Online Education: A Unique Opportunity for Cognitive Scientists to Integrate Research and Practice

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Abstract

That there is a rapid expansion of online education is much better understood than what its consequences will be. This symposium considers that one key feature of "real-world" education that takes place on the Internet is that it provides a high level of experimental control and automatic data collection & analysis, which can support cognitive science research that was previously only possible in laboratory settings and small-scale educational environments. The presenters discuss the unprecedented opportunities online learning provides for conducting research in ecologically valid contexts: linking existing laboratory experiments to relevant online contexts, personalizing adaptive instruction, embedding *in vivo* research studies of education, and using the vast amount of high quality data available. The product of such work is not only theories and empirical discoveries that better characterize learning, but also the opportunity to directly translate these into practical benefits to students through concrete improvements to educational resources.

Keywords: learning; education; technology; online education; online learning; e-learning; intelligent tutors; educational data mining;

Laboratory experiments and classrooms rarely overlap in the physical world, much to the chagrin of educational psychologists. But researchers increasingly use computers and the Internet to run experiments, and the recent explosion of online education now brings student learning into the very same digital medium. Hundreds of thousands of students take Massive Open Online Courses (MOOCs from Coursera, Udacity, EdX) at the university level, use websites like www.mathtutor.cmu.edu, www.khanacademy.org or www.mathalicious.com that are populated with K-12 videos & interactive exercises, not to mention a host of supplementary online educational resources that can be delivered over devices as ubiquitous as smartphones.

These web-based resources offer the potential for extensive novel research on learning (Anderson, 2008; Ally, 2004; Linn et al, 2004; Pea, 2003). One distinctive feature is the possibility of embedding *in vivo* randomized experimental comparisons (Koedinger et al, 2012) into these (now) ecologically valid online educational environments. Furthermore, unlike educational environments in bricks-and-mortar education, in a digital medium there can be precise control over materials and instructions, and systematic collection of data from large samples (Stamper et al, 2012). In addition to investigating learning processes in authentic educational contexts, studying online learning provides an unprecedented opportunity to simultaneously carry out basic and applied research. When experimental manipulations correspond to comparisons of instructional effectiveness, stimuli are educational materials, and dependent measures are students' learning outcomes, experimental methodology from cognitive science can be used to iteratively improve the pedagogical principles incorporated into online educational resources. Rather than years of laboratory research that "suggest" instructional principles or are eventually followed by a laborious classroom study, the steps from basic to translational research are greatly simplified.

Moreover, the product of research programs that investigate online learning is not only new scientific knowledge, but specific products that concretely instantiate theories and learning principles. These proven and iteratively improved resources can be provided directly to students for use as they exhibit such great fidelity to research context. And using the Internet, they can be disseminated to hundreds of thousands of students over an extended period of time, all across the world – a clear contribution of cognitive scientists to public education.

Mapping laboratory studies to online educational settings

In the context of his research on the role of explanation in learning, Joseph Jay Williams presents a perspective from basic experimental psychology on finding fruitful connections between lab experiments and experimental manipulations embedded in authentic online educational resources. He discusses the interplay and transitions between typical lab experiments (research on explaining membership in artificial categories, Williams & Lombrozo, 2010), to online studies using convenience samples from Amazon Mechanical Turk (in which explaining promotes learning of mathematics, Williams et al, 2012), and experiments implemented using identical mathematics exercises on Khan Academy's educational platform, but with real students who visit the site for genuine help with authentic schoolwork.

This approach blends rigorous experimentation in contexts with different levels of control, rapid iterative improvement, and the development of an ecologically valid educational resource. Such web resources serve a basic research goal, as (for example) the structure and dynamics of an interactive video or exercise reflects a concrete and empirically supported instantiation of theoretical principles and empirical discoveries that would otherwise be verbally communicated – reminiscent of the benefits of computational models. They also serve a clear practical goal, as the products of research are empirically evaluated and multiply revised resources that have been shown to work in learning online. They can therefore be disseminated using the massive scale of the internet, to improve education for thousands of students over an extended period of time.

Using Eye-Tracking and Rapid Assessment to Detect and Address Knowledge Gaps During Learning

Alexander Renkl has conducted extensive research in computer environments, such as investigating how learning from worked examples can be enhanced by the use of scaffolding, fading and other instructional design features. He reports a project that bears on the ability of online environments to personalize instruction.

The project develops and researches an adaptive approach to closing gaps in students' knowledge that remain after initially studying the learning materials. Rapid assessment tasks are interspersed in the learning environment to identify the knowledge deficits in individual students, which can then be targeted by prompting learners to engage in remedial activities. In the first experiment, university students (N = 71) learned about mitosis in a multimedia learning environment. When rapid assessment tasks indicated gaps in students' knowledge, the experimental manipulation was to randomly assign them to one of three different types of prompts, hypothesized to be optimal for the particular deficit. However, we found that each type of prompt was equally effective in closing the knowledge gaps identified by rapid assessment.

In the second experiment we obtained further results as to the effects of different prompts – finding that ostensibly "enriched" prompts even led to sub-optimal effects. Comparing our results to the final test of learning outcomes, we identified our rapid assessment tasks as failing to detect important knowledge gaps. Rather than risk disturbing learning by increasing the number of rapid assessment tasks, we now integrate eye-tracking data to improve our assessment. We use this data to select rapid assessments to *verify* the presence of a knowledge gap. Pilot data suggests such a combined approach is more effective for learning.

In-vivo experiments with cognitive tutors

As director of the Pittsburgh Science of Learning Center and one of the pioneers in the development of intelligent tutoring systems, Ken Koedinger has helped set the standards of rigorous research in realistic educational contexts. He discusses how cognitive tutors can be used to conduct *in vivo* experiments in classroom environments, collecting sophisticated learning measures and giving personalized feedback to learners. He considers how cognitive tutors and in vivo experiments can be integrated with online education platforms to take advantage of complementary strengths and disseminate these benefits on a large scale.

Automated improvement of instructional systems using educational data mining

John Stamper runs Datashop, the largest openly available repository of detailed student learning data, with learning and instructional events logged as often as every 10 seconds, scored, and tagged based on models of student learning. He will discuss how educational data mining and statistical models of students' learning can be used to infer improvements to instructional systems, automatically develop intelligent tutoring systems, and shed light on many of the problems that typically are solvable only through extensive human investment.

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