SHOULD WE CONTINUE TO PROVIDE LIFE SUPPORT TO THE TRADITIONAL UNDERGRADUATE TEACHING LABORATORY OR IS IT TIME TO LET IT GO?

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Abstract

Teaching laboratories have been a fixture in science education since the mid-1800′s. Considered essential for introducing students to the hands-on techniques and critical thought necessary to become practicing scientists, teaching labs have enjoyed a sacred and untouchable status in higher education. However, teaching labs also represent an investment in time, space, resources and personnel, an investment that in a period of dramatic budget reductions is increasingly being challