Open Educational Resources (OER) and Connexions

C. Sidney Burrus csb@rice.edu
ECE Dept. and Connexions, Rice University, Houston, Texas USA
cnx.org
2/3/2014

For those of us who are interested in education and also in the opportunities for technology to improve education, we are seeing indications that something truly significant is happening just now. There are non-trivial experiments being conducted and changes being tried in a wide variety of aspects of education. These range from advances in brain science to copyright systems to applications of machine learning for adaptive learning to semantic mark-up languages to new business models with combinations of open and closed content to new pedagogies. They are at all levels from K-12 through higher education, continuing education, workforce training, and self learning. They are used with traditional printed books, downloaded pdf files, on-line (including interactive) use on a computer screen, or mobile use on a tablet or cell phone such as a Kindle, iPad, iPhone, or Android. They are used with traditional lecture courses, with massive open online courses (MOOCs) from providers such as edX, Coursera, and Udacity, and for self-study. Some of the new distance education and on-line courses will use OER and Personalized Learning Systems such as OpenStax Tutor that employ artificial intelligence and machine learning techniques.

The high cost of books together with the difficulty in keeping the content fresh and up to date is part of what is driving these new experiments but now the more obvious need for personalized, dynamic, interactive on-line or mobile learning environments is an even more compelling driver for innovations in the use of technology in education. There is also an assumption that making educational resources accessible to the widest possible range of students, teachers, and authors is essential to our economic and social health. This essay tries to find the common threads in all of these experiments and new systems and to build models that we can use to pull all of it together and make deployment successful.

These educational projects are developing in parallel and in conjunction with new approaches to scholarly publishing, essay publishing, and even news publications. They are all being driven by the same changes in technology and society and are part of the larger intellectual, cultural, and financial eco-system.

Part of the results of this investigation is the creation of the Connexions http://cnx.org/ and OpenStax projects http://openstaxcollege.org/ which are our responses to a very wide variety of changes across all disciplines, all levels, and all learning situations. Another dimension is in Personalized Learning or adaptive learning https://openstaxtutor.org/ which applies machine learning to the student learning problem. Much of the vision was inspired by the experiences of those in the open source software movement.

Models for the Impact of New Technology

The impact of a truly new and disruptive technology can be **modeled** as occurring in two phases. In the *first phase*, the new technology does what the old technology did only better. In the *second phase*, this new technology redefines the problem and the questions that first phase dealt with and comes up with truly new results. Indeed, it the second phase that the visionaries see and try to realize. And by its very nature, it is the second phase where real innovation occurs.

The project by Google to scan books and make them available on the web is a phase one effort. It is doing what traditional books do, only better. It is making content written for traditional media available to a wider audience and essentially free. Making videos of course lectures (MOOCs and Khan Academy) and putting them on the web is likewise phase one. E-book readers like the Amazon Kindle, B&N Nook, and Apple iPad are currently phase one but have the potential of becoming phase two.

Most of our visionary images of the future are phase two where the very nature of the activity is changed. In phase one, the impact of the new technology is fairly predictable because it is solving the same problem. However, it is in phase two that "unintended consequences" can occur because the situation is different than it ever has been before. Deep understanding of all of this is necessary so that we maximize the positive surprises and minimize the negative ones.

A **second model** of change is made by grouping those who *adopt* the new technology. This comes from Everett Rogers [6], Geoffrey Moore, and others. The groups who adopt it first are called the "early adopters" and they will tolerate difficulties in order to benefit from the advantage and participate in the activity. If the early adopters demonstrate the potential of the new technology, a second group can be defined who will put up with minor inconveniences but wants demonstrated significant improvement. The third group will go along with the new "standard" but want guaranteed results and easy use. Finally, the laggards will not change even for reliable demonstrated advantage simply because it is *change*. The earliest of the early adopters are the innovators who literally invent or create the new technology. Imagine the early days of the automobile where punctured tires, engine failures, and no mechanics scared off all but the truly adventurous "early adopters".

A **third model** looks at technology as a sequence of "problem solving" phases where you first solve the immediate presenting problem, then you go on to solve the next phase of the problem, given the solution of the first phase. However, unless some idea of the second (and perhaps third and fourth) phase is taken into account in solving the first phase, decisions will be made that make the solution of later phases inefficient or impossible. Choosing the wrong format for your educational content can make later re-use and/or maintenance difficult or impossible (a bit mapped scan, for example). The same is true in choosing a copyright license. Choosing a non-commercial license may make sustainability difficult.

A **fourth model** looks specifically at the historical development of information technology that has produced the printed book [20]. An important transition occurred

around 2000 BCE when writing was invented. This was the transition from an oral process where knowledge was passed from generation to generation and from group to group orally to a written process with hand written manuscripts read by the literate few [1]. The second transition occurred around 500 years ago when the movable type printing press was invented and we moved from a written culture to a print culture. This transition is an excellent place to use the "two phase" model to see the early printed books as simply being a better version of the hand written ones. But the literate world was revolutionized by the large number of cheap, accurate books [2]. The third transition is the one we are in now going from the print world to the electronic or digital world [3]. The first two transitions had fundamental effects on education and scholarship. The impact of the third transition is what this essay is about.

All four of these models and other ideas from educational pedagogy, andragogy, cognitive science, learning theory, open copyrights, and social entrepreneurship have been use to plan the development of Connexions and OpenStax.

Open Educational Resources (OER)

A large number of educators, writers, and scholars feel that educational content and resources should be freely available to all teachers, learners and potential learners, regardless of circumstances [16,18,12,13]. This comes partially from philosophical, social, and political considerations and partially from the success of three open access systems: MIT's OpenCourseWare (OCW), Rice's Connexions (Cnx), and Wikipedia and the more recent edX, OpenStax, and Coursera.

Another source of inspiration for the OER activities is the remarkable success of the open source software movement [17]. The original idea of open source simply said the source code for computer software should be made available to the users of the code so they could better understand and apply it. It rather quickly evolved a philosophy, Free Software (Gnu system, free as freedom not no cost), that said the code should not only be visible, it should be free, modifiable, and community supported and maintained. This movement has produced Linux, Firefox, Apache, Open Office, and many other successful products and companies. However, it should be noted that computer code and educational resources are not the same thing so a direct translation is not appropriate but an inspiration is.

Connexions

Connexions (Cnx) is an Internet repository of XML (or HTML5+) encoded educational content, organized in modules (cnx.org). It has tools for writing, maintaining, organizing, and using the content. It has tools for assembling collections of modules such as essays, books, courses, even entire curricula. And it is a community of authors, teachers, and learners that create and use the repository and tools. The Cnx content can be used on-line or to produce a printed book or to produce an eBook. It can be used to support a traditional course, distance education, or self

education in synchronous or asynchronous applications. It can be integrated into a CMS such as Moodle or Sakai. It can be use for pre-K through graduate education in all disciplines. All of the content in Cnx is copyrighted under the Creative Commons attribution license which allows completely open use and reuse provided the author is attributed. It has a powerful and flexible facility for quality assurance through peer review and other endorsements.

Printed Books and eBooks from OER

The phase one of OER is the easy production, maintenance, and use of printed books. XML allows a flexibility of use and re-use that simply cannot be achieved with any non-semantic system. Even with all the advantages of OER books and eBooks, they are phase one. It is the dynamic, interactive on-line use where phase two becomes real.

Several courses at Rice and other universities use text books that are in Connexions. They are free for on line use and low-cost for a professionally printed version. A book that might cost $130 from a traditional publisher costs $30 through a print-on-demand company. A very exciting project in Connexions has just produced a text book for Statistics. This is being used in the California community college system and is spreading to other systems. Nationally, the cost of text books is a major limitation to education in community colleges.

OpenStax College (OSC) is our latest project with a goal of specifically creating high quality, up-to-date, inexpensive (or free) community college text books. So far, a Physic and a Sociology text book have been published and a total of 25 is planned.

