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Catalyzing Curriculum Evolution in Graduate Science Education

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Strategies in life science graduate education must evolve in order to train a modern workforce capable of integrative solutions to challenging problems. Our institution has catalyzed such evolution through building a postdoctoral Curriculum Fellows Program that provides a collaborative and scholarly education laboratory for innovation in graduate training.

The modernization of science education requires a shift from a content-driven curriculum to an interdisciplinary, concept-driven curriculum (Association of American Medical Colleges and Howard Hughes Medical Institute, 2009; American Association for the Advancement of Science, 2009; National Research Council, 2003, 2009). Such a curriculum organizes information around unifying concepts and frees educators from the insurmountable task of presenting the complete breadth of an ever-expanding scientific knowledge base (D'Avanzo, 2008). Concept-driven education is increasingly seen as fundamental for contemporary research scientists and physicians (Association of American Medical Colleges and Howard Hughes Medical Institute, 2009). An important complement to concept-driven education is the incorporation of skill-building curricula into STEM education (Carnegie Institute for Advanced Study Commission on Mathematics and Science Education, 2009; Coil et al., 2010). A Commentary in *Cell* (Lorsch and Nichols, 2011) articulates a concise vision for redesigning graduate education around integrated themes, required skills, and technical methodology, particularly for broad "umbrella" life science programs that naturally occupy interdisciplinary territory. Although many similar reports offer recommendations, few offer practical strategies to achieve these changes. For the past 6 years, our institution has begun to catalyze the evolution of our existing life sciences graduate curriculum toward many of these goals and describe here some effective solutions.

Challenges to Modernizing Graduate Education

There are several barriers to innovation of interdisciplinary, concept-driven curricula that also develop skills in analytical thinking, experimental design, and technological fluency. Developing a cohesive graduate curriculum requires that diverse teams of faculty collaborate to reach consensus on the core conceptual learning goals for the curriculum and how to best meet these goals. Furthermore, particularly for large programs and schools, there is a challenge as to how these concepts will be aligned among multiple courses taught by different faculty members, what specific content will be used to illustrate these concepts in each course, and what content will be left for self-education. Graduate education must teach students to think independently, learn how to best access existing information, and acquire new knowledge on their own. Therefore, the curriculum must help develop these skills of the autodidact, while also identifying significant conceptual gaps in students' backgrounds. It is a challenging task indeed to create an integrated curriculum that addresses prior misconceptions and gaps in knowledge and develops skills in experimental design, critical paper reading, and technical fluency and, at the same time, fosters the development of creative, independent, critical thinkers. At Harvard Medical School (HMS), we have approached this challenge by critically examining and iteratively redesigning existing core content courses to meet these needs, while also developing new courses and course formats to reinforce content and build skills and technical fluency.

Another challenge, particularly for large programs at major research universities, is that PhD laboratory training takes place across many departments on multiple campuses and affiliate institutions. Faculty at large research institutions are under increasing pressure for funding support, and teaching takes time away from research. Moreover, teaching is not consistently rewarded in the tenure review process. The task of mounting new courses requires intense time and effort and therefore, historically, curricula for these programs were acquired from existing departmental courses. As Lorsch and Nichols point out, when umbrella programs "became the predominant model for graduate training in the life sciences, these departmental course structures were used to build the new curricula for first-year students" (Lorsch and Nichols, 2011). However, because such courses derived from traditional departmental silos and were not often designed simultaneously, they are not uniformly integrated nor do they stress core conceptual knowledge across various levels of biological inquiry. Nonetheless, it is often impractical to completely dismantle the existing curriculum and replace it all at once. A much more practical strategy is to evolve the courses in real time. Such an evolving curriculum can and should continue to seek optimal structure as scientific fields continue to progress.

