Reform or Revolution?
Undergraduate Science Education in Diverse Contexts for Learning

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Abstract

Science education at all levels is embedded in large systems that are being challenged by the rapid growth of information technologies. While the existence of these technologies depends in part on university science education, delivering that education is slow to respond to the implications of that technology. Governance and reward structures draw faculty away from engagement with undergraduates even as science education is promoted as an essential for all students. Research is building our knowledge about effective teaching and learning both in and outside the classroom, yet inertia of the system threatens to dampen or swallow innovation. We are experiencing a revolution in the contexts of learning that may bring a full-scale cultural change in the way faculty interact with students to promote understanding in science.

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Collegiate teaching is receiving increased attention as the portion of state budgets for state-supported universities shrink and tuition increases. The proportion of parent and/or student income devoted to a college education is increasing and parents and students are giving greater scrutiny to the return they hope to get for this investment. The classroom has become the focus of the lion's share of this scrutiny where the overriding questions are, Am I being given the opportunity to learn? and Am I being given the opportunity to demonstrate that learning? (Kirschner, 2012). Colleges and universities are also becoming sensitive to the changes in the learning environments that surround them. This includes changes in standards affecting high school students as well as the influence of information technologies on learning environments in general (Stokes, 2011; "Rebooting", 2012).

First we look at the trajectory of science and mathematics reform in K-12 education affecting thinking about instruction in higher education. The Next Generation of Science Education Standards (NGSS) (NRC, 2012) and the Common Core State Standards for Mathematics (CCSSM) ("National Governors", 2010) present a major shift in the way schools will instruct in science and mathematics. Even with the standard inertia resisting the pace of change, the ideas in these documents grow from a strong research base that will have lasting effects. Following an examination of science and mathematics education standards we will briefly survey influences of electronic media and information technologies on higher education.

New Standards in Science and Mathematics Education

Emerging standards in K-12 science and mathematics education shifts instructional focus toward specific disciplinary practices across the STEM disciplines. This shift is driven by research suggesting significant opportunities for improved learning within and across disciplines accrue from instructional designs that engage students in discourse that emphasizes how knowledge is built in the disciplines (Duschl, Schweingruber, & Shouse, 2007). The general theory of change says that by teaching students how to engage in key practices of the discipline they are supported in constructing knowledge in the context of the discipline understanding that knowledge as a human accomplishment and not something abstractly handed down over time. Goodyear and Ellis (2011) writing in the context of higher education refer to this as "knowledge work". Knowledge work is the expectation but rarely achieved goal of engaging students in processing course information to fashion new understandings that can be applied to new problems.

Although many of these practices have been core within previous reform documents (c.f., NCTM, 2000), they did not necessarily translate into clear policy at the state level nor did they take hold in the majority of adopted curricula or state level assessments. Currently approximately 44 states have adopted the Common Core State Standards for Mathematics and a number of states have volunteered as pilot states for NGSS. As a result, this shift poses challenges for the nation's educators since many have not had opportunities to

explore these ideas within their own content preparation in college and they have few resources at their finger-tips that genuinely take up these ideas (Sztajn, Marrongelle, & Smith, 2011).

We develop one example of how these standards will be driving K-12 education and demonstrate the impact on higher education. Modeling and argumentation are examples of core practices shared among the STEM disciplines and emphasized by the CCSSM, NGSS, and two technology standards documents, the International Society for Technology in Education's National Education Technology Standards (2000) and the International Technology Education Association's Standards for Technological Literacy (2000) currently adopted or under consideration across the United States. These practices provide a means of linking STEM disciplines and supporting the inclusion of engineering education, which is a specific element in the NGSS. However, developing the use of modeling and argumentation skills in students requires a different approach to teaching, one that supports student discourse skills as a necessary form of processing ideas. Goodyear and Ellis (2011) refer to instruction that guides students in how to engage in discipline practices as an "epistemic game". The authors appropriate the term "epistemic" to emphasize the central goal of making sense and meaning. An epistemic game employs the skills and practices that support participation in an "epistemic form". Here we refer to the forms "argumentation" and "modeling". The epistemic game of using, sharing, critiquing, and revising information that is presented in class according to CCSSM and NGSS must be developed in students in order to participate in knowledge building in the collaborative group of a classroom and small groups.