Another very exciting project has begun in South Africa where the Schuttleworth Foundation has funded the Siyavula Project to place the entire K-12 curriculum content into Connexions. This is making high quality educational content available free on the web and at a very low cost in print form to everyone. Although this is targeted for the South Africa school system, it is available to everyone in the world. http://cnx.org/news/connexions-was-top-choice-for-siyavula-project

States and countries see OER as a means to reduce educational cost while improving quality and accessibility. Educational bills have been introduced and, in some cases, passed in California, Texas, and Minnesota as well as in the US congress to allow and encourage the use of OER in public schools and colleges.

On-Line Use of OER

XML and HTML5+ allow the implementation of virtual laboratories, it allows the dynamic simulation of complex systems under the control of the learner, and it allows the use of graphics, audio, video, etc that is semantically tagged in a way that has never existed before. Mathematics can done not just described. Likewise with chemistry and other sciences. Music can be played, transposed, etc. Virtual laboratories can be “run”, not just statically illustrated on a page. Short, just-in-time

labs called “Lablets” are effective new devices. Assessment can be made in real-time to give immediate feedback to a student [25]. This is truly phase two and we can only vaguely predict its future but it is extremely exciting. The OER “books” can be linked to the massive, open, online courses (MOOCs) to provide a powerful learning environment at all levels and on all topics [48,49].

Extendable Markup Language (XML) and HTML5

While the formal definition of XML is “Extendable Markup Language”, after considering mathML, chemistryML, and musicML, another definition might define X as the unknown that you substitute your discipline into. It allows the encoding of the foundation of a discipline into the electronic document. In a book or in conventional HTML, you have a picture of the mathematical formula. In XML, you have the actual rules of the math coded into the formula, or the valences of the atoms encoded into the molecule, or the frequency of a note in a music score.

With the maturing of XML and the development of HTML5+, and as teachers and authors learn how to use them in new forms of pedagogy and as better authoring tools are developed, a completely new learning environment can evolve and emerge.

Open Copyright Licenses

Even with the technical power of XML, the modular architecture of the Connexions organization, and the access over the Internet, a new copyright license that is consistent with and supportive of the open philosophy must be used. The Creative Commons organization founded by Larry Lessig [7,8] and others has created a set of licenses that do exactly that (http://creativecommons.org/). In order for the “viral” or exponential growth of educational content to happen [17], the copyright license must not only be “open”, but allow derivative works to be generated and allow commercialization to sustain the various projects using the OERs and to allow the partnering of OER with commercial companies [27].

Quality Assurance and Post-Publication Peer-Review

In order to assure the quality of content of any Open Educational Resource, some assessment procedure must exist [15]. In Connexions, a portal or filter that we call a “lens” can be created so that modules and collections that have been evaluated and endorsed can be tagged by the “owners” of the lens. Then, looking at the Connexions repository through the lens will present only the endorsed content. For example, a society or agency or organization can create a lens and use a traditional peer-review system to decide which modules will be endorsed and, therefore, seen through the lens.

Connexions and the Signal Processing Society of the IEEE (Institute of Electrical and Electronic Engineers) have launched a collaboration where researchers and teachers will publish their manuscript in Connexions, then request that the SPS review it [IEEE]. If the review is favorable, the paper will be tagged so that the SPS lens will

show it. This allows a much more flexible publication system and allows open access to the work while it is being review. The lenses are controlled by their creator, not by Connexions, and not editable by anyone other than the owner. This is a post-publication review rather than a pre-publication review system [15]. It scales much better with the gate keeping review not being the bottle-neck that it has been traditionally.