Tools for Curricular Evolution

Development of Short-Format Skill-Building Courses

Nanocourses. Graduate students need access to courses that can teach them technical skills as their need to learn these new skills arises. Furthermore, students learn best when they have an innate motivation for their learning (Wlodkowski, 2008). Therefore, an early goal for HMS faculty working on curricular revisions has been to create a variety of new courses that expose graduate students to cutting-edge techniques and new scientific frontiers. The nanocourse format (6 contact hr), introduced in 2006 (Bentley et al., 2008), is a dynamic way of teaching advanced scientific topics in a condensed fashion (see https://nanosandothercourses.hms.harvard.edu/node/8 for more information on nanocourses). The goal for this teaching tool is to create a curriculum that is responsive to the changing nature of any scientific field, that takes maximum advantage of the diverse expertise of the faculty across the campus, and that appeals to a wide variety of students, postdocs, medical fellows, and faculty. These courses offer a modular curriculum in which students can take a course on a particular topic or technique at the time when they are most motivated to learn about it. Therefore, students can assemble a self-directed curriculum, which spans the various expertises required for their individualized training. Nanocourses frequently bring together multiple faculty members to present distinct perspectives or approaches on the same topic. These often include, for example, clinicians and basic scientists or researchers examining a problem at various levels of scale from structural biologists to cell and organismal biologists. Nanocourses can provide training in technical skills (such as mass spectrometry or fluorescence live-cell microscopy), strategic academic skills (such as scientific presentation), or translational science (for instance, autism spectrum disorders examined from the perspectives of a pediatrician, a human geneticist, and a molecular neuroscientist). Students and faculty can also easily propose and develop new nanocourses on specific topics, allowing the curriculum to evolve rapidly as new research fields emerge. Moreover, because these are only 6 hr courses, faculty members with relevant expertise can easily be recruited to teach new courses without agreeing to dedicate too much time away from their own research.

Experimental Design. Experimental design is a central skill that integrates many aspects of scientific training. To help contextualize the graduate curriculum and laboratory research in a framework of effective experimental design, entering first-year students in various graduate programs at HMS now participate in a multiday skill-building course (for more materials related to the 2012 offering of this course, see https://nanosandothercourses.hms.harvard.edu/node/198). In this course, the process of experimental design is made explicit in a didactic format with small discussion group activities that allow students to practice framing experiments into larger scientific contexts and disciplines, devising experimental hypotheses and questions, proposing proper system validation and experimental controls, flow-charting projects, and anticipating issues of data interpretation (Glass, 2007). The faculty members in the course are drawn from multiple departments and programs to promote collaboration across silos. This course was originally offered as a nanocourse and then as a half-semester course before being adapted for a 4 day intensive format for newly matriculated students. Therefore, the short course format can also serve as an incubator for the evolution of new longer-format courses taught to wider audiences. This progression allows the course to be evaluated, vetted, and modified before offering it to a large cohort of students. Refinements continue based upon student and instructor feedback. For example, students who participated in the experimental design orientation course recently expressed that they would like to apply these skills to identify critical aspects of design using their own first-year research rotations. Therefore, we are now experimenting with a 3 day experimental design course where the first day is a full-day workshop during the August orientation period that introduces students to critical elements in experimental design. The students then return to their small groups in the late fall and spring to present and analyze the experimental design of current rotation research projects. By revisiting this content throughout the first year, we hope that students will become more fluent in the skills to properly design an experiment from the outset.

Quantitative Science. Contemporary research in the life sciences increasingly requires quantitative approaches. This has been recognized at the national level, where reports have repeatedly called for science instruction to include training in the techniques of quantitative biology (Gross, 2000; National Research Council, 2003; American Association for the Advancement of Science, 2009). To address this need, a second new short-format course, ~30 hr over five days, the Quantitative Modeling Boot Camp course (QMBC; http://springerlab.org/qmbc/), was created by Dr. Michael Springer and codeveloped by Dr. Rick Born. It is offered twice during the year, once during the orientation period for incoming graduate students at HMS and a second time for upper-level graduate students and postdoctoral fellows. Although the course is ostensibly designed to teach students the basics of programming, the deeper goal is to teach students how to think about problems quantitatively. This starts with data visualization and extends through data analysis, statistics, and modeling. The goal of course is to introduce these concepts and thereby lower the barrier for students to take further classes and learn more on their own. By teaching incoming graduate students before classes begin, other courses can build upon this foundation and integrate quantitative methods throughout the curriculum. The course also provides students with basic knowledge and tools for data analysis prior to starting their laboratory rotations.