Research supporting modeling and argumentation as key discipline practices within K-12 science and mathematics has taken root over the last two decades (Bailer-Jones, 2002; Harel & Sowder, 1998; Knuth, 2002; Lesh & Doerr, 2003; Nersessian, 1999; Smith, Haarer & Confrey, 1997; Svoboda & Passmore, 2011). A number of researchers have examined the demands placed on teachers as they attempt to engage learners in scientific and mathematical modeling (Lehrer & Schauble, 2006; Newton, Driver, & Osborne, 1999; Oh & Oh, 2010; Windschitl, Thompson & Braaten, 2008) and argumentation (Staples, Bartlo, & Thanheiser, manuscript in preparation). This work has gained momentum resulting in practitioner texts sponsored by National Council of Teachers of Mathematics to develop teachers' knowledge of mathematical reasoning, justification and proof for teaching (Ellis, Bieda & Knuth, in press; Lannin, Ellis, & Elliott, 2011).

Despite this interest in modeling and argumentation by researchers, Lehrer and Schauble (2003) suggest that even though modeling is key to mathematics and science there is little attention to it in classrooms. Further, Doerr & English (2003) suggests that learning opportunities for modeling are rich with potential, yet typically they are limited to textbook problems "where data sets are preprocessed and detached" making it difficult to for students to see the meaning and utility of modeling (p.111). Similarly, studies examining curricular and instructional opportunities for mathematical reasoning and justification have found that these opportunities are lost as classroom discussion typically falls short of supporting robust student learning of justification (Bieda, 2010).

The value of these practices derive from the way the scientific and mathematical disciplines are prosecuted, yet for as much influence as higher education has on the K-12 curriculum, these are not elements highlighted in college science or mathematics classes. While one might think that this developing research in K-12 education might have drawn considerable interest at the college level, it seems to have gone unnoticed. Goodyear and Ellis (2011) also point out that significant research on understanding how people learn from discussion and group interactions has likewise gone unnoticed by instructors in higher education. They make note that laboratory classes in science, while placing students in potentially meaningful roles engaged in the practices of science, there is rarely any purposeful development of discourse skills for engaging in this epistemic form. As teachers attempt to take on the work of building student capabilities in learning science and mathematics through discipline practices, there will be a pressure to adapt course content for majors, especially those who will become teachers.

Secondary and college educators are challenged to support learning in culturally more diverse classrooms by engaging all students in cognitively demanding tasks authentic to the discipline and experientially real (Jackson & Cobb, 2010). Research has demonstrated that enacting these ambitious notions of teaching improves knowledge, skills and dispositions toward mathematics and science in classes with culturally diverse backgrounds (Boaler, 2002; Franke, Web, Chan, et al., 2009; Thompson et al., 2010). This kind of instruction has been called *ambitious teaching* because of its attention to eliciting and supporting thinking in *all* students and further, to use this thinking in sense making as they participate in cognitively demanding tasks (Lampert et al., 2010). Data suggest that implementing ambitious teaching results in equitable access to rigorous learning for more students.

Recent work by secondary mathematics and science educators carry implications for collegiate teaching and is consistent with existing research at the college level (see for example Mazur, 2008; Goodyear & Zenios, 2007). Windschitl, Thompson, and Braaten (2011) suggest specific instructional tools such as protocols and rubrics for analyzing student work in science centered on the use of scientific models in classroom inquiry. Similarly, in mathematics, protocols for particular bounded instructional activities support, for example, the complex work of orchestrating students' development of convincing arguments for the mathematics used in high cognitive tasks and the investigation and coordination of mathematical models to examine equality and symbolic expressions. These tools lessen the complexity of teaching giving educators mental space to provide equitable access to ideas by attending to student thinking and providing time and psychological space to dwell on important ideas within the typically fast-paced complex work of instruction (Kazemi, Ghousseini, Beasley, et al. 2010). These tools also frame "what counts" as evidence for assertions about student learning and support educators in building skills for teaching. In addition to their functions for individual educators, such supports serve a valuable function in professional development by introducing a more rigorous vocabulary for describing different types of learning and teaching (Curry, 2008). Goodyear and Ellis (2011) have analyzed interviews with college instructors that show language about instruction and learning differs markedly from the language of current research.

