

The open education (OE) movement provides new mechanisms to democratize education by interconnecting ideas, learners, and instructors in new kinds of constructs that replace traditional textbooks, courses, and certifications.

Opening Education



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The clamor surrounding the high cost, limited access, static nature, and often low quality of the world's education systems is reaching a crescendo. Many observers claim a serious threat to the future of youth, the training of workforces worldwide, and even the democratic process. In addition, education is out of reach for many in the developing world, widening the gap between rich and poor people and countries.

The statistics are alarming. As Figure 1 shows, since 1978 textbook costs in the United States have risen 812 percent, more than three times the consumer price index (Perry 2012). No wonder that US student debt has topped \$1 trillion and that a recent California study found that 7 out of 10 college students now choose not to purchase textbooks (Redden 2011). Adjusted for inflation, tuition costs at US colleges rose over 25 percent in the past decade. Besides cost, there is also the challenge of inadequate educational facilities. At a South African university in 2012, 11,000 desperate applicants vying for 800 openings induced a stampede that left one person dead and 22 injured.

Now imagine a world that has forestalled this crisis: a world where textbooks and other learning materials are free for all on the web and low-cost in print, adapted to many backgrounds and learning styles, interactive and immersive, translated into numerous languages, continually updated and corrected, and never out of print. A world where computers assist in teaching so

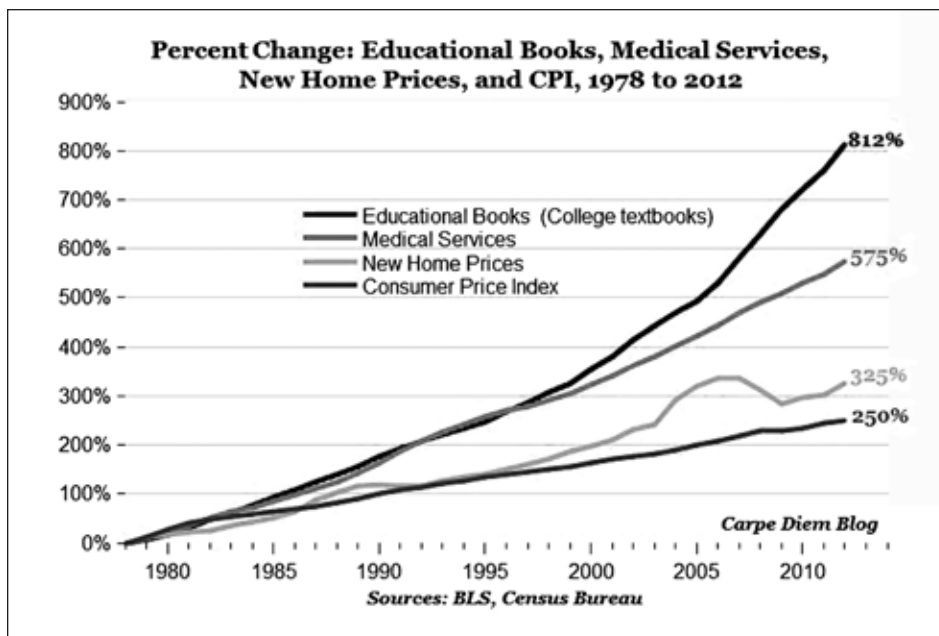


FIGURE 1 Percent changes from 1978 to 2012 in three Bureau of Labor Statistics' consumer price index (CPI) categories—educational books and supplies, medical services, and an aggregate of all goods and services (designated Consumer Price Index in the graph)—as well as the median price for new homes from the Census Bureau. Since 1978 textbook costs have risen more than *three* times the average increase for all goods and services. Reprinted with permission from Perry (2012).

that instructors can spend more time teaching concepts and values, giving insights, and providing inspiration. A world where courses can be taken from anywhere at any hour of the day or night. A world where a student study group encircles the globe. A world of “living” (i.e., constantly updatable) certifications and degrees that continuously document students' and lifelong learners' accomplishments.

While this world was just a dream even a decade ago, the open education (OE) movement that aims to create it is coalescing and gaining momentum. The movement is based on a set of intuitions shared by a remarkably wide range of academics and students: knowledge should be free and open to use and reuse; collaboration should be easier, not harder; and people should receive credit for what they've learned and demonstrated.

The OE movement is rapidly gaining momentum because of a “perfect storm” comprising two converging factors. First, the global financial downturn is forcing education systems worldwide to dramatically reduce costs on every front by updating their business models. Second, powerful telecommunication and information technologies are providing new, cost-effective ways to distribute content, support personal interactions, and store information.