Proposal Writing and Scientific Communication. Proposal writing is a skill that is essential for academic scientists. Effective written communication is also highly transferrable to careers beyond the bench. Although many core science content courses require written proposals as part of their assessment, they do not necessarily teach the skills necessary to write a competitive grant. The course "Critical Thinking and Research Proposal Writing" was developed over a decade ago as an elective for the Biological and Biomedical Sciences (BBS) program at HMS to systematically guide students in the writing of original, hypothesis-driven research proposals in a small-group tutorial format. Under direction of Dr. Monica Colaiacovo, this course (BBS 330) is now being adapted for all second-year graduate students in BBS. BBS 330 will offer students an opportunity to develop their thesis proposals with supportive and objective criticism from experienced faculty. The recent Biomedical Workforce Report, published by the National Institutes of Health (NIH), recommends an increase in the proportion of funding from student fellowship sources and a reduction in trainee funding on principal investigator research grants (National Institutes of Health, 2012). Therefore, in future years, it will be increasingly important for students to submit their own predoctoral funding proposals. One aspiration for this course is that it increases the number of thesis proposals that are submitted and receive funding.

Scientific presentation is another critical skill for scientists as well as a skill that is transferrable to almost any other profession. At HMS, we offer a 3 day short course in scientific presentation. The first day consists of lectures and activities that present best practices in introductory framework, logical structure, slide design, delivery, and audience engagement. At the second session, students practice a 5 min slide talk about their research. They are given feedback on all aspects of their presentation from faculty members and peers, and they are recorded so they can assess their own performance. They then return on a third day to give an edited version of their talk, which incorporates and addresses the feedback from the first version. Although students typically have the opportunity to give scientific talks in other courses, conferences, and seminars, this course offers a foundational opportunity for them to focus on refining presentation style and strategy. This course is currently offered in the late spring, and first- and second-year students are encouraged to participate.

Laboratory-Based Bootcamp Courses. Interdisciplinary experimental design requires the integration of multiple technologies and thus can be facilitated by exposure of students to a broad range of research methods. Although new techniques can be learned in the lab or through collaborations specialized courses focused on a technical arsenal in a particular research area are often very effective. Indeed, many students take advantage of existing practical courses at institutions such as the Woods Hole Marine Biological Laboratories (MBL), Cold Spring Harbor Laboratories (CSHL), or the European Molecular Biology Laboratory (EMBL). However, these lab courses can accommodate only a relatively small number of students. Therefore, HMS faculty members have collaborated to develop multiple laboratory-based courses that provide specialized training in new technologies and exposure to their laboratory applications (see https://nanosandothercourses.hms.harvard.edu/boot-camp-courses for a list of bootcamps offered and a short description of each; see Document S1 available online for sample course manuals). The 1 to 2 week "bootcamp" courses bring students into research laboratories where, in one or two days, the students progress from a lecture about the framework questions in the field to participation in laboratory exercises to experience specific techniques and model systems. In these bootcamp courses, students learn approaches that are being used to investigate questions within a broad, integrated discipline, such as developmental and regenerative biology, cancer pathology, or genetics and genomics. Like the courses at MBL or CSHL, HMS bootcamp courses are short and intensive, focus on the application of techniques, and engender an exploratory and fearless attitude toward adopting new approaches. Because these courses are offered every year, they can meet the demand even in a large program.