Both the NGSS and the CCSSM define eight practices within their disciplines for integration into the K-12 classroom (see Table 1). A number of these practices are sufficiently unique to the disciplines (e.g., "Planning and carrying out investigations" in science and engineering and "Attend to precision" in mathematics) while others, such as modeling and argumentation, are core practices in each discipline. Emphasis on teaching disciplinary practices implies synergies across disciplines. Clearly, science and engineering are cast as close partners in the current organizational structure of standards. But, meaningful development of student understandings of not only the disciplinary practices but the concept of 'practices' in STEM fields virtually requires elements of instructional collaboration across classes. This has significant implications for teaching in high school and college. We will show how the evolution of requirements for high quality high school teaching puts pressure on college courses to reevaluate content as well as the presentation of content.

Table 1: Discipline-based Practices as Defined by the NGSS and CCSSM

Scientific and Engineering Practices	Mathematical Practices
1. Asking questions (for science) and defining problems (for engineering) 2. Developing and using models 3. Planning and carrying out investigations 4. Analyzing and interpreting data 5. Using mathematics, information and computer technology, and computational thinking 6. Constructing explanations (for science) and designing solutions (for engineering) 7. Engaging in argument from evidence 8. Obtaining, evaluating, and communicating information	1. Make sense of problems and persevere in solving them 2. Reason abstractly and quantitatively 3. Construct viable arguments and critique the reasoning of others 4. Model with mathematics 5. Use appropriate tools strategically 6. Attend to precision 7. Look for and make use of structure 8. Look for and express regularity in repeated reasoning

Changing Contexts for Learning

Some will say that classrooms haven't change much for 150 years. Students still sit in chairs facing the front of the room with a single teacher guiding lessons. In a university, the scale differs but the setting is similar. Sometimes you still find classrooms where the chairs are bolted to the floor. However, there are clear indications that this image is fading. On many university campuses it is not difficult to find places where this mold has been broken. Old lecture classrooms in need of remodeling are being changed over to flexible seating where students work at tables and whose chairs swivel so that they can more easily talk with those around them and engage in small group work.

Campuses are creating technology groups that support faculty in using new information technologies and act as consultants in designing new learning spaces. At OSU, the Technology Across the Curriculum group has a budget of $250,000. They are brought in to help design space and to install new technologies. Today a standard package for a technology-enhanced classroom includes not only web service and a flat screen monitor but the ability to make a video connection on a closed circuit network within the state with a phone call. This allows courses to be offered across campuses located in different cities. Presentation capture software allows faculty to digitally record their voice and classroom presentations (PowerPoint, document camera, video) and upload the lectures to the web or into a BlackBoard course. These records can be used to leverage instructor time by putting lectures on line as part of on campus course support or for distance delivery.

Salman Kahn began making short videos to tutor his cousins at a distance. He placed these videos on YouTube and encouraged feedback ("Rebooting", 2012). In a few short years he has created a nonprofit Kahn Academy with a library of more than 3000 education videos and materials. In the last 18 months there were 41 million visitors in the US alone. In one sense, his central concept goes against a fundamental principle of science education reform: focus on big ideas. The Kahn Academy, which is not really an academy but a repository, is a collection of small pieces of information ranging from "evaluating expressions with two variables" to "Botticelli's Birth of Venus". What message do we get from this?

One message is that the generator of big ideas is the individual. We can design curriculum around big ideas but in the end the big idea is generated by the learner. A learner can come to the Kahn Academy looking for parts of a big idea he or she is trying to learn in some other venue and in a non-threatening, self-paced environment find pieces that fit. Another learner may watch a video for its own sake and generate a different big idea while listening to Salman Kahn or others present ideas based on observations of art or of numbers. Like surfing the Internet, we build ideas from pieces.