In this article I describe developments on four fronts that promise to reinvent the way educators produce and disseminate educational materials and fundamentally change students' relationship with content. These four “frontline” areas are textbooks, courses, personalized learning, and certification.

While the timescale of education transformation has until now been measured in decades, even centuries, OE has the potential to radically alter the way authors, instructors, and students interact worldwide virtually overnight.

Open Textbooks

The textbook was the answer to the educational challenges of the 19th century, but it is the bottleneck of the 21st century. The textbook of today is static, linear in organization, time-consuming to develop, soon out of date, and expensive. Moreover, it provides only “one-size-fits-all” learning that doesn't cater to the background, interests, abilities, and goals of individual students.

Open Educational Resources

Communication and information technologies provide a golden opportunity to reinvent the textbook. Open educational resources (OER) include text, images, audio, video, interactive simulations, problems and answers, and games that are free to use and reuse in new ways by anyone around the world. The key elements of OER are:

- *open copyright licenses*, like those of Creative Commons, that turn educational materials into living objects that can be continuously developed, remixed, and maintained by a worldwide community of authors and editors; and
- *information technologies*, like the Internet and web, that enable easy digital content reorganization and virtually free content distribution.

The OER approach to textbooks has several important benefits:

- It brings *people* back into the educational equation. Those who have been “shut out” of the traditional publishing world—talented K–12 teachers, community college instructors, and scientists and engineers in industry—can add tremendous diversity and depth to the educational experience.
- It reduces the high *cost* of teaching materials. In many states, college students now spend more on textbooks than tuition.
- It reduces the *time lag* between the production of learning materials and their delivery to students. Many books are out of date by the time they are printed. This is particularly problematic in fast-moving areas of engineering, science, and medicine.
- It enables *reuse*, recontextualization, and customization such as translation and localization of course materials in myriad languages and cultures. This step is critical for reaching the entire world’s population, where clearly one size does not fit all for education.

“Connexions” at Rice University

Several OER projects are already attracting millions of users per month. Some, like MIT OpenCourseWare (ocw.mit.edu), are top-down-organized institutional repositories that showcase their institutions’ curricula. Others, like Wikipedia, are grassroots organized and encourage contributions from all comers.

In addition, there is Connexions (cnx.org), which I founded in 1999 with three primary goals: (1) to convey the interconnected nature of knowledge across disciplines, courses, and curricula; (2) to move away from a solitary authoring, publishing, and learning process to one based on connecting people in open, global learning communities that share knowledge; and (3) to support personalized learning (more on this below). Connexions has grown into one of the largest and most used OER platforms—each month millions of users access over 20,000 educational “building blocks” and 1300 e-textbooks (as of April 2013). In addition to web and e-book outputs, a sophisticated print-on-demand system enables the production of inexpensive paper books for those who prefer or need them, at a fraction of the cost of books from a conventional publisher.

Content contributions come from all over the world in more than 40 languages, including Spanish,

Chinese, Vietnamese, and Afrikaans. In South Africa, Siyavula (cnx.org/lenses/siyavula), a nonprofit resource for technology-powered learning based in Cape Town, is developing a complete K–12 curriculum. Vietnam is using Connexions as a faculty development tool (voer.edu.vn). Professional societies such as the IEEE are advancing their global educational outreach and inreach through content development and peer review (ieeecnx.org; Kelty et al. 2008). Indeed, because the Connexions founders and early adopters were signal processing faculty and IEEE members, there is a strong extant signal processing foundation to build on.

To help busy college instructors adopt OER and save students money, Connexions recently partnered with a consortium of philanthropic foundations to launch OpenStax College (openstaxcollege.org) to provide free textbooks for today’s highest-impact college courses. Textbooks are authored by professional domain experts and peer reviewed by practicing college instructors, and the library also offers lecture slides, image libraries, and test banks.

Open educational resources (OER) include text, images, audio, video, interactive simulations, problems, and games that are free for anyone to use.

The initial reaction to the project has been very positive. As of April 2013, more than 150 institutions had formally adopted the library’s *College Physics*, *Introduction to Sociology*, *Biology*, and *Concepts of Biology* texts. *College Physics* now exceeds 3 percent market share. On an annual basis, more than 23,000 students are saving more than \$2.3 million. When completed, every year the initial 25-book OpenStax College library will benefit over 1.2 million students at a 10 percent market share, saving students an estimated \$120 million. Compared to the philanthropic investment required to build the library, the return on investment in terms of student savings is approximately 600 percent per year. And a number of planned translation/localization projects aim to make a further global impact.