Benefits for the Existing Curriculum. Our new technology and skills development courses offered in the first year of graduate study complement a more traditional, semester-long course in critical reading of the scientific literature, where students analyze papers through in-depth discussions with peers and faculty members. However, having taken a didactic course in experimental design, students can approach this critical reading course not just as the critic, but also as the composer. Therefore, in their critical reading class, students not only learn the skill of deconstructing a flawed paper, but they are also challenged to extract and understand the design elements of what constitutes an excellent set of experiments. The papers chosen for this course focus on core integrating concepts investigated at various levels of inquiry, from structural to systems approaches. These are the same core concepts that provide the overarching framework for the traditional first-year content courses. Thus, by adding new skills courses in experimental design and quantitative methodology and by articulating an overarching core conceptual framework for the first-year curriculum, changes within traditional, long-standing courses have been catalyzed.

Innovating Traditional Core Content Courses

Following up on successful experiments with short-format courses that have enriched our advanced curriculum, we began a wholesale effort to revise the core content courses for first-year graduate students in the BBS program at HMS. BBS offers broad and interdisciplinary research training in cell and molecular biology. Students from multiple graduate programs at Harvard Medical School rely on BBS core courses for their fundamental content. The first-year coursework for students in the BBS program includes four core scientific content courses. These courses—molecular biology, cell biology, genetics, and protein biochemistry—were originally designed within traditional departmental structures. As science has become more integrated, these departments have become broader, and more faculty members are prepared to teach across disciplines. To align our courses toward a central teaching platform that emphasizes a set of core integrative concepts, faculty course directors from the departments across HMS were asked to collaborate in a central curriculum committee to map this conceptual landscape.

Our curriculum committee has delineated central conceptual learning goals for these core content courses and has decided how these could be illustrated within the existing courses to reflect different research approaches at various scales (from atomic to systems) to create an integrated core curriculum. New skills-based learning objectives for these courses have also been defined in order to build upon and reinforce the new first- and second-year skills curriculum (Figure 1). For example, in order to fortify the skills in experimental design, the core courses have begun to emphasize fluency in experimental design as a central goal for students. The teaching of scientific process is emphasized rather than the teaching of specific content details.

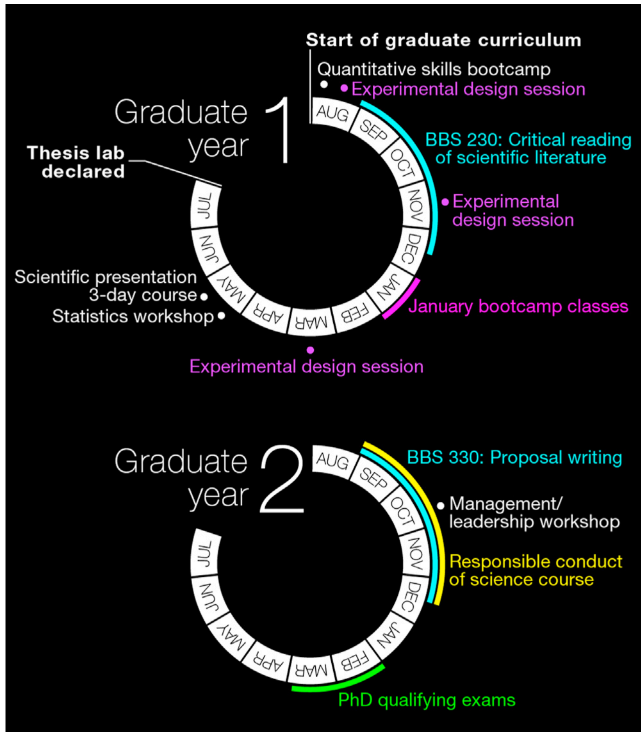

Figure 1. A Skills Training Curriculum for Graduate Students
Depicted are the required and supplemental curriculum in skills training provided for the first- (G1) and second- (G2) year graduate students in the BBS Graduate Program at Harvard Medical School. Experimental Design, BBS 230, BBS 330, the Management/Leadership Workshop and the Responsible Conduct of Science course are all required for BBS students. During their G1 year, they also typically take scientific content courses in Molecular Biology (fall), Genetics (fall), Cell Biology (spring), and Biochemistry (spring).