Candice Thille was frustrated by the high failure rate in large introductory courses at Carnegie Mellon University ("Rebooting", 2012). In the Open Learning Initiative she combines the power of intelligent tutoring software with large data-collection and storage capacity to create a system where students spend time working on course material outside of class. She guides the creation of online modules that present core course content designed by professors in charge of the course. Students are prompted with questions and their responses become part of a large database of information about how students build understandings or fail to do so. The idea is that faculty learn from this accumulation of data what kinds of ideas and tasks should be built into face-to-face time. A learning environment outside of the classroom, that is well tuned to the course, leverages student time and as a result student learning.

During a search the Wikipedia presented the following statement as a mission or goal, "All the world's knowledge, available to all the people, all the time." This is becoming closer to reality. John Wilkin at the University of Michigan first began thinking about the digital availability of multiple university libraries what he was at the University of Virginia. UVa

was one of the first to implement the Fedora Repository Project (Flexible Extensible Digital Object Repository Architecture) (Fedora, n.d.). Fedora is an open source system originally developed by researchers at Cornell University as an architecture for storing, managing, and accessing digital content in the form of *digital objects*. Wilkin now is the executive director of HathiTrust, a digital repository of more that 10 million volumes. Housed at Michigan, it draws on more than 60 partner institutions.   Along with other university online text collections, Google Books, and Project Gutenberg, these projects are creating an environment where not only books, but artifacts of all kinds are made available for study. When we think about how we go about our work as faculty, it is second nature, almost an unconscious act to move to the Internet and back to the library to get an electronic file of an article or document. The flow of information through virtual, asynchronous communication becomes transparent as we are constructing a syllabus or writing a paper. Yet, when we step into a classroom much of that kind of communication comes to an end. It actually doesn't end, in that students continue a similar routine of flowing through various pathways of communication. The challenge is to work with this rich flow of information and not against it.

We all have informal networks of people we call to get advice and to give feedback on papers we are writing. Asking someone to read a manuscript requires a significant investment of time. Peer review also requires considerable time and papers can sit for months in this process. Kathleen Fitzpatrick was in this situation as a young faculty member when she posted to a blog the idea that scholars should share drafts of papers online for peer review similar to blog posts ("Rebooting", 2012). A group of like-minded scholars soon co-founded Media Commons ("Media", n.d.), a digital scholarly network. Their goal is to change the meaning of "publishing" so that the interaction of the author, the publisher, and the reader becomes a process as visible as the published manuscript itself. This idea got the attention of the Modern Language Association who has launched an office of Scholarly Communication (MLA, n.d.). While this is a relatively new venture it is significant to note a major 30,000+ member organization utilizing a more open process of peer review while still adhering to rigorous standards. This larger phenomenon expands a well-worked teaching method of students sharing work in class. This work can be original papers, critiques of the work of others, or visible products such as a practice teaching lesson. In the captive environment of a classroom, critical evaluation skills are often bounded by the interjections of the professor. In a more open environment, where critique and feedback is more frequent and fluid, we see the need for greater skill both in generating critical feedback and in how to receive it.

New concepts of information access and networks of human interaction challenge the traditional model of a classroom directed from the point of view of a professor. This brave new world conjures images of plagiarism and students cutting and pasting a paper into existence. Along with technological improvements for information access have come new methods for checking authenticity. Turnitin (n.d.) uses databases of 20+ billion web pages, 220+ million archive student papers, and 120+ million articles from 90,000+ journals and periodicals and books to check submitted work. However, the real challenge is to create instruction that builds skills in analysis and synthesis in students such that efforts to plagiarize become transparently obvious to students themselves. The current model of

instruction might be characterized as student-reception of instructor-validated information. This has led to the pejorative joke about the lecture method as the most efficient way of transferring the professor's notes to the student's notes without passing through the minds of either one. The various configurations of information access and communication among users have magnified the importance of being much clearer about what we want our students to learn.