Open Courses

A student transported from 1900 to the present would feel quite at home in one of today's typical lecture courses. Lectures remain a primarily passive experience of copying down what an instructor says and writes on a board (or projects on a screen). Such "teaching by telling" is effective for conveying information, but ineffective for imparting knowledge and actively engaging students.

Communication and information technologies make it possible to do much more. Schools have offered distance learning courses for decades. New technologies now make it straightforward to replace in-person lectures with YouTube videos, paper-based homework with web pages, and graders with computer algorithms. OE is taking the concept even further by opening access to any student, anywhere.

The Khan Academy (khanacademy.org) advanced OE by demonstrating the power of freely distributed short (10-minute) videos of mini-lectures and worked problems, thus enabling students anywhere to learn a new subject, solidify their understanding, or clear up their misconceptions. Moreover, the videos enable teachers to "flip the classroom" by having students view the lecture materials online on their own and then using valuable class time to discuss and work problems. The flipped classroom aligns with the philosophy of Confucius, who famously remarked: "I hear and I forget. I see and I remember. I do and I understand."

Massive online open courses (MOOCs) open up access by transporting lectures, examples, homework, tests, and office hours to the web.

Massive open online courses (MOOCs) take this concept a step further by transporting *all* the components of a course—not just lectures and examples, but also homework, tests, and office hours—to the web and opening up access to all. The canonical success story of a MOOC is Stanford University's fall 2011 Artificial Intelligence course that enrolled over 160,000 students from 190 countries. Volunteers translated it into 44 lan-

guages, and more than 23,000 students completed the course. Adding a human element to the course, thousands of study groups formed spontaneously via social networking sites, some grounded locally and others distributed globally.

The success of this initial experiment spawned a menage of educational MOOC enterprises, such as the for-profit Coursera, Udacity, and Google CourseBuilder and the nonprofit edX and Class2Go. A related enterprise is TED-Ed, a new education arm of the successful TED franchise that enables the remix of video lectures (not unlike the work of Connexions with textbooks).

Like OER, MOOCs democratize access to high-quality learning experiences and provide a large and widespread potential audience for enterprising instructors. They also enable students to form long-lasting social bonds with students from around the world, which bodes well for the increasingly global economy. The ability to replay online course material as many times as needed makes it possible to move away from competition in education (competition for access to courses, for the instructor's time, against each other due to curve-based grading) toward a world where everyone eventually masters the material and gets a good grade. Finally, MOOCs and other online courses will afford an unprecedented opportunity to observe and analyze student learning experiences, and the resulting quantities of data can be used to improve and eventually personalize the learning process.

Personalized Learning

At all levels of education, students typically receive instruction and activities as a group, regardless of differences in aptitude, prior knowledge, motivation, or interest. This one-size-fits-all approach forces students into artificial timelines for learning that often cause them to become bored or fall behind. Recent advances in technology provide the opportunity to revolutionize education by gathering data on student learning interactions and using the information to tailor instruction and activities to the needs and characteristics of each student in order to maximize learning outcomes.¹

Limited but promising progress on computer-based personalized learning has built on a *content-centric* approach in which human domain experts tease apart

¹ Such personalized education is one of the NAE's Grand Challenges for Engineering (www.engineeringchallenges.org/cms/8996/9127.aspx).

and exhaustively encode (using ontologies, rule-based systems, etc.) the relationships among content, concepts, misconceptions, problems, solutions, and potential feedback in a subject. Although successful, this approach to facilitate learning has been extremely difficult to realize without major investments of time, money, and expertise. For instance, my discussions with a number of commercial providers of personalized learning systems have revealed that developing a single personalized learning course requires a multimillion-dollar investment and several years of work by disciplinary specialists. Progress in this area will entail not only lowering the costs and complexities of developing personalized learning systems but also increasing their range beyond that provided by hand-coded rules.

A promising alternative to the content-centric approach to personalized learning is a *data-centric* approach. In contrast to the years needed for humans to estimate how an individual student *might* interact with the content, a data-centric personalized learning system gathers data from *actual* learner interactions with the content and uses the data to tune the presentation and feedback to students. For the last four years, I have led a multidisciplinary team of researchers in machine learning, computer systems, cognitive psychology, and education from Rice University and Duke University in developing a data-centric personalized learning system called OpenStax Tutor (openstax-tutor.org). Its three central elements are:

- **Cognitive science.** We leverage three cognitive science principles—retrieval practice, spacing, and feedback—that are robust and highly

replicable; generalize themselves across different types of learners, materials, and contexts; and increase long-term retention and transfer of learning. To maximize learning efficacy, the learning plan carefully sequences content and practice opportunities to allow retrieval practice and spacing while providing detailed, timely, and appropriate feedback.

