of innovation and changes that you have been talking about."[36] This, of course, is the heart of the problem.

As Matthews points out, "The bedrock assumption that education must take place in classrooms in which a professor teaches a group of students underlies the entire organizational framework for higher education—affecting everything from course accounting and faculty workload to tuition and state funding. But this assumption is no longer valid, mainly because of advances in information technology."[37] Most discussions about innovation in higher education involve tweaking the existing system by squeezing out costs and waste. A move to more advanced learning enabled by new technology tools will require a much different approach.

Effective use of technology will, for example, require redefining many of the roles played by instructional faculty. It is highly likely that the best use of talented faculty time is not giving lectures. The package of activities now bundled into a description of a teacher could be unbundled into different roles and specialties. There will always be a need for inspirational speakers, and for individual counseling and tutoring. The instructional staff can, however, spend much more time working with individuals and small groups if the more routine parts of instruction are provided by technology that can provide individualized instruction built around simulations, virtual environments, and the games and challenges that can be built around them. Scale economies demand that projects involve contributions from experts around the world. Some faculty could choose to specialize in building and maintaining these new systems, while others may elect to provide specialized services (such as in-game tutoring). It is possible that the task of building simulated historic cities, biological simulations, and other virtual worlds will be a new kind of publication—at a minimum, a new way of organizing knowledge and developing connections between diverse disciplines.

Obviously there are many unknowns in the way future learning systems will operate, but it's a rich field for exploration. Unfortunately, the kinds of changes needed to explore them cannot be considered, let alone implemented, given the constraints of existing university management. Such changes would require an approach to management that explores changes that involve not just individuals and small groups but the entire scope of activities that contribute to instruction. It is extremely difficult to undertake such a process, given the way institutions of higher learning are now managed.

No Process for Managing Continuous Improvement, Innovation

Many institutions of higher education lack processes for stimulating ongoing innovation, performance improvement, and organizational change.

While the policy solutions advocated by Secretary of Education Margaret Spellings's Commission on the Future of Higher Education[38] have been widely criticized,[39] it would be a mistake to overlook many of the problems it identified. The commission found, for example, that American higher education has taken little advantage of important innovations that would increase institutional capacity, effectiveness, and productivity, and that it needs to embrace a culture of continuous innovation and quality improvement by developing new pedagogies, curricula, and technologies to improve learning.

In contrast, most public and private-sector organizations that have successfully undertaken major efforts to improve performance have done so by institutionalizing a formal process to identify opportunities for improvement and manage change. While the choice of improvement approaches, tools, and techniques vary widely, generic features typically include commitment from the organization's top leaders, a determination of the requirements of the organization's customers or markets, measurement and analysis to identify opportunities for improvement and to gauge performance, workforce involvement in the improvement effort, and a focus on the design of and improvements in work systems.[40] In addition, many institutions of learning do not continuously identify new learning science and technologies and evaluate these for application.

Many service businesses have achieved significant savings by focusing on their core mission and outsourcing other activities to specialized providers. The strategy also has been used successfully by a number of universities.[41] It makes perfect sense to bring in specialists from government, industry, and other fields to teach or enrich courses—particularly advanced courses that require non-academic perspectives. But while the data is thin, it does appear that most universities have in fact outsourced the teaching of much of the core curriculum—courses that the tenured faculty doesn't want to teach. Non-tenure-track individuals are now half of the teaching faculty,[42] which effectively means abrogating responsibility for managing continuous improvement in a large fraction of its courses.

Problems of Measurement

One of the biggest problems with performance improvement in educational institutions is the absence of any agreed-upon method for measuring what the institutions are delivering. There is probably less information available about the operation of the $340 billion[43] higher education enterprise in the United States than any other major part of the economy. There is, for example, no data on the courses students are taking,[44] let alone information on what value they obtained from these courses. There is essentially no information available on the "value added" by different educational institutions that would account both for the performance of students emerging from the institutions and the backgrounds and abilities of students entering the system.