Current Landscape of Innovation

Kershner (2012) described the pace of innovation in higher education as somewhere between "sluggish and glacial". The inertia created by the deeply rooted tenure and promotion process makes risk taking and innovation sometimes dangerous to young faculty who worry about the appearance of student evaluations in their dossier. In the few research intensive and research extensive institutions, the reward structure provides "buyouts" that actually pulls faculty away from students providing little incentive to innovate in courses or programs which requires even more time devoted to teaching. In smaller or private universities the inertia is often a combination of student conservatism with faculty and administration concern for maintain student enrollment, the life-blood of the institutional budget.

Established colleges and universities feel that they are protected by their prestige with their recognized brands. In a given state or region, there is likely an established division of labor where each institution has found a niche in which they are more or less comfortable and that provides adequate enrollment (Kershner, 2012). This perception can make an institution blind to the change going on around it. We use two examples in business where complacent reliance in customer loyalty and confidence in branding led to rude awakenings. It is not hard to replace business leadership with higher education administration and faculty.

The perception of market dominance and history of loyal customers deluded the three major networks that they had nothing to fear from the upstart new technologies of cable, satellite, home video, and Internet. Currently the networks have only a sliver of the market. It is laughable today to recall a comment from Harry M. Warner of Warner Brothers in 1927 commenting on the prospect of adding sound to movies, "Who the hell wants to hear actors talk?" Such companies survived because they heeded the signs of change in time. When David Sarnoff, employed by the Marconi Wireless Telegraph Company of America, urged the management to invest in radio in the 1920's, he received this response from an executive, "The wireless music box has no imaginable commercial value. Who would pay for a message sent to nobody in particular?" Sometimes the pace and direction of change is so unlike what we are able to conceive that we simply dismiss the idea. Think about what is happening to television programming and reflect on its implications for high education. There is more viewer-centered variety. DVRs time-shift programming. HDTV is changing viewer expectations. Putting TV on phones means TV whenever, wherever. iTunes, Hulu, and YouTube allows you to buy only the content you want, watch missed episodes, and share what you like (Bruns, 2012).

American Telephone and Telegraph (AT&T) in the late 60's felt that the network of buried copper cable was a national resource, something to be guarded for its high value. Company leaders, of what was affectionately referred to as "Ma Bell", would joke about how the mining of copper brought it out of the ground only to be buried again in the form of telephone wires at a higher value. University administrations and trustees undoubtedly hold their campuses in the same high esteem. AT&T claimed that customers would not tolerate lower quality "foreign" devices (telephones not made by AT&T at Western Electric) being connected to the network and downgrading service. This sounds like the talk by established, campus-based faculty about the quality of electronic distance learning. New companies like Sprint were just making a splash by providing low cost long-distance service on high-volume routes between large metropolitan areas. Ma Bell had traditionally rationalized charging very high prices for long distance service in order to subsidize telephone service to 100% of the households in the US. But in 1974 the US Department of Justice filed an antitrust lawsuit that resulted in the divestiture of local service companies from AT&T. AT&T become one long distance service out of what was to become a large number of companies who offer "nationwide calling" no longer called long distance and not from buried copper cables but through the airwaves. AT&T did begin to change its price structure and did allow non-AT&T equipment to be attached to their network, but not fast enough. Nor would any amount of incremental change have been enough to maintain the status quo in a market changing so rapidly. Ultimately in order to adapt to the new world of electronic communication, AT&T would have to reinvent itself as a number of separate and competing companies in regions around the country. This resistance to change, relying on a broadly recognizable brand, is echoed in this comment made a century earlier in a Western Union memo of 1876, "This *telephone* has too many shortcomings to be seriously considered as a means of communication. The device is inherently of no value to us." Science educators are embedded in a larger system of physical infrastructure and educational culture that resists change. The irony is that STEM education in higher education has had a major role to play in fostering the very changes that challenge institutions and its faculty. Those scientists who can't imagine a laboratory experience outside of their newly refurbished lab space may find their words coming back to haunt them in the not too distant future. Science educators who think that learning to teach science requires the model of one student teacher, one cooperating teacher, and one university supervisor all in the same classroom will likely find themselves wondering where their students have gone. Once #1 in college degrees held by 25-34 year olds, US is 12 among 36 developed countries (Brewer & Tierney, 2011). Debt in student loans has reached $1 trillion, more than all consumer debt combined, and we are in the worst job market in years (Kershner, 2012).

