Education Technology as a Transformational Innovation

Candace Thille
Carnegie Mellon University

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President Obama's goal to raise the nation's college graduation rate to 60% by 2020 demands that we address the seemingly impossible challenge of making higher education less expensive and more accessible while also increasing its effectiveness. The difficulty is heightened by the fact that faculty and institutions must support not only an increase in the number of students but also greater variability in the student population's background knowledge, relevant skills and future goals. Educational technology can be a key component of success, but only if it leverages the results and methodologies of learning science to create transformational innovations that fundamentally change the way higher education is developed, delivered and improved year-after-year.

Addressing the cost of higher education will clearly be an important factor in increasing graduation rates. From 1982 to 2006, the cost of higher education in the U.S. increased 439%, far outstripping the consumer price index, which increased 106% over the same period.[i] Explanations of the high cost of higher education abound, and include: efforts to improve service to students and the professional lives of faculty[ii]; poor management practices; new requirements for complying with government regulations[iii]; and increased capital equipment costs associated with teaching increasingly complex topics requiring more expensive technology.[iv]

Of particular interest is the analysis of cost pressures in most service industries, first described by William Baumol and William Bowen in 1965[v], and again by Baumol in 1967 when he explicitly identified education as one service industry subject to seemingly uncontrollable upward price increases.[vi]. In many industries, employees are continually more productive thanks to technological innovation in tools and equipment. In contrast, in traditionally labor-intensive sectors, such as higher education, there is little or no growth in productivity over time. Meanwhile, wages in those very service sectors without productivity gains naturally rise because those industries must compete for labor with production sectors that have achieved productivity gains through technology and hence can pay higher salaries. This explanation of rising costs has come to be known as Baumol and Bowen's "cost disease."

In his 1967 article, Baumol seemed pessimistic about technology making a significant difference in education. Unfortunately, the history of the use of information technology in higher education over the last three decades has justified much of his pessimism. The advent of the personal computer, the Internet, and the World Wide Web has led to a focus on delivery of traditional materials through these new channels as a way to address the problem of access and cost. Many colleges, universities and Open Educational Resource providers have rushed to provide an online presence with little consideration of how online materials would be used to create an effective learning experience, or how they would actually meet the skyrocketing demand for quality education.[vii] Even today, we see policies advocating "online courses" or "open educational resources" as though the medium alone were the solution. But simply putting materials online is not enough. The important question is not "Is online education as good as (or better than) traditional education?" but, "How can the online technology be used to transform education?"

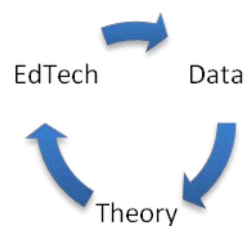
One current strategy for using information technology to create more access and lower cost is to record lectures and make those recordings available as an educational resource to both matriculated students and the world at large. Providing 7x24 Web access to lectures is viewed as a possible path for lowering the cost per student because more students can be provided the same service of listening to a lecture at only the incremental cost of recording and webcasting the lecture. The problem with this solution is that technology is being used to provide lower-cost access to the service of lecturing but that is not, ultimately, the most important service provided by higher education. The service that needs to be made available at lower cost is the collection of learning activities that improve learning outcomes. Our understanding of human learning from the last 20 years of research tells us that learning is an active, not a passive process and simply providing lectures is not sufficient.

Advances in learning science, combined with advances in information technology, can create just the transformative force needed to make higher education more affordable and help it to better serve a larger number of students.

The premise of learning science, still a young field, is that much of student learning is driven by a set of learning mechanisms. The goal of learning science is to articulate these mechanisms and thereby describe, explain, and predict human learning. While many practitioners say they "know what works," based on apparently successful efforts in particular classes or at particular institutions, the descriptions of "what works" are often complex exemplars that are challenging to replicate and scale and, even when replicated and scaled, often do not "work" in the new context or for the new population.

When the precise underlying mechanisms of learning are not known, instruction must be provided through "intuitive instruction" in which quality instruction is provided only by talented or highly-trained professionals - "great teachers". However, as patterns in student learning are studied by scientists and the underlying mechanisms of learning are articulated and tested, instruction can evolve into the realm of "evidence-based instruction" – where data are gathered to show that certain approaches are better than others and to stipulate the contexts in which they are likely to work. To replicate and scale effective instructional practice, we need to be able to describe what works as a set of underlying mechanisms that are influenced by a set of student and contextual variables. In other words, we need to create better theories of learning, which inform both teaching practice and the design of educational technology. To develop better theories, we need more data from more students in more contexts.

One unique power of educational technology is its ability to embed assessment into virtually every instructional activity and use the data gathered to create a virtuous cycle for continuous improvement:



Educational technology becomes a transformative innovation when it instantiates learning science into reusable and easily accessible technology-enabled courses, which simultaneously collect the data that learning scientists need in order to better understand and articulate the underlying mechanisms of human learning.