This focus on fundamental overarching concepts and development of the essential skills of an experimental scientist necessarily means that faculty members in these core courses have had to adapt their lecture content to stress the critical insights and technological approaches that led to specific scientific discoveries. This has also required that breadth of coverage and delineation of all mechanistic details be sacrificed for the sake of in-depth exploration of key experiments and discoveries that bring critical overarching concepts into focus. This has resulted in clearer and more thematically focused lectures. To better assess student learning in real time, interactive teaching strategies such as "clicker" questions, peer-to-peer learning, and online forums have also been introduced into these courses. New assessment tools allow students to practice the skills of experimental design and presentation in the context of course-specific content (Allen and Tanner, 2005). In this way, the first-year curriculum has evolved to reflect coordinated overarching course goals and teaching strategies.

This evolution in our curriculum has resulted in the students participating more actively in their own learning and thus in increased student satisfaction with the courses. In three classes in which such improvements have been made in teaching and curriculum, the consecutive annual change in overall quality of the courses as ranked by the students has increased by 54%, 18%, and 14.5% (average number of students, respectively, is 18, 22, 68; average evaluation response rate, respectively, is 78%, 63%, and 87%). New assessment metrics are being developed to more accurately and directly measure the impact of the changes in these courses on student learning.

A Training Laboratory as a Catalyst for Change

One novel and key resource that has propelled this energy-intensive evolutionary process forward is the creation of a new education and training laboratory, the HMS Curriculum Fellows Program (CFP). The CFP began as a way to help faculty effect change in their individual classrooms while creating a training path for bench scientists interested in transitioning into careers in education. Curriculum Fellows (CFs) are PhD scientists with career goals in teaching, science education research, and higher education administration. They collaborate full time with course directors to help manage courses, develop curriculum, adopt modern teaching tools, and devise strategies to increase and assess student learning. Because the CFs are at the postdoctoral level, they serve as a liaison between the students and the faculty members and facilitate communication between these populations. Also, like postdoctoral fellows in a traditional research laboratory, the CFs acquire insights from the current literature in science education to bring researched interventions to the HMS graduate and medical classrooms. By working to improve individual courses, CFs gain access to the course material and develop a collaborative relationship with the course faculty. Because most core courses have a CF working on it, the CFs collectively have knowledge of all of the content being taught across the first-year curriculum. Because CFs also interact as part of the CFP education and training laboratory and because they are integral to the BBS curriculum committee, their contribution to individual courses also stimulates coordinated changes across the whole curriculum.

Our goal at HMS is to present a unified first-year graduate curriculum where central concepts are taught across disciplines and at multiple levels of inquiry. The essential skills curriculum overlays this by teaching and reinforcing these tools within the coursework. For example, concepts like equilibrium constants and the meaning and value of understanding binding kinetics are central concepts that can be illustrated in the context of genetics, molecular biology, biochemistry, and cell biology courses. Skills in designing experiments and grantsmanship can also be infused into these courses with new assignment formats. In their paper, Lorsch and Nichols (2011) provide a theoretical framework for the development of a new curriculum. Our challenge at HMS has been to map such concepts and skills onto the existing courses in order to direct the evolution of these courses to meet these goals. The CFs have begun this work by taking an inventory of the first-year courses to catalog the content, concepts, and skills currently taught and to identify those that are missing or redundant. This catalog serves as the basis for a dialog to identify the essential concepts and skills to be introduced, reinforced, and built upon across the curriculum (Marbach-Ad et al., 2007), with the goal of a wholesale integration of the core courses and evolution toward a concept-centered curriculum.