- **Open community.** We expand the universe of learning content, problems, solutions, and feedback available to the learner by bringing together materials and metadata generated by an open community of contributors, including conventional authors, educators, and even learners. In particular, we leverage Connections and QuadBase (quadbase.org), an open-source repository of homework and test questions founded at Rice University.

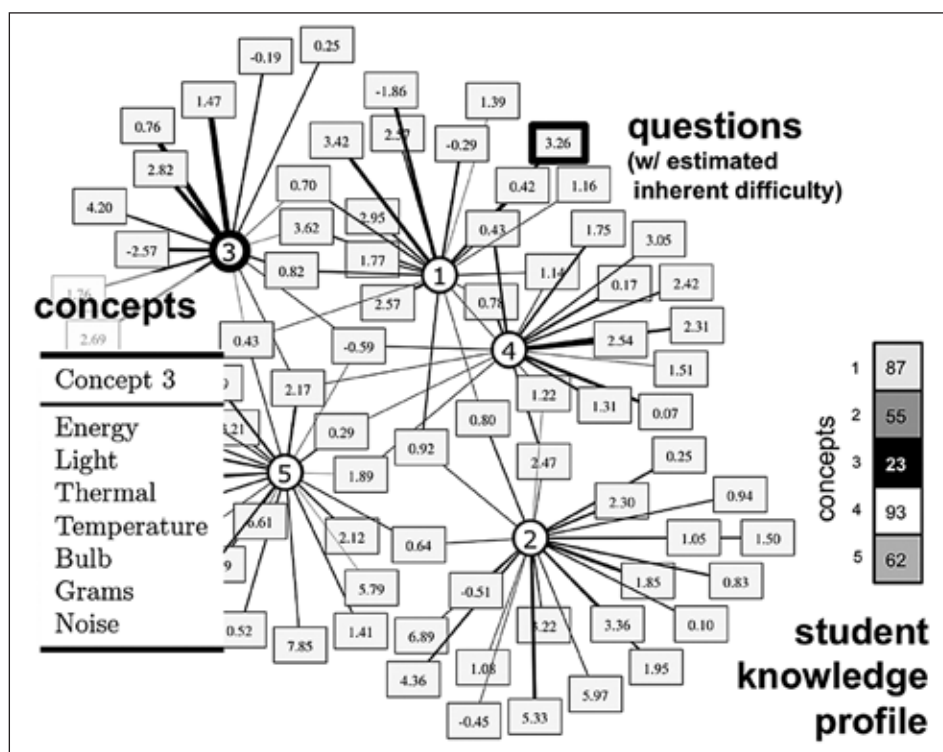


FIGURE 2 The result of applying a sparse factor analysis (SPARFA; Lan et al. 2012) learning/content analytics algorithm to data from a grade 8 science course in STEMscopes, an online science curriculum program. The data input to SPARFA consisted solely of whether a student answered a given potential homework or exam question correctly or incorrectly. From these limited and quantized data, SPARFA automatically estimates (a) a collection (in this case five) of abstract “concepts” that underlie the course (“Concept 3” is illustrated here); (b) a graph that links each question (rectangular box) to one or more of the concepts (circles), with thicker links indicating a stronger association with the concept; (c) the intrinsic difficulty of each question, indicated by the number in each box; (d) descriptive word tags drawn from the text of the questions, their solutions, and instructor-provided metadata that make each concept interpretable (as shown for Concept 3); and (e) each student’s knowledge profile, which indicates both estimated knowledge of each concept and concepts ripe for remediation or enrichment. Reprinted with permission from Lan et al. (2012).

- **Machine learning.** We increase the flexibility, generalizability, and scalability of OpenStax Tutor by eschewing hand-coded rule-based systems for providing feedback in favor of data-driven machine learning algorithms that adapt and optimize feedback and learning plans by analyzing the content, problems, and solutions plus data from a large number of learner interactions. For example, Figure 2 illustrates a concept graph that was automatically generated by a sparse factor analysis (SPARFA) learning/content analytics algorithm using only the course “grade book” matrix indicating which students answered which questions (in)correctly (Lan et al. 2012).