Community Building and Quality Control

The organization of Connexions allows three locations for the OER modules to exist. **First**, there are work groups created by authors, potential authors, and maintainers of the content. The modules in a work group are visible and available only to the members of the work group. These people form a collaborative community developing high quality educational content as a team [13]. The work group might consist of only one author. It might consist of a faculty member and a student. It might consist of several faculty members at one institution or many institutions. It might consist of a whole department, or laboratory, or school. While in the work group, the modules are visible to and modifiable by all members of the group but no one else. After the group agrees the module is ready for the public, it is "published" which places it in the open Connexions repository. This publishing is non-reversible. Once published, the module is public and in the **second** location for ever. It may be revised, modified, re-written, or up-dated, but all versions are public and accessible by anyone with Internet access and a browser.

It is when a module is published that the group decides who the authors are, who the maintainers are, and who holds the copyright. The module is then a full fledged member of the OER world and it can be used, reused, modified, or anything else, but the author(s) name cannot be removed according to the CC copyright rules. The authors of the modules or anyone else can author a "collection" or a book by stringing a set of modules together to form an essay, article, book, course, or curriculum. That collection can then be "published" just as the module was in the repository. The modules and collections in the repository are open and free in the same sense that software in the open source, free software movement are.

Placing modules in the Connexions repository is open to anyone who signs up for an account. However, the **third** location is controlled by a lens and that is not open to anyone other than the lens creator and owner. It is the lens that allows a strict quality assurance, just as journals control the quality of the content they publish. The lenses may be owned by an individual, or by a society, or by a commercial enterprise, or by anybody. The owner controls what modules and/or collections are in a lens and they may remove content from the lens (but not from the repository) if the opinion of quality changes.

The existence of these three locations allows an extraordinary variety of OER usage. It allows completely individual authorship or completely communal writing or, more likely, some combination. It allows a completely open authoring, teaching, and learning environment. But, it also allows strict evaluation and quality control with the criteria determined by the lens creators.

Evaluation of Open Educational and It's Resources

Just now, there is considerable conversation as to the value of the various new, technology enhanced learning tools. Part of the difficulty comes in choosing a measure or a metric. The primary measure for the traditional, for-profit publishing companies (and many not-for-profit) is monetary. The board of a company is legally obligated to maximize profits for the investors, so maximizing learning is not the first priority (it may be a priority, just not first). Many assessment tools (e.g. state mandated test in K-12) distort the teaching with the instructors teaching to the test and the students "gaming", placing test scores above learning. The recent "competency based learning" is an effort to measure the content learned by the student rather than the material covered by the teacher, however, it has the same distorting effect that the other testing based systems do. If the assessment can be integrated into the learning process rather than done by discrete "tests", there may be a way reducing the negative effects of testing.

If the assessment is integrated into the learning process in such a way as to help the student to learn rather than to evaluate the student and teacher, it less of a distorting effect. It has been well documented that students are very poor at assessing their own level of learning. Poor students over estimate how well they have done and good students under estimate their achievement, so all students need some kind of aid in assessing their own progress and readiness for moving to the next stage.