Carnegie Mellon's Open Learning Initiative (OLI): One Example of Such a Transformational Innovation

OLI learning environments use intelligent tutoring systems, virtual labs, simulations, and frequent opportunities for assessment and feedback to produce the kind of dynamic, flexible, and responsive instruction that fosters robust learning. The OLI approach is not to be confused with most models of online learning or open courseware repositories. The OLI model is different in three ways:

- OLI courses are developed by teams composed of learning scientists, faculty content experts, human-computer interaction experts, and software engineers in order to make best use of multidisciplinary knowledge for designing effective learning environments.

- The OLI system collects real-time, interaction-level data on how and what students are learning and uses this data to drive positive feedback loops to students, instructors, course design teams, institutions, and learning science researchers.

- The OLI approach contributes new knowledge to learning science—a new academic discipline that is emerging from a combination of disciplines, including cognitive psychology, computer science, human-computer interaction, and machine learning.

The OLI evaluation teams (internal and external to the project) have conducted a number of learning and effectiveness studies that have shown that in measuring learning outcomes, OLI courses used with minimal instructor support are just as effective as traditional instruction. OLI evaluators have also conducted *accelerated learning studies* [*] that have shown how the combination of scientific design of instruction and robust, continuous feedback improves instruction along an important dimension – time to completion – with no diminution of quality.

Evaluation studies have been conducted at institutions spanning a range of Carnegie classifications, including community colleges and have shown accelerated learning, reduced attrition and significant correlations between OLI learning activities and learning gain. Results include:

- Students using the OLI course in hybrid mode successfully learned as much material in less than half the time (completed the course in 7.5 weeks with 2 class meeting per week while traditional students completed the course in 15 weeks with 4 class meetings per week) and the OLI students demonstrated learning outcomes that were as good as or better than traditional students. Further, there was no significant difference in retention between OLI students and traditional students in tests given 1+ semesters later[viii].

- Students using OLI in the fully online mode at a large state university achieved the same learning outcomes as students in traditional instruction and many more successfully completed the course. In this study of nearly 300 students, students only 41% of the students in the traditional instruction completed the course while 99% of the students in the OLI condition successfully completed the course[ix].

- Community College accelerated learning study in Logic: An instructor with minimal experience in logic. Students obtained high levels of performance on more advanced content (~33%) not covered in traditional instruction[x].

- Studies of the data logs for students from multiple institutions in the OLI Statistics, Biology and Engineering Courses show a positive and significant correlation between student use of OLI learning activities and their quiz scores on the corresponding target topics with no such no correlation with unrelated topics -“a dose response effect”. The findings in some of these studies also indicate that self-regulation of learning was more correlated with performance than sheer quantity of usage[xi].

- A study conducted on the OLI Chemistry course revealed that the number of engaged actions with the virtual lab explained about 48% of the variation observed in the post- test scores. The number of interactions with the virtual lab outweighed ALL other

[*]In the accelerated learning studies students use OLI courses in hybrid mode which is a combination of classroom instruction and online material but with significantly less classroom time than a regular course.

factors, including gender and SAT score as the predictor of positive learning outcome[xii].

Supporting students with learning environments that more effectively teach the course content can only be part of the solution. We know that a student's motivation, goals, implicit theory of intelligence, and meta-cognitive and self-regulated learning competencies all play interrelated and significant roles in learning success. Supported by research colleagues at the Pittsburgh Science of Learning Center (a National Science Foundation-funded project), the OLI project is also exploring the impact of these other factors that contribute to high dropout or failure rates, and refining our approaches to mitigating those factors. Each use of an OLI course is an opportunity to disentangle these factors and refine methods for better supporting student learning.

A New Model of Course Development

Together with community colleges, OLI is experimenting with new collaborative models of evidence-based course development and adaptation. The CC-OLI (Community College Open Learning Initiative) statistics course development team was launched in January 2010. The team finished its initial target goal, releasing two new versions of the OLI statistics course in August 2010, modified to fit community college needs. Faculty from multiple community colleges across the country joined the CC-OLI development team to adapt and improve the course. The team used the data collected over multiple semesters of student use to drive the redesign.

The team increased the number of interactive activities by more than 30% and moved many of the activities that were previously located behind links into the main content flow, as the student-log data gave compelling evidence that students are more likely to complete the activities if they are placed in the flow of the page rather than behind a link. The course was also restructured to reduce barriers to adoption by making it easier for instructors to choose topics to include/exclude from their courses while still maintaining the overall coherence of the course. The revised course is being used and evaluated in more than 25 institutions in the fall of 2010. The data collected from this next round of use and evaluation will be used again to focus the efforts for further refinement.