In beta testing, Rice University electrical and computer engineering students who used OpenStax Tutor during the 2011–12 academic year improved their learning outcomes by one-half to one letter grade compared to those who relied on the standard practice of weekly homework without retrieval practice, spacing, and timely feedback. Beta testing is continuing with engineering students at Rice, Georgia Tech, the University of Texas at El Paso, and the Rose-Hulman Institute of Technology (Terre Haute, Indiana).

Personalized learning systems like OpenStax Tutor can both enhance the learning experience for students and provide college instructors and K–12 teachers with immediate data to better inform their instruction and forge a more direct connection with their students. They enable teachers to immediately understand not only how their students are performing on the core course concepts but also what they are doing that influences their students’ success (and failures) in their learning. Significantly more efficient and effective learning should result.

Credit and Open Certification

OER and MOOCs enable flexible new ways to learn, but how do students (of any age) get credit for what they’ve learned? Today, in order to get credit, one typically enrolls in a rigid, often multiyear program that measures learning achievement in terms of “seat time.” Such rigidity is no longer practical in the modern knowledge economy, as more and more careers require constant training on new knowledge and skills. As John Seely Brown (2005, p. 4.3) put it, “As [workers] move from career to career, much of what they will need to learn won’t be what they learned in school a decade earlier. They will have to be able to pick up new skills outside of today’s traditional educational institution.”

Clearly, students and lifelong learners need a more flexible system for certifying their skills acquired both in and out of school. Again, communication and information technologies offer a solution.

Recently developed “stacked credentials” record and track learning achievements in subjects such as web design, welding, and calculus. In particular, Mozilla’s Open Badges project (mozilla.org/badges) has developed tools to make it easy to earn, issue, and display “badges” (a simple kind of credential) on the web. Badges allow people to provide a more complete picture of their skills and competencies to potential employers, mentors, peers, and collaborators. They acknowledge the fact that learning happens everywhere (not just in school) and document much more than a report card about people’s acquired skills and competencies. The beauty of badges is that, like OER, they are modular and thus enable learners to build a career ladder over time, transforming the learner from a passive consumer in a constrained system to an active participant in a lifelong process.

MOOC and badge-based certification are nascent but gaining momentum, as illustrated in the following examples:

- The major MOOC providers all offer a certificate of accomplishment for students who successfully complete their courses online.
- The American Council on Education is reviewing MOOCs offered by several elite universities and may recommend that other colleges grant credit for them (Young 2012).
- Industry associations, such as the Manufacturing Institute, are developing badges that recognize skills highly sought after by manufacturers.
- Peer-to-Peer University (p2pu.org), a grassroots OE project, is offering badges for the completion of online courses.

The Open Road Ahead

The world is increasingly connected, yet educational systems cling to the disconnected past. The OE movement provides new mechanisms to democratize education by interconnecting ideas, learners, and instructors in new kinds of constructs that replace traditional textbooks, courses, and certifications. OE has the potential to realize the dream of providing not only universal access to all the world’s knowledge but also the tools required to

acquire it. The result will be a revolutionary advance in the world's standard of education at all levels.

But OE is also a disruptive force in the academic world (Christensen and Horn 2011). OER promises to disintermediate the scholarly publishing industry, rendering some current business models unviable and inventing new viable ones. Furthermore, MOOCs, badges, and personalized learning systems have the potential to disaggregate schools and colleges, enabling new efficiencies but also devaluing certain aspects.

Thus, however exciting, the OE movement raises many questions, most of them revolving around ways to maximize the impact of OE while mitigating undesired, unintended consequences. Research and experience are needed to address the following questions:

- What measures may be necessary to prevent OE from “regressing to the mean” and providing only an average education to an average student?
- What is the balance between the (inexpensive) massive online aspect of OE and the (expensive) face-to-face contact that defines current education systems?
- Will the future of education be dominated by a few massive “university networks” with “talking head” instructors?
- What is the utility of a final exam or high-stakes test when machine learning analytics can accurately predict a student's score from the regular coursework?
- How much does teaching improve with the use of learning analytics to track both student and instructor performance?
- Can the use of analytics transform the educational system from one where time is held constant and the amount of learning is variable to a system where the amount of learning is held constant and time is the variable?
- Are there risks or tradeoffs if companies looking to hire prefer a solid collection of industry-approved badges over a college degree?
- How does OE impact academic freedom?
- What measures may be necessary to safeguard a student's lifelong electronic learning record?
- How can OE enterprises be financially sustained over the long term while remaining as accessible as possible?

Clearly the education world is in for a turbulent, yet fruitful, next decade.

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