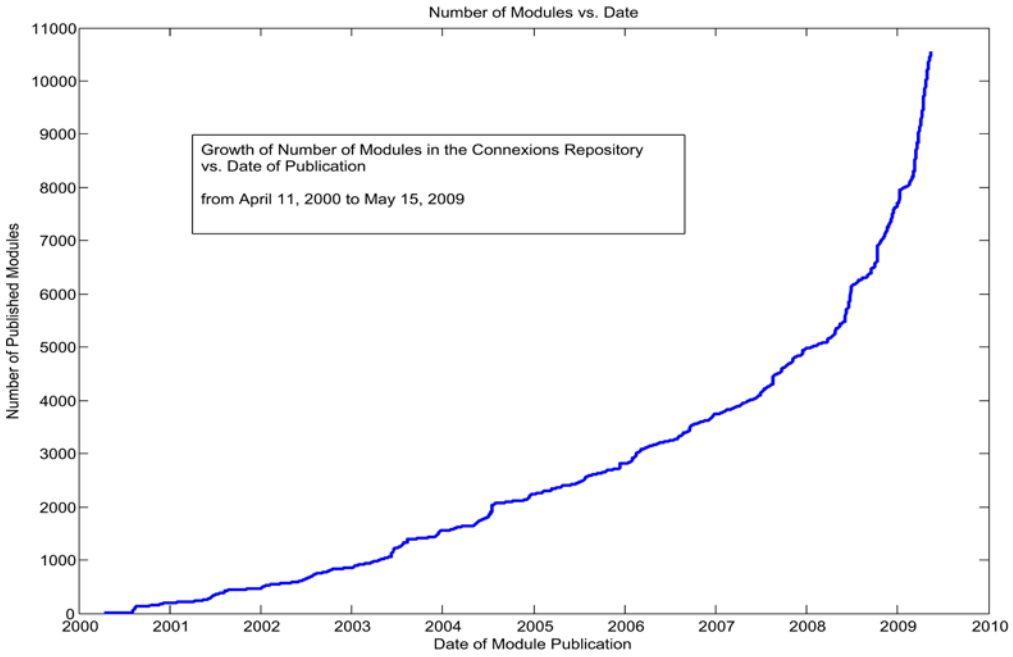
In traditional university classes, success is often measured by how many students finish or pass the course. By that measure, MOOCs are declared a dismal failure with very small fractions of the enrolling students finishing most MOOCs. This is an inappropriate comparison. A student in a tradition college course has paid (or their parents have paid) a tution, needs the credit hours to graduate, needs the knowledge and a passing grade to take following courses, and has parential and peer pressure to finish and pass. The person who registers for a MOOC does none of these. In fact, many register just in order to see what the course is about. A better comparison with the MOOC would be a person who goes into a book store to browse. That person will look a variety of books, open some and look at the table of contents, scan the preface of others, perhaps buy a few, perhaps read a few chapters of some, but few actually read the total book, cover to cover to a degree that they could pass an exam on it. I think the fraction of people who consider a book in a book store (or library, for that matter) that completely read the book are probably similar to the fraction of people who register for a MOOC and finish it.

Growth of Connexions

Connexions was founded by Prof. Richard Baraniuk in 1999 at Rice University. In March 2012 the repository had over 20,270 modules and over 1200 collections or books. The level of the content ranges from K-12 through graduate research and continuing education. The variety of content ranges from art to anthropology, from music to mathematics, and from engineering to history. University Presses are using Connexions (with lenses) as the production and distribution "engine". A conference could use it to produce a much more widely used proceedings than the traditional CD

or printed proceedings. A research project could use it to disseminate their results. The NSF is recommending it to disseminate the results of grants. Imagine the increase in impact if all MS and PhD theses were put into Connexions.

If the number of modules and collections in Connexions only came from the efforts of the staff, board, and a fixed size group of followers, the growth would be linear. If people involved with Connections in some way cause other people to become involved and they, in turn, cause still other people to become involved, the growth is exponential and the spread is called "viral". This kind of growth sets Connexions apart from others in the open educational repository world. This is analyzed and discussed in the 2007 article by Ochoa [21]
http://ariadne.cti.espol.edu.ec/xavier/papers/Ochoa-TLT2009b.pdf



Note, the number of modules has been growing exponentially since mid-2004. During that recent period, the Cnx staff has been working particularly on improving the environment for authors. It is also the same period that the efforts of the NSF grant 0538934 [27] have had an effect. We are also seeing the effects of the Shuttleworth Siyavula project in South Africa.

The usage is in over 150 countries and, although most of the content is in English, there is a wide variety of other languages, including those using non-Latin alphabets. Although the Connexions content is not universally available, it will be in the near future as the Internet invades all the nooks and crannies of our globe. It indeed looks like OER in general and perhaps Connexions in particular will be the next phase in the evolution of the textbook. We are now starting development of the next phase where we develop completely new learning paradigms on this powerful and flexible platform [30-32].