Just as with successful postdoctoral fellows in the research lab, the CFP has created other unanticipated benefits for the community of faculty and trainees at HMS. Although the job of an academic scientist often requires that one teach, there are few opportunities for students to receive formal training in teaching and learning. The CFP has produced a series of pedagogy courses that guide graduate students and postdocs from theory and current research in science education to best practices in the classroom. Not only does this curriculum offer students opportunities to practice lesson planning, lecture skills, and development of assessment items, but students are also encouraged to apply the same scientific approach to their classroom as they do to their research. Effective teachers articulate clear learning goals for their students, design assessments to measure whether students reach those goals, routinely question which teaching approaches work and which do not, and based on these discoveries, refine their teaching for increased learning gains (Handelsman et al., 2004, 2006). Indeed, recent research suggests that teaching experiences not only prepare graduate students for their future roles as academicians, but also improve their performance as lab researchers (Feldon et al., 2011).

As in research training, effective teacher preparation requires exposure to both the theory and the practice of pedagogy. One of the CF-developed resources achieves this by embedding a pedagogy course into the teaching fellow (TF) experience. Former students in BBS core courses are recruited as TFs; they teach sections but also take a parallel course where they learn about effective teaching methods and curriculum design. Through this parallel process, TFs apply, reflect, and refine their teaching strategy in a live classroom. This course creates a feedback mechanism whereby TFs can consider their own experiences as students in these courses and, through the lens of an educator, contribute to the improvement of the courses. This also creates a feedforward mechanism by which these students become the agents of change in academe, ensuring that future generations of professors are familiar with the methods of scientific teaching and are practiced in the art of developing their classroom and their curriculum with a researcher's perspective. Just as the current generation of faculty have modeled the existing graduate programs after their own graduate experience, it is vital to train the next generation of scientists to evolve the development of curriculum and the practice of teaching to keep pace with discoveries in the laboratory and innovation in the classroom (Wendler et al., 2010).

As technical innovation opens new opportunities for innovation in research, next-generation technology promises to revolutionize in the classroom. From tools that allow instructors to measure student learning in real time (Prensky, 2011) to the development of multiuniversity partners in the realm of distance and online education and research (DeSantis, 2012), contemporary teachers encounter a new and rapidly evolving set of tools and demands for their teaching (e.g., https://learningcatalytics.com/). The power to create new kinds of teaching that incorporate cloud-based applications, Web 2.0 technologies, distance learning, simulations, and gaming is inspiring, but these tools also require a skilled teacher to deliver them in a way that maximizes student learning in a blended learning environment. Because the CFP is a training program, these individuals are poised at the ideal moment in their development as educators to learn how to work with these new technologies in the HMS classrooms and in their own classrooms in the future.

One growth area for the CFP is in the development of formal assessments to measure the impact of the changes they have catalyzed in the classroom. The CFs are working with partners across the university to develop these metrics. By measuring the impact of the changes being made within an individual classroom and across an integrated curriculum, the CFs and their faculty partners will gain a clearer vision of which interventions make the biggest impacts on student learning, retention, and training success. Furthermore, by learning to develop these assessment tools, the CFs will add a significant strength to their professional capabilities. They will be better poised to measure the impact of their own teaching on student learning, but they will also have the skills to develop tools to assess larger endeavors, such as grant-funded training programs. The CFs are also collaborating with faculty members across the university to build a curriculum that teaches the fundamental skills required to develop learning assessment tools and program evaluation instruments. This curriculum will be used to train graduate students, postdoctoral fellows, and future CFs in these critical skills.

Conclusions

Wholesale change of an existing graduate curriculum to meet the mandates of increased interdisciplinary and skill-building coursework is a daunting project. Faculty members at HMS have taken on this challenge by iteratively examining and evolving the existing coursework to meet new goals and adapt to the changing research horizon. This has been done by creating agile short-course formats to introduce cutting-edge research areas and techniques and to develop required skills of the research scientist while also reframing the first-year graduate coursework around fundamental integrated concepts. Bringing researched interventions from science education literature into the classroom has improved teaching and increased student engagement and learning. The creation of the HMS CFP has catalyzed this evolution by recruiting a community of scholars dedicated to developing and researching new strategies in the classroom and across the curriculum. The community of the CFP has entrepreneurially developed courses in pedagogy for graduate and postdoctoral trainees, better preparing them for their teaching responsibilities in the future and involving students in the transformation of their own curriculum. By engaging graduate students and CFs in the evolution of the HMS curriculum toward interdisciplinary concept- and skills-driven coursework, the hope is that these young educators will take this same approach to developing their courses in the future.