Metrics are essential for any effective system to reward institutions that are doing a better job in instruction. As Massy points out, "Absent direct information on quality, prospective students must use surrogates like selectivity, faculty-student ratios, research prowess, and even price itself."[45]

The root problem comes with defining what should be delivered by higher education. Newman, Couturier, and Scurry observe that "almost never do institutions [of higher education] set out a clear statement of what the student is expected to learn in terms of knowledge, intellectual skills, competencies, and attitudes in order to become a well educated graduate."[46] Indeed, faculties are often adverse to attempts to define these goals. Massey notes that "each professor is entitled to his or her system of values and priorities, and no authority should be able to say that one system is better or worse than another."[47]

Expertise is notoriously difficult to define, let alone measure, and a key output question rests not just with the end point achieved, but also the value added by any given educational experience. Measuring educational gains directly is difficult if not impossible in many liberal studies and advanced courses that deal with specialties only a few faculty members have mastered. But this reality should not block efforts to collect the information that is essential for improving the basic and introductory courses taken by most of the 20 million people participating in U.S. higher education, and the large number of courses aimed at providing specific employment skills.

The lack of high-quality measurement prevents effective internal management and makes it impossible for ordinary markets to work. In trying to determine which college to attend, students have no practical way to compare the efficacy of competing institutions. They recognize that the prestige of an institution will help them get jobs, but, as Massy points out, "prestige doesn't equate to education quality."[48] A graduate from a prestigious institution may be better qualified because of a diligent admissions process and the ability to associate with other highly talented students, but not necessarily because of quality instruction.

Other surrogates, such as the annual college rankings in *U.S. News & World Report,* are widely denounced by universities that offer no other performance measurements or explanation of how the market for good education should operate. The value of a degree is in fact linked to the degree-granting institution's prestige more than to its demonstrated ability to convey knowledge, and prestige is almost entirely linked to the faculty's research accomplishments—not its teaching expertise. This creates a double distortion in the market for educational value: students and the public may place a higher value on prestige than on educational value, and therefore use research-driven prestige as a measure of educational value. However, the connection between prestige in research and an institution's ability to add value to a student's mastery of complex subjects is very weak. With the exception of small seminars focused on a research faculty's narrow line of work, there may not be much of a link between an institution's research prowess and its ability to deliver educational value to the general population of its students.

CAN WE DO BETTER?

Higher education is under enormous pressure to provide a large percentage of the population with sophisticated skills at low cost. For the most part, these institutions have not taken a serious look at the structural changes needed to do this. This is essentially a problem of management. The demand is enormous, tools to meet the new demand are available, but the process of connecting solutions to problems is not functioning effectively. Given the high national stakes involved, the federal government has a unique responsibility to intervene in ways that facilitate the search for solutions. It should not do this by imposing a rigid set of prescriptions, but should instead encourage the emergence of an infrastructure that would facilitate the development and vetting of new approaches, backed by a serious and sustained program of research that could both drive basic invention and provide national metrics of success.

A strategy of four key components could be considered.

Metrics

The earlier discussion focused on measuring the quality of individual institutions. The capabilities of modern information technologies, however, open an entirely new set of possibilities: systems that permit superior approaches to delivering learning services, which will enable education institutions to acquire national and international markets quickly if they achieve results. Such systems would permit the operation of a worldwide market for effective approaches to learning, independent of the specific institution delivering instruction. These markets would have to operate on a national or international scale to be effective. The basis of competition would presumably include price, time to achieve mastery, and the quality of the student's experience.

Such a system would depend on agreeing how to evaluate whether an individual had achieved an acceptable level of expertise in a field—something that may well be impossible in some fields—and it would require some market-like mechanism with which students, faculty, and others could rate and rank different approaches so that market-like forces could drive continuous improvement. In principle, the market could evaluate both the approach to instruction (Did the students find it engaging and effective? Did subsequent instructors find the students well prepared?) and the methods used to evaluate expertise (Did the measurement translate into effective performance in either a job or an advanced course?).