Connexions 2.0: Personalized Learning System (PLS)

The twin goals of Connexions at its founding were to provide free access to all the world's knowledge **and** to exploit this knowledge to provide personalized environments that optimize learning. Since good momentum is being built towards the first goal, we are ramping up development towards the second goal. Connexions is currently undergoing an extension from an OER repository of free e-textbooks to an adaptive "Learning Machine" that learns about users as they use it to learn [24]. We are moving from phase one to phase two! http://dsp.rice.edu/lml this is called OpenStax Tutor https://openstaxtutor.org/

Research has shown that it is not the information students are given that determines learning, but what they do with it, how they process it, how they construct knowledge, and how they use knowledge in collaboration with others [25]. Nevertheless, the primary modes of instruction today, including lecture and text and even most e-learning, still remain passive experiences for students. In the language of control theory, the current educational system runs in a substantially "open loop" mode.

Our approach aims to "close the loop" by making many aspects of educational design, delivery, and redesign more interactive and self-constructing and self-correcting. This must be achieved by not just delivering interactive content to the student, but by also monitoring student interactions with the content, analyzing the interactions, and then sending feedback to the student, to the instructor, and to the authors of the materials, all of whom can act in response [27]. Moreover, we must close the communication loop between instructors and authors, so that they can form communities to share the load of responding to this feedback by developing, refining, and extending educational content and tools. Finally, this feedback and adaptation process must take place continuously on a time scale commensurate with the activity: for the learning process in minutes or hours, not weeks or months; for the iterative curriculum development process in weeks or months, not years. Standard practice mechanisms for gathering and providing critical feedback (e.g., mid-term exams and time-limited grading of homework) are meager, slow, and provide little support for analyzing the causes of successful learning.

Over the past four years, machine learning [24] and signal processing researchers in the Electrical and Computer Engineering Department at Rice University along with cognitive scientists at Duke and elsewhere have been developing a Learning Machine architecture that extends the Connexions repository to enable closed-loop, deeper learning. The key elements of the system are:

- seamless integration of video and audio modules to complement text-based materials;
- interactive simulations via National Instrument's LabVIEW and Wolfram's Mathematica web players [29];
- QuADbase, a question and answer database that enables an instructor community to develop and share assessments;

- FOCUS (focus.rice.edu), a peer review facilitation system that interfaces directly with Connexions lens system (cnx.org/lenses) to enable quality control of content and professional development for authors and instructors; integrated data collection to continuously track and feedback information on each students progress through all aspects of a course, including their performance on frequent problem sets to check their local understanding, as well as homework and tests that check their more global understanding;
- an automated "tutoring engine" that uses advanced machine learning algorithms to close the loop by suggesting to the student and instructor "just-in-time" hints and remedial materials for concepts the student is finding difficult [31].

The multidisciplinary Learning Machine team includes experts across several universities in computational science, cognitive science, education, and education policy. Testing began in early 2011 and is underway now at several universities. https://openstaxtutor.org/

Disruptive Impact

Clayton Christensen, professor at the Harvard Business School, has written on the way new technologies impact an existing system. He has several books [45,46] discussing this in general, and one applying it to universities [47]. OER (Cnx and OpenStax in particular) including MOOCs are doing exactly what he describes [48,49].

Acknowledgements

The Connexions project has been generously supported by the Hewlett foundation and Rice University, as well as the Maxfield Foundation, the Gates Foundation, Twenty Million Minds, the Open Society Foundation, the National Science Foundation [29-32], and several individuals. The founder and Director of Connexions is Prof. Richard Baraniuk who continues to provide vision and leadership. The platform has been developed and supported by Dr. Joel Thierstein, Katherine Fletcher, Daniel Williamson, J.P. Slavinsky, and their staff. The work on OpenStax Tutor is a collaboration with researchers at Georgia Tech, Duke, Washington University, Rose-Hulman, UT-El Paso, and ISKME.

References

1. Walter J. Ong, *Orality & Literacy: The Technologizing of the Word*, Routledge, 1982, second edition 2002.

2. Elizabeth L. Eisenstein, *The Printing Revolution in Early Modern Europe*, Cambridge, 1983. This is a combined and abridged version of the 1979 editions.