Commercial enterprise is driven to continual improvement by competition, consumer demand, and responsibility to their stockholders. Kershner (2012) observes that higher education has much to learn from this environment. The New York Times reported from 1998 to 2008 enrollment in public and private universities grew less than 25%. Enrollment in for-profit colleges grew by 236% during the same period. The Federal Government estimates 7500 for-profits enroll 670,000 students in degree programs. While some of these degrees are being challenged as not worth the money, how soon will that same challenge be leveled at some degrees in some public institutions? Using the

telephone industry for one more example that highlights a similar issue in higher education, is the major responsibility for company wellbeing to address stockholder focus on the bottom line or to provide the best service to customers? Universities face a similar dynamic tension in their efforts to be accountable to students, families, taxpayers, legislators, and donors.

Kershner (2012) outlines six necessary topics that universities should give focused consideration:
- Streamlining pathways to degrees
- Revolutionary models of instruction
- Recognizing, assessing, and credit for competencies
- Advising informed by much higher quality and quantity of data
- Hard look at underperforming programs
- More comprehensive support services with regular feedback focused on bringing students to well defined, high level outcomes

Kershner goes on to point out that as well meaning faculty and administrators take up these important considerations, they still face a structure of decentralized decision-making that tends to swallow innovation. To bring research to bear on the work of faculty in order to develop new and promising ideas to scale requires the cooperation of a large number of individuals who each have, by tradition, a veto power over change. The culture of tenure protects academic freedom but does it also provide a roadblock to change that may be necessary for the survival of the institution? When the University of Minnesota decided to build a new branch campus in Rochester, the new chancellor negotiated a new kind of institution that did not separate teaching from research. The new chancellor also wanted professors to work together and therefore did away with departments. Part of the qualification for tenure was research in a discipline and research in teaching the discipline (Carey, 2011). In science education, one would think that this is what we do. It is not hard to find pockets of this work in science and mathematics education that offer significant advances (see for example Hammer, 1996; Kazemi & Hubbard, 2008; Windschitl & Thompson, 2011; Elliott, Gray, & Flick, 2012). However, a close look at these and other projects show that they struggle to develop and thrive inside a system where professionals are focused on multiple elements that distract attention from promising change.

Examples of University Faculty with Advanced Pedagogical Skills

Even in a context that stifles innovation, there are faculty who develop advance pedagogical skills. Their work becomes known through the reaction of students and the recognition by some peers. Higher education institutions, even when other forces drive faculty away from teaching, often support teaching awards. These faculty become spokespeople for innovative work in classes and even in programs. One of the authors (Flick) spent time with three OSU faculty who had become known for their teaching and asked them to comment on their work in undergraduate science teaching. These faculty span the subject matter of biology, microbiology, and biophysics. Their work also spans a range of pedagogical activity. Dr. Leslie Blair runs the BI 20X series for majors and non-majors. She

runs lectures of 300-500 students. Dr. Andy Karplus, son of Robert Karplus, is a research scientist and started this year experimenting with a "student-centered" approach to teaching BioPhys III to 25 senior majors. Dr. Kevin Ahern teaches a range of courses in biochemistry and talked to me about his work with online materials.

Dr. Blair thinks about how do you make the experience in a class carry the signature of the institution that delivers it. Increasingly, students have a choice about where they get their education. If they choose to come to the OSU campus, what do they get there that they would not get anywhere else? This is a significant challenge in that the idea is to incorporate elements from many parts of the university. She described doing a study of students who had taken her large lecture course a year or two earlier. To her astonishment, when they were asked what they remember, it was not uncommon for the student to report, sometimes word for word, the stories she told in class. Dr. Blair not only told stories representative of work at OSU but also about her own life as an "explorer of nature". She also told stories from her knowledge of the lives of noted scientists and historical figures in science. Implicit in her discussion was that her lectures carry an aspect of theater. She feels that when it comes to offering a lecture, the bigger the better. When it comes to a campus educational context you have classes, labs, and there are lectures. Even a lecture of 200 is not big enough to achieve what she called a concert experience. At 500 you can produce a wave across the lecture hall. The idea is that if you are on campus there should be a distinctly campus flavor associated with educational experience. If you are taking a class online, then you emphasize features that can only come in that venue, such as geographical diversity, real time cultural diversity, and linguistic diversity. Consistent with current studies she felt that an ideal situation would be where you integrate the best of the two environments. The technology is readily available to connect online students to on campus students and enrich the experience of all.