Some market-like mechanism is essential to achieve a process of continual invention and improvement in educational service delivery. Traditional methods of using large statistical samples to determine whether an educational intervention is working make no sense in an environment where many experiments must be underway simultaneously and where the underlying technology is changing continuously.[49] Many modern firms now make the bulk of their income from products and services that weren't available a year earlier. They are forced to rely on agile methods for testing new concepts and on markets to tell them whether they are succeeding. It is difficult to maintain a solid research base that ensures that concepts requiring long-term basic inquiry get adequate support. The federal government has a unique role in filling this gap—an issue I will discuss later.

The metric of a student's expertise driving the markets could mean a student's mastery of a complex body of knowledge as evidenced by an ability to perform difficult tasks. Student expertise can also mean an ability to operate effectively in situations closely mimicking work environments—whether this means perfecting social skills, a capacity for assembling information and making decisions, or an ability to display complex engineering or laboratory expertise in difficult situations.

Any process of defining metrics of expertise should include both scholars in the field and the people who may hire the graduates. Employers should participate in defining both types of expertise they need in new hires and should be willing to accept performance-based testing as a criteria for making hiring decisions. Institutions of higher learning must also be willing to accept such measurements of student performance as the basis for moving to higher levels of instruction and for receiving degrees and other certification.

It is much more likely that two-year institutions and for-profit colleges and universities would be willing to participate in such an experiment with metrics of student expertise if employers were also willing to link measured performance to hiring. Employees taking courses that lead to specific certificates or certifications would be obvious early candidates.

The danger of starting with specific skills and certifications is that it may make it too easy for prestigious universities and colleges to argue that the system may work for working-class skills but never for the high-level intellectual achievements expected of their graduates. Of course, simulation-based exploration and learning cannot replace all conventional learning. There should be a variety of tools that could support to varying degrees a wide range of learning modalities—tutors, simulations, collaborative platforms, virtual-delivery mechanisms, etc.—that can be applied to a wide range of learning objectives, approaches, and course materials.

A New National Learning Infrastructure

The national and international markets for innovative learning systems just described require a new kind of infrastructure to operate effectively. It is clearly possible to build such a system by adapting available commercial products for use in learning. Service enterprises worldwide have developed radically improved business practices that depend in large part on an infrastructure that supports constant collaboration and customer access, but with little regard for geographic location or work site. Efficient markets operate in ways that reward successful strategies with return customers and provide strong incentives for continuous innovation.

No such tools are available to education organizations, in part because the very idea of a large team working to build and improve a course of instruction is not part of the current approach to education. Given the right infrastructure and review process, there is good reason to believe that many individuals working in higher education would willingly participate if the tools were available. Many people have contributed to the development of Wikipedia and the virtual-world Second Life, and a growing number of businesses have deployed platforms that encourage the public to help the company solve problems, identify innovations, and improve products.

It would be possible, for example, to have large numbers of people worldwide collaborate in building sophisticated simulations that could be used for many different types of instruction. Some of these could involve building historic cities complete with architecture, art, and music, and simulations of the economic and cultural activities underway in these cities. The construction would require contributions from historians in many fields. Each object and activity would be peer reviewed. A viewer walking through the virtual city would be able to open any object (say, by clicking on it) and open a path to a complete set of documentation, pointers to online reference material, and review comments made while the object was being created. This could be continuously updated. A similar approach could be used to build a sophisticated simulation of anatomy or other biological models.

These systems could be collaboratively built through a process managed in a way that combines a journal publication and software production. Instead of being built and abandoned, the system would be continuously improved by new research and by responding to comments from users. One enormous advantage of the new virtual-world platforms such as Wonderland, Second Life, Croquet, and Active Worlds[50] is that they ensure that codes will not be rendered obsolete by changes in computer operating systems, graphic chips, and other changes that have often left sophisticated simulations stranded by obsolete media.