3. James J. O'Donnell, *Avatars of the Word: from Papyrus to Cyberspace*, Harvard, 1998.

4. Vannevar Bush, "As We May Think", *The Atlantic Monthly*, Vol. 176, No. 1, pp 101-108, July 1945

5. Pierre Levy, *Collective Intelligence: Mankind's Emerging World in Cyberspace*, Plenum Trade, 1995, translation 1997.

6. Everett M. Rogers, *Diffusion of Innovations*, Fifth Edition, Free Press, 2003.

7. Creative Commons: http://creativecommons.org/

8. Lawrence Lessig, *The Future of Ideas: The Tale of the Commons in a Connected World*, Random House, 2001. also *Remix*, Penguin, 2008

9. Tim Berners-Lee, James Hendler, and Ora Lassila, "The Semantic Web," *Scientific American*, May 17, 2001. A new form of Web content that is meaningful to computers will unleash a revolution of new possibilities

10. Richard G. Baraniuk and C. Sidney Burrus, "The Connexions Project: Education for a Networked World", *ASEE/SEFI/TUB International Colloquium on "Global Changes in Engineering Education"*, Technical University of Berlin, October 2002.

11. Richard G. Baraniuk, C. Sidney Burrus, Don H. Johnson, and Douglas L. Jones, "Sharing Knowledge and Building Communities in Signal Processing", *IEEE Signal Processing Magazine*, vol.21, no. 5, September 2004, pp. 10-16.

12. C. Sidney Burrus, "Connexions: An Open Educational Resource for the 21st Century", *Educational Technology*, vol. 47, November-December 2007, pp 19-23.

13. Richard G. Baraniuk, "Challenges and Opportunities for the Open Education Movement: A Connexions Case Study", Chapter 15 in *Opening Up Education: the Collective Advancement of Education through Open Technology, Open Content, and Open Knowledge*, MIT Press, 2008, pp 229-247.

14. Utpal M. Dholakia and Richard G. Baraniuk, "The Roles of Social Networks and Communities in Open Education Programs", Chapter in *Social Software and Developing Community Ontologies*, S. Hatzipanagos and S. Warburton editors, IGI Global Publishing, 2008.

15. Christopher M. Kelty, C. Sidney Burrus, and Richard G. Baraniuk, "Peer Review Anew: Three Principles and a Case Study in Postpublication Quality Assurance", *Proceedings of the IEEE*, invited paper, vol. 96, no. 6, June 2008. pp 1000-1011.

16. Richard G. Baraniuk, and C. Sidney Burrus, "Global Warming toward Open Educational Resources", Viewpoint, *Communications of the ACM*, vol. 51, no. 9, September 2008, pp 30-32.

17. David Bollier, *Viral Spiral*, New Press, 2008.

18. Curtis J. Bonk, *The World is Open*, How Web Technology is Revolutionizing Education, Jossey-Bass, 2009.

19. C. Sidney Burrus, "Open Educational Resources", *World Innovation Summit on Education*, Doha, Qatar, Nov. 16-18, 2009. http://www.wise-qatar.org/

20. C. S. Burrus and R. G. Baraniuk, "Three Special Events in the History of Technology for Creating, Organizing, and Sharing Information", Module in Connexions first written in 2004, revised in 2010. http://cnx.org/content/m13676/latest/

21. Xavier Ochoa, "Connexions: a Social and Successful Anomaly among Learning Object Repositories", *Journal of Emerging Technologies in Web Intelligence*, vol. 2, no. 1, February 2010. pp 11-22.

22. Jordan Frith, *The Open Revolution: An Environmental Scan of the Open Textbook Landscape*, NCSU Libraries, Aug. 2009.

23. Hal Plotkin, *Free to Learn*, published by Creative Commons, 2010. http://wiki.creativecommons.org/Free_to_Learn_Guide

24. Christopher Bishop, *Pattern Recognition and Machine Learning*, Springer Verlag, 2006.

25. Jeffrey D. Karpicke and Henry L. Roediger, III, "The Critical Importance of Retrieval for Learning", *Science,* vol. 319. no. 5865, 15 February 2008. pp. 966 – 968.