Dr. Karplus chose a course where it was safe to experiment for his first time to try a student-centered class. The course was ideal for creating a synthesis of content from the previous two courses. His plan was to expose the students to skills needed to effectively read and analyze professional research in biophysics. He wanted to develop the capabilities for being critical consumers of the literature and for selecting research that interested them and that they could grow from as a result of their own efforts. The students read one professional paper a week. Dr. Karplus selected the topics that students needed to review to appreciate the paper. In randomly assigned groups, each member became an "expert" in one of the topics. Prior to class each student emailed text and a figure to use in class related to their topic, thus making each student in a group accountable. Student presentations and questions brought them up to speed on the content. They read the paper. Dr. Karplus posed questions and offered instruction on key points. His criteria was based on what he would expect of a graduate student who was going to join his lab. Dr. Karplus noted that the students didn't perform has he intended but that he will get better at framing the work and they will get better too. His knowledge of the education literature suggested it will take four years before this course operates as he expects. That expectation is that students will read a paper and understand it such that they "own it".

Dr. Ahern is an experienced and award winning instructor in biochemistry and biophysics. Reflecting on his teaching is a routine for him. He has made video records of over 300 lectures all of which are on YouTube. He has received messages from students around the country and the world describing how they have used his lectures to increase their knowledge. Like Dr. Blair, Dr. Ahern wants his lecture experience to create a signature experience for the College of Science and for OSU. Each lecture has links to OSU. Unlike Dr. Blair, he is concerned about how you make a personal connection to a large lecture class. Out of his teaching, he has written an iBook that is available free at the Mac App Store, *Biochemistry Free & Easy*, by Kevin Ahern and Indira Rajagopal. He has used the features of iBook Author in the book to insert galleries of pictures, video, interactive diagrams, 3D objects, and more. The book is a personal expression of the material that students can explore on their own, anywhere, on any device. He achieves a personal connection by this technological extension of his passion for the content.

These three examples illustrate the effects of a passion for science and a personal interest in student learning on achieving higher levels of pedagogical skills. What we see are faculty working on their own to achieve noteworthy effects. However, working alone is not a model for advancing in most fields. Their jobs do not directly advantage the use of time for instructional innovation. Without a broader community within which to discuss ideas and the relevance of high quality educational research, they can't effectively assess the likelihood of any innovation they may think of or hear about making a difference. This lack of institutional attention to teaching means that institutional memory for innovation, successful or otherwise, is lost. The individual faculty member is the holder of idiosyncratic ideas. In other cases, faculty may be connected to a broader network but outside the institution (Flick, 2009). When you couple this with very generic institutional goals for quality instruction, you end up with short-sighted decisions guiding the use of limited instructional funds and for setting priorities for faculty. Overall there is little incentive built into science faculty positions for trying new instructional approaches. The culture and infrastructure of the academy favors disciplinary research and does not provide perks for examining the interaction of discipline knowledge with educational research. The synthesis of research expressed through new science and mathematics education standards in K-12 education mentioned above offer promising motivation for focused thinking in this area, but the culture of the academy will have to change for such ideas to have an impact. One observation that highlights this issue concerns a growing emphasis on assessment coming from accrediting agencies (NWCCU, 2010). One key feature is new requirements for articulating assessable outcomes. From a rational and empirical point of view, seemingly consistent with scientific thinking, this would be a powerful first step in gaining productive insight into student performance. In general, faculty resist and complain. Deep in the cultural is the model that high levels of scientific knowledge lead to high capabilities in teaching.