SUPPLEMENTAL INFORMATION

Supplemental Information includes sample boot-camp course materials and can be found with this article online at http://dx.doi.org/10.1016/j.cell.2013.04.027.

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REFERENCES

Allen, D., and Tanner, K. (2005). Cell Biol. Educ. *4*, 262–268.

American Association for the Advancement of Science (2009). Vision and Change in Undergraduate Biology Education: A Call to Action. http://visionandchange.org.

Association of American Medical Colleges and Howard Hughes Medical Institute. (2009). Scientific Foundations for Future Physicians: Report of the AAMC-HHMI Committee (Washington, DC, and Chevy Chase, MD: Association of American HHMI and Medical Colleges).

Bentley, A.M., Artavanis-Tsakonas, S., and Stanford, J.S. (2008). CBE Life Sci. Educ. *7*, 175–183.

Carnegie Institute for Advanced Study Commission on Mathematics and Science Education (2009). The Opportunity Equation: Transforming Mathematics and Science Education for Citizenship and the Global Economy. http://opportunityequation.org/.

Coil, D., Wenderoth, M.P., Cunningham, M., and Dirks, C. (2010). CBE Life Sci. Educ. *9*, 524–535.

D'Avanzo, C. (2008). BioScience *58*, 1079–1085.

DeSantis, N. (2012) Harvard and MIT Put $60-Million Into New Platform for Free Online Courses. http://chronicle.com/blogs/wiredcampus/harvard-and-mit-put-60-million-into-new-platform-for-free-online-courses/36284.

Feldon, D.F., Peugh, J., Timmerman, B.E., Maher, M.A., Hurst, M., Strickland, D., Gilmore, J.A., and Stiegelmeyer, C. (2011). Science *333*, 1037–1039.

Glass, D.J. (2007). Experimental Design for Biologists (Cold Spring Harbor, New York: Cold Spring Harbor Laboratory Press).

Gross, L.J. (2000). Science *288*, 807–809.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S.M., and Wood, W.B. (2004). Science *304*, 521–522.

Handelsman, J., Miller, S., and Pfund, C. (2006). Scientific Teaching (New York: W.H. Freeman and Company).

Lorsch, J.R., and Nichols, D.G. (2011). Cell *146*, 506–509.

Marbach-Ad, G., Briken, V., Frauwirth, K., Gao, L.-Y., Hutcheson, S.W., Joseph, S.W., Mosser, D., Parent, B., Shields, P., Song, W., et al. (2007). CBE Life Sci. Educ. *6*, 155–162.

National Institutes of Health (2012). Biomedical Research Workforce Working Group Report. http://acd.od.nih.gov/Biomedical_research_wgreport.pdf.

National Research Council. (2003). BIO2010, Transforming Undergraduate Education for Future Research Biologists (Washington, DC: National Academies Press).

National Research Council. (2009). A New Biology for the 21st Century: Ensuring the United States Leads the Coming Biology Revolution (Washington, DC: National Academies Press).

Prensky, M. (2011). Educational Technology *Nov–Dec*, 1–4.

Wendler, C., Bridgeman, B., Cline, F., Millett, C., Rock, J., Bell, N., and McAllister, P. (2010). The Path Forward: The Future of Graduate Education in the United States (Princeton, NJ: Educational Testing Service).

Wlodkowski, R.J. (2008). Enhancing Adult Motivation to Learn: A Comprehensive Guide for Teaching All Adults, Third Edition (San Francisco, CA: Jossey-Bass).