26. Jeffrey D. Karpicke and Henry L. Roediger, III, "Is expanding retrieval a superior method for learning text materials?", *Memory & Cognition*, vol. 38, no. 1, 2010, pp. 116-124

27. Andrew C. Butler and Henry L. Roediger, III, "Feedback enhances the positive effects and reduces the negative effects of multiple-choice testing", *Journal of the Psychonomic Society*, 2007.

28. Benedict Carey, "Forget What You Know about Good Study Habits", *New York Times*, September 6, 2010.

29. NSF: EEC-0538934: "Building Communities and Sharing Knowledge in Engineering Education: A Univ. / Partnership for Innovation" grant, Collaborative project between Rice and National Instruments. $600,000, 2/14/2006-2010.

30. NSF 1041396: Cyberinfrastructure TEAM grant. Collaborative Research: CI-Team Implementation Project: "The Signal Processing Education Network". $480,000. 10/2010-2013.

31. NSF 1123420 CCLI TUES proposal, "Transforming STEM Education via Networks of Knowledge", collaborative effort with Georgia Tech, Duke, Rose-Hulman, and UTEP, submitted 1/14/2011.

32. NSF Cyberlearning proposal, DIP: Collaborative Research: A Personalized Cyberlearning System based on Cognitive Science, collaborative effort with Georgia Tech, Duke, Rose-Hulman, and UTEP, submitted 2/2011.

33. Alfred Chandler and James Cortada, *A Nation Transformed by Information*, How Information has shaped the United States from Colonial Times to the Present, Oxford Press, 2000.

34. James Gleick, *The Information: A Theory, a History, a Flood*, Pantheon Books, 2011
35. Creative Commons, *The Power of Open*, Creative Commons, 2011
36. Charles M. Vest, "Open Content and the Emerging Global Meta-University", *EDUCAUSE Review*, vol. 41, no. 3, May/June 2006.
37. David Dobbs, "Beautiful Brains", in *National Geographic*, vol. 220, no. 4, Oct. 2011, pp. 37-59. The new science of the Teenage Brain.
38. Knowles, Holton, and Swanson, *The Adult Learner, The Definitive Classic in Adult Education and Human Resource Development*, Routledge, 2012 (seventh edition).
39. Daniel Pink, *To Sell is Human, The Surprising Truth about Moving Others*, 2012.
40. Igor Aleksander and Helen Morton, *Aristotle's Laptop, The Discovery of our Informational Mind*, World Scientific, 2012.
41. Susan Singer and William Bonvillian, "Two Revolutions in Learning", *Science*, vol. 339, March 22, 2013, page 1359.
42. Susan Singer, et al, "Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering", *Report of board on science education*, sponsored by the NSF and published by the National Academies, Oct. 2012.
43. Daniel Seaton, Yav Bergner, Isaac Chuang, Piotr Mitros, and David Pritchard, "Who does What in a Massive Open Online Course?", manuscript out of MIT, March 2013.
44. Susan Dobra, "The Gift of Theuth: Plato on Writing (again)", CSU-Chico, *preprint* April 2013, http://www.csuchico.edu/phil/sdobra_mat/platopaper.html
45. Clayton M. Christensen, *The Innovator's Dilemma*, Harper Business, 1997
46. Clayton M. Christensen and Michael E. Raynor, *The Innovator's Solution*, Harvard Business School, 2003
47. Clayton M. Christensen and Henry J. Eyring, *The Innovative University*, Jossey-Bass, 2011.
48. Richard G. Baraniuk, "Open Education", *The Bridge*, The National Academy of Engineering, Summer 2013, pp 41-47.
49. Kevin Carey, "MOOCs, Robots, and the Secret of Life", *New America Foundation*, June 7, 2013
50. Siyavula Project, South African OER textbook project