Built collectively by many contributors, much like traditional publications, these virtual worlds would combine knowledge from individual experts in a unique way. All objects in the virtual world would need to connect directly in the most concrete ways: virtual representations of historic buildings, for example, would be located in the (virtual) sites where the actual buildings were located. Since all objects in the virtual world will be linked seamlessly to the 2D web and citations to traditional literature, the new publication form would be an extension of rather than a substitution for traditional methods.

Once such systems were built, other teams of people could use them as the basis for a variety of approaches to learning. The learning could be as simple as leading students on a guided tour through the space and asking questions, or it could be as sophisticated as designing elaborate problem sets and challenges where success requires mastery of the subject matter. Instructors or assistants could participate by appearing as avatars in the space or manipulating the simulation in response to student actions. Avatars with artificial intelligence could also provide answers and pointers to the literature. Learning modules could be rated by instructors and students—important parts of the system. Assembling a course could include exploring the most successful learning modules developed worldwide. The way these markets could evolve is unclear; however, individual universities could establish their own branding by offering experiences in publicly available virtual worlds that are supported by unique contributions of their own faculty, who could meet students in person and in the virtual spaces.

Like the World Wide Web itself, the technical core of the system would be an agreed-to set of standards that would allow combining different software services. Most of the software needed to deliver component services (e.g., instructional management tools, virtual 3D worlds, identity management tools, project management tools, tools for locating people with appropriate skill sets such as Facebook, and standardized approaches to graphics and scripting) is already available.[51] The computing and communication needed to support a national and international system are already in place.

There are precedents for a publicly supported education infrastructure. A generation ago, the Corporation for Public Broadcasting used federal funds to purchase satellite communication services to deliver public broadcasting information, including a significant amount of educational video material.[52] The National Science Foundation has invested heavily in supercomputer centers and high-speed networking that connects university and college campuses.[53] It is also possible that major foundations would be willing to provide startup support for such a system if there were evidence that it would be used effectively.

While a significant amount of the material created should be in the public domain, there must also be room for proprietary and protected extensions. Individual universities would continue to compete on the basis of the quality of their campuses faculty and facilities and access to faculty mentors who would facilitate online learning.

The missing element in all of this is a management system capable of building the few pieces of software needed to permit the system to operate, and encouraging agreement on standards. This could facilitate the formation of teams that would build key instructional simulations (e.g., the cities and other simulations). Success will depend on whether higher education is willing to provide the incentives needed to let scholars participate in the construction of these simulations and whether they are willing to accept the skills demonstrated in them as valid measures of student expertise.

Experiments with New Organizational Models

The proposed infrastructure would permit ambitious institutional experiments in a virtual world that could short-circuit the elephantine decision-making processes that would have to be undertaken to conduct such experiments within existing institutions. Unfortunately, the volunteer users will remain marginal without a willingness from higher education institutions to experiment with the structural and institutional reforms needed to make these new tools more than a curiosity.

The key issue is how to encourage experiments in the use of new technologies in higher education. It is possible that incentives provided by both employers and a federal agency could encourage experiments on a national level. The incentives would have to be both financial—inducements through hiring based on an agreed-to metric—and prestigious—based on proving that a new approach allowed for quicker mastery and used a method that learners found inherently more engaging.

By far the majority of courses offered in higher education deal with basic subjects in engineering, biology, psychology, and other areas where large numbers of students take virtually identical classes. Teaching in these subject areas could benefit enormously from a technical infrastructure designed to help students master ideas at rates tailored to each individual, and it could also help close the gap between abstract knowledge and practical applications. It's likely that even some advanced seminars could benefit if the faculty led a small group of students, who could be physically located in many parts of the world, through a simulated human cell showing how recent discoveries have updated standard models of cell biology.