The technologies supported on campuses can be a barrier to innovation by remaining staunchly proprietary. The image here is the comical and now dated reputation of the librarian who is so concerned about the care and cataloging of books that circulation is discourage. Barriers to innovation on campuses will be slowly revealed as pressure for

new forms of instruction and access to information make their way into the work of the professoriate.

Implications

We offer eight final thoughts on the revolution in contexts for learning and implications for undergraduate science education. This paper has stressed that understanding reform involves examining the larger systems of which undergraduate STEM education is a part. We have outlined the larger online environment that is impacting college teaching. This environment has multiple features each capable of exerting significant influence on undergraduate science. The online environment is providing an increasing number of avenues for both gathering information and aids in processing information. Wikipedia provides information in propositional form but the Kahn Academy and TED Talks provide ideas in conversational and video formats. The Internet is bringing institutions together in a kind of market place for learning where instructional formats can be compared and synthesized by the user. Courses and programs are available side-by-side, some of them are free of charge. This larger environment will raise questions about the relative value of degrees, certificates and "badges" of completion. The shear variety of content presentations will force examination of standard, on campus learning environments.

Along with the technological supports for delivering information and instruction comes an increased facility in gathering and analyzing data on the behavior of learners. The work of Candace Thille ("Rebooting", 2012) *Online Learning Initiative* points the way toward using new computing power to gather more and more meaningful data on student performance. We will find new ways for collecting data for advising and tracking our students towards university-worthy outcomes that have been vetted with faculty, students, families, business leaders, and donors.

The press for innovation in learning environments has implications for the structure of jobs in institutions. The University of Minnesota Rochester has linked research in the discipline with research on teaching. As institutions compete for students in a larger market place, there will be greater emphasis on the value of inquiry into teaching practices. This inquiry will extend into learning environments more generally with a tendency to mix electronic resources with traditional face-to-face venues.

Instruction, once conceived as a single instructor meeting with a single class, will become the responsibility of a team. The team will likely be made up of content experts, often from across disciplines, and electronic media and instructional design experts. Institutions are creating campus "centers for teaching and learning" that support the development of pedagogical skills. These centers have tended to work in the current environment of single instructors and classrooms. A newer strategy will be to bring faculty together and foster productive work groups across disciplines to share pedagogical tools and concepts between for example, English literature and physics.

It has not been typical for higher education institutions to think of growing instructional ideas to scale, as is done in commercial enterprises, but perhaps it should, at least in certain

segments of its work (Kershner, 2012, p. B9). Following Dr. Blair's reflection, as we mix online information tools with on campus course designs, we can build innovative links between the signature experiences on campus with the unique qualities of online environments. An ideal for John Dewey was that education provide ways of bringing people together. That ideal may now be achieved at scales never before imagined.

Along with greater inquiry into teaching practice and instructional design will come a greater emphasis in professional and scholarly societies on how to bring the meaning of new research results to students and a larger audience of learners on the Internet. Fitzpatrick's ("Rebooting", 2012) insight for increasing exposure of new ideas to increase immediacy of peer review can be extended to those who are inquiring into teaching practices.

The online environment offers potential for synergies across institutions. Whereas in one view, institutions seek to create their own signature programs online, a collaborative venture multiplies the opportunities for students and faculty. Harvard and MIT have pooled $60 million to offer free online courses under a brand called edX. This sidesteps the use of Harvard and MIT brands, which perhaps keeps the venture experimental. However, collaborations extend the reach of educational ideas and offers opportunities to learn more about learning and innovative delivery of content.

New standards in science and mathematics in K-12 education adopt the use of disciplinary practices as key pedagogical tools for teaching core content. Higher education will learn from the research demonstrating the power of focusing instructional effort in building intellectual capacity through structured discourse. Disciplinary practices provide a framework for structuring student talk to support higher-level thinking in the use of evidence (in science) and making justifications and generalizations (in mathematics). This approach draws directly from the work in disciplines and highlights the pedagogical benefits of using synergies across disciplines to effectively teach core content.

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