The new course also includes a refined "Learning Dashboard" for instructors. The "Learning Dashboard" is a tool that provides instructors detailed reports about what their class has mastered by working in the OLI environment and which concepts and skills will need more attention in class. Based on feedback and user testing with instructors, the new version features a streamlined user interface designed to allow instructors to reach the information they need more quickly and to focus the instructors' attention on learning outcomes. Unlike reports from traditional course management systems, the Learning Dashboard presents instructors with a measure of predicted student mastery displayed by learning objective. The dashboard also provides more detailed information, such as the class's predicted mastery of sub-objectives, predicted mastery for individual students, and the types of tasks with which the students are struggling the most.

Challenges to Bringing this Model to Scale

Colleges are conservative institutions, and a general aversion to change poses a risk to institutional and faculty acceptance of these new approaches. The OLI technology is surely a disruptive one, requiring a switch from an intuitive approach to an evidence-based approach for course development, delivery, and assessment. Tight funding environments may heighten this inherent resistance to innovation, as instructors and staff fear for their jobs and academic freedom. Even when colleges recognize the power of educational technology to improve instruction, a "not invented here" mentality may exacerbate reluctance to adopt the concepts central to OLI's effectiveness. Understanding the faculty and institutional issues in adoption and use is clearly critical to supporting innovation at scale. Therefore, in addition to conducting new large-scale studies that demonstrate the effectiveness of the OLI learning environments in increasing completion rates, OLI researchers are also studying the conditions and impact of OLI use on faculty and institutions.

Recommendations for Policy:

Policy recommendations for "expanding the use of technology in teaching and learning" or "developing/utilizing open source learning materials" should be refined to clarify that the technology must demonstrate effectiveness in supporting students to achieve learning outcomes. Ideally, the technology should build the mechanisms for assessing both student achievement and the effectiveness of the instructional intervention directly into the teaching and learning process. Without continuous, robust assessment of all instructional strategies aimed at articulating the underlying mechanisms, we will continue to see "one off" successes with little understanding of what works, what doesn't work, and how to bring effective strategies to scale.

We need further integrated research to determine which interactive teaching strategies yield the biggest gains in student learning in various contexts. Technology can offer ways of creating, over time, a complex stream of data about how students think and reason while engaged in important learning activities. Additional research on the data representations and analysis methods best
suited for different audiences and objectives are clearly needed.

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[i] *Measuring Up, The National Report Card on Higher Education*, 2008, p. 8. http://measuringup2008.highereducation.org/

[ii] See the discussion on the "administrative lattice" and "academic ratchet" in, Robert Zemsky, Gregory R. Wenger, and William F. Massy, *Remaking the American University: Market-Smart and Mission-Centered* (Rutgers University Press, 2006)

[iii] Malcolm Getz and John J. Siegfried, "Cost and Productivity in American Colleges and Universities," in Charles Clotfelter, Ronald Ehrenberg, Malcolm Getz, and John J. Siegfried (eds.), *Economic Challenges in Higher Education* (University of Chicago Press, 1991), pp. 261-392.

[iv] Robert Archibald and David Feldman, "What Do Higher Education Costs Rise More Rapidly than Prices in General?," *Change Magazine*, May/June 2008, pp. 25-31.

[v] William J. Baumol and William G. Bowen, "On the Performing Arts: The Anatomy of their Economic Problems." *The American Economic Review*, (1965), pp. 495-502.

[vi], William Baumol ,"Macroeconomics of Unbalanced Growth: The Anatomy of Urban Crisis," *The American Economic Review*, (1967), pp. 415-426.

[vii] Zemsky, Robert and Massy, William. Thwarted Innovation, What Happened to e-Learning and Why, The Learning Alliance, 2004.

[viii] M. Lovett, O. Meyer, & C. Thille, C., "The Open Learning Initiative: Measuring the effectiveness of the OLI statistics course in accelerating student learning," *Journal of Interactive Media in Education* (2008), http:// jime.open.ac.uk/2008/14/

[ix] C. D. Schunn and M. Patchan, "An evaluation of accelerated learning in the CMU Open Learning Initiative course 'Logic & Proofs,'" *Technical Report by Learning Research and Development Center*, University of Pittsburgh, (2009)

[x] C. D. Schunn and M. Patchan, "An evaluation of accelerated learning in the CMU Open Learning Initiative course 'Logic & Proofs,'" *Technical Report by Learning Research and Development Center*, University of Pittsburgh, (2009)

[xi] P. S. Steif and A. Dollár, "Study of Usage Patterns and Learning Gains in a Web-based Interactive Static Course", Journal of Engineering Education, Vol. 98, No. 4, pp. 321-333, (2009)

[xii] *K. Evans, D. Yaron, G. Leinhardt, "Learning stoichiometry: a comparison of text and multimedia formats."* ***Chemistry Education Research and Practice*** (2008) **pp.** 208 – 218.