One intriguing possibility is that if learning productivity could in fact be increased by 30 percent or more,[54] it might be possible for students to master the basic skills of a two-year college graduate by the 12th grade, thus making these skills a universal requirement of a high school education.

Rapidly accelerating basic learning may seem out of reach, given the current K–12 system's struggle to meet even elementary quality goals. However, a new approach could well increase the quality and interest in education in ways that could reengage the large number of students now bored or burdened with second-rate instruction. If this becomes possible, higher education could focus on both building key 21st-century skills and the specialized credentials needed in fields such as law, engineering, and medicine.

Research and Development

Research in educational theory, pedagogy, and the neuroscience of education has greatly expanded our understanding of how people learn. Little work has been done, however, on the challenge of converting this knowledge into practical, actionable programs that can achieve learning productivity gains for large numbers of people—even though it would be difficult to find an area where research investment could have a more important impact on the nation's future. There is currently no national infrastructure for funding or conducting the ambitious program of research, development, demonstration, and evaluation needed in education. We urgently need a structure capable of emulating the kinds of government, university, and business collaborations supported by institutions like the Semiconductor Manufacturing Technology Consortium (SEMATECH) which plays such a critical role in maintaining U.S. competitiveness in semiconductors. The "National Center for Research in Advanced Information and Digital Technologies," recently passed as a part of the Higher Education Opportunity Act, has the potential to be the nucleus of such an operation.[55]

Detailed roadmaps of research needs have been designed by groups of experts spanning many disciplines.[56] Research needs include developing a better understanding of how people learn and master expertise most effectively in complex fields using technology-enabled learning tools, tailoring the pace and nature of instruction to individuals and teams, and finding ways to both define and measure the real expertise of these individuals and teams.

CONCLUSION

There's no question that U.S. universities have been key enablers of national scientific and technical progress for a generation and have set a gold standard for universities worldwide. But these institutions have resisted the new technology, management, and organizational approaches that have enabled other service-providing enterprises to improve quality and cut costs. This failure is making it increasingly difficult to ensure that all Americans have access to the quality of educational services that the modern economy demands. Furthermore, rapidly rising tuition has put the issue into the national spotlight. Instead of reacting with creative new approaches, however, it is possible that the reforms introduced to cut costs will actually reduce the quality of the education delivered or force educational institutions to seek ever greater levels of funding.

The economist William Baumol has argued that there is no great harm in the growing cost of education, since the increasing returns to education justify paying more.[57] This is both a false choice and an example of market inefficiency. Just because the returns to education are rising is no excuse for failing to seek greater quality and efficiency of education and reducing its cost. Improving the quality and reducing the cost of education is especially important, given that a broader portion of the population, many with moderate economic means, need access to some postsecondary education and training simply to maintain a middle-class status.

Other information-intensive service industries have found creative ways to use new technology to improve what they offer, including personalizing services. There is every reason to believe that the same result can be achieved in education. Given the resistance higher education institutions have to the kinds of changes required, however, external force may need to be applied to stimulate the development of the basic processes and skill sets needed to attain essential change.

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1. Examples of thoughtful efforts in improving undergraduate education can be found at <http://web.mit.edu/urop/research/tll.html>, and <http://www-tech.mit.edu/V127/N20/harvard.html/>.
2. The New Commission on the Skills of the American Workforce, Charles B. Knapp Chairman (authors), National Center on Education and the Economy, Tough Choices or Tough Times, , National Center on Education and the Economy, 2007. http://www.skillscommission.org/
3. Frank Levy and Richard Murnane, *How Computerized Work and Globalization Shape Human Skills Demand*, Harvard University, (revised) May 31, 2006 http://web.mit.edu/flevy/www/computers_offshoring_and_skills.pdf First published in *The New Division of Labor: How Computers are Creating the Next Job Market* (Princeton University Press, 2004).
4. Anthony P. Carnevale, "College for All?" Change: The Magazine of Higher Learning, Volume 40, Number 1 / January-February 2008 Pages 22 - 31. 5. Chart 2-6. Real Median Weekly Earnings for College Graduates Have Trended Up Over Time, Charting the U.S. Labor Market in 2006, U.S. Department of Labor, Bureau of Labor Statistics, August 2007. http://www.bls.gov/cps/labor2006/chart2-6.pdf
6. Chart 2-4. Education Pays, Charting the U.S. Labor Market in 2006, U.S. Department of Labor, Bureau of Labor Statistics, August 2007. http://www.bls.gov/cps/labor2006/chart2-4.pdf
7. John Immerwahr and Jean Johnson, Squeeze Play: How Parents and the Public Look at Higher Education Today, report prepared by Public Agenda for the National Center for Public Policy and Higher Education, May 2007.
<http://www.highereducation.org/reports/squeeze_play/squeeze_play.pdf>
8. U.S. Census Bureau, Table 1. Population and Area: 1790 to 2000, 2007. Page 7 (http://www.census.gov/prod/2006pubs/07statab/pop.pdf
U.S. Census Bureau, Population: 1960 to 2005, 2007. Page 7
<http://www.census.gov/prod/2006pubs/07statab/pop.pdf>
National Center for Educational StatisticsTable 181. College enrollment and enrollment rates of recent high school completers, by race/ethnicity: 1960 through 2004, 2006
http://nces.ed.gov/programs/digest/d05/tables/dt05_181.asp
9. U.S. Department of Education, Digest of Educational Statistics. Table 9. Number of persons age 18 and over, by highest level of education attained, age, sex, and race/ethnicity: 2007 2006. <http://nces.ed.gov/programs/digest/d07/tables/dt07_009.asp?referrer=list>
10. U.S. Census Bureau 2008, http://www.census.gov/cgi-bin/ipc/agggen International Data Base (IDB) <http://www.census.gov/ipc/www/idb/> (queried July 30, 2008)
11. U.S. Census Bureau see
<http://www.census.gov/population/www/socdemo/school/cps2006.html> and Table 270. U.S. Census Bureau, College Enrollment by Sex and Attendance Status: 1983 to 2005 http://www.census.gov/compendia/statab/tables/08s0270.xls#Notes!A1)
12. Carnevale see note 4.
13. Barry Bosworth and Jack Triplett, *Is the 21st Century Productivity Expansion Still in Services? And What Should Be Done about It?*
<http://www.brookings.edu/~/media/Files/rc/papers/2007/01_productivity_bosworth/01_pro-

ductivity_bosworth.pdf> (Paper prepared for the National Bureau of Economic Research and the Conference on Research in Income and Wealth, Cambridge, MA, July 17, 2006.)

14. Jack E. Triplett and Barry P. Bosworth, "Productivity Measurement Issues in Services Industries: Baumol's Disease Has Been Cured," *FRBNY Economic Policy Review,* September 2003 Vol. 9, No. 3, September 2003. It is online at <http://www.newyorkfed.org/research/epr/03v09n3/0309trip.pdf>.
15. Chris Anderson, "The Long Tail," *Wired*, October 2004.
16. Ben S. Bernanke, remarks presented to Leadership South Carolina, Greenville, SC, August 31, 2006, available online at www.federalreserve.gov/newsevents/speech/Bernanke20060831a.htm.
17. *Organization for Economic Co-operation and Development Education at a Glance 2007*, http://www.oecd.org/dataoecd/4/55/39313286.pdf
18. Table 208. School Expenditures by Type of Control and Level of Instruction in Constant (2004-2005) Dollars 1980-2005, 2008 Statistical Abstract of the United States, U.S. Bureau of the Census. http://www.census.gov/prod/www/statistical-abstract-1995_2000.html
19. Barry Bosworth, "Productivity in Education and the Growing Gap with Service Industries," paper delivered to the The Internet and the University Forum, Aspen CO, 2004.
20. Henry C. Kelly, "Games Cookies and the Future of Education," *Issues in Science and Technology*, summer 2005, available online at http://www.issues.org/21.4/kelly.html.
21. John Bransford et. al., *How People Learn: Brain, Mind, Experience, and School*, Washington DC, National Academies Press, 1999.
22. Benjamin S. Bloom, "The 2 Sigma Problem: The Search For Methods of Group Instruction as Effective as One-to-One Tutoring," *Educational Researcher*, Vol. 13, No. 6 (Jun.-Jul., 1984), pp. 4-16):
23. Arthur C. Graesser and Natalie. K. Person, "Question Asking during Tutoring." American Educational Research Journal, 31, 1 (1994): 104-137.
24. Mihaly Csikszentmihalyi, Flow: The Psychology of Optimal Experience, New York: Harper & Row, 1990, .
25. Henry C. Kelly, "More Tests Please," *Science Progress*, 2008, available online at http://www.scienceprogress.org/2008/02/more-tests-please/.
26. Federation of American Scientists, Learning Technologies Roadmap: FAS Summit on Educational Games , 2006, Washington DC. Available at <http://www.fas.org/gamesummit/Resources/Summit%20on%20Educational%20Games.pdf>
27. J. D. Fletcher, Advanced Technologies for Learning in the Department of Defense, paper presented at Forum on the Digital Promise, Washington DC, June 14, 2006.
28. Jesse Orlanski, "The Cost Effectiveness of Military Training, in Proceedings of the Symposium on the Military Value and Cost Effectiveness of Training, NATO headquarters, Defense research Group on the Defense Applications of Research (DS/A/DR(85)167), Brussels, Belgium, January 1985. Also see Howard.R. Champion and Gerald.A. Higgins (2000) Charting the Vision for the Future of Simulation Training in the Military: Meta-Analysis and Planning, NTIS DAMD17-99-2-9028. Also see Howard.R. Champion and Gerald.A. Higgins (2000) Charting the Vision for the Future of Simulation Training in the Military: Meta-Analysis and Planning, NTIS DAMD17-99-2-9028.
29. VADM Kevin Moran, Commander Education and Training Command, Sea Warrior and the Revolution in Training: The Right Person, Right Place, Right Skill, Right Time, Best Value, presented at Navy, 2006, presented at the Implementation Fest, Joint Advanced Distributed Learning Co-Laboratory, August 22-24, 2006, Lake Buena Vista, Florida. http://www.jointadlcolab.org/downloads/ifest/2006/presentations/Vice_Admiral_Kevin_Moran .ppt#413,3,5 Vector Model
30. James D. Westwood, Randy S. Haluck, Helene M. Hoffman, Greg T. Mogel, Roger Phillips, Richart A. Robb, Kirby G. Vosburgh eds. Medicine Meets Virtual Reality 14: Accelerating Change in Healthcare, IOS press, Amsterdam, the Netherlands, 2006. 31. Teodor. P. Grantcharov, Linda. Bardram, Peter Funch-Jensen, and Jacob. Rosenberg, "Learning Curves and Impact of Previous Operative Experience on Performance on a Virtual Reality Simulator To Test Laparoscopic

Surgical Skills," *The American journal of surgery* 2003, vol. 185, no2, pp. 146-149

32. Steven. S. McNatt and C. Daniel. Smith, "A Computer-Based Laparoscopic Skills Assessment Device Differentiates Experienced from Novice Laparoscopic Surgeons," *Surgical Endoscopy* 15, 2001, vol. 15, no10, pp. 1085-1089.
33. Linda T. Kohn, Janet M. Corrigan, Molla S. Donaldson, editors, *To Err Is Human: Building a Safer Health System*, Institute of Medicine, National Academy Press , Washington DC, 1999.
34. Steadman Randolph H. ; Coates Wendy C. ; Yue Ming Huang; Matevosian Rima ; Larmon Baxter R. ; McCullough Lynne; Ariel Danit "Simulation-Based Training Is Superior to Problem-Based Learning for the Acquisition of Critical Assessment and Management Skills," *Critical Care Medicine* . 34, no. 1 (January 2006): 151-157.
35. Kenneth R. Koedlinger, Albert T. Corbett, Steven Ritter, Lora J. Shapiro, Carnegie Learning's Cognitive Tutor: Summary Research Results, 2007. http://www.carnegielearning.com/web_docs/CMU_research_results.pdf 2007.
36. Summit on Education Games, see note 26.
37. DeWayne Matthews, The Transformation of Higher Education through Information Technology: Implications for State Higher Education Finance Policy, Western Interstate Commission for Higher Education, January 26, 1998. http://www.wiche.edu/Telecom/projects/tcm/it_fin.htm.
38. A Report of the Commission Appointed by Secretary of Education Margaret Spellings, Charles Miller Chairman,, A Test of Leadership: Charting the Future of U.S. Higher Education, available online at http://www.ed.gov/about/bdscomm/list/hiedfuture/reports/final-report.pdf.
39. Statement of the Committee on Government Relations, AAUP Statement on Spellings Commission Report , http://www.aaup.org/AAUP/GR/federal/FutureofHigherEd/spellrep.htm .
40. The Malcolm Baldrige National Quality Award "Criteria for Performance Excellence" is among the popular frameworks characterized by these generic features.
41. Lucie Lapovsky, Engaging the Board in Conversations about College Costs, report prepared for the Association of Governing Boards of Universities and Colleges, 2006. http://www.agb.org/user-assets/Documents/research/costs/lapovsky.pdf
42. Jennifer Washburn, *University Inc.*, Basic Books, New York, NY 2005
43. Table 208. School Expenditures by Type of Control and Level of Instruction in Constant (2004-2005) Dollars: 1980 to 2005, 2008 U.S. Statistical Abstract, U.S. Bureau of the Census. http://www.census.gov/compendia/statab/tables/08s0208.pdf .
44. The National Center for Educational statistics has some data for the 1992-1993 school year, but it has not been tabulated and remains on archived tapes.
45. William F. Massy, *Honoring the Trust: Quality and Cost Containment in Higher Education*, Anker Publishing Company, Inc, Bolton, MA, 2003p 42.
46. Frank Newman, Lara Couturier, and Jamie Scurry, *The Future of Higher Education*, Jossey-Boss, San Francisco, 2004 p. 135.
47. Massy, p. 15.
48. Massy, p. 5.
49. The Department of Education attempted to do this in a $10 million dollar study in 2007, titled "Effectiveness of Reading and Mathematics Software Products: Findings from the First Student Cohort," but its approach was widely criticized. See H. Kelly, "Technology Can Transform Schools," Education Week, Aprill 3, 2007.
50. See http://vworld.fas.org/bin/view.
51. For a survey of available tools see http://faslearn.org/universalclient/index.php?title=Universal_Opensource_Virtual_Worlds_Client_Whitepaper
52. See Corporation for Public Broadcasting http://www.cpb.org/aboutcpb/.
53. See the National Coordination Office for Networking and Information Technology www.nitrd.gov.
54. See Fletcher, *Advanced Technologies for Learning*.
55. HR 4137, Section 802. http://www.rules.house.gov/110/text/110_hr4137.pdf

56. Learning Federation. For broad research goals and medical research, see http://www.fas.org/programs/ltp/publications/roadmaps.html; for using game concepts in learning, see http://www.fas.org/programs/ltp/publications/summit/index.html.
57. Quoted in James Duderstadt, *A University for the 21st Century*, University of Michigan Press, Ann Arbor, MI, 2000, p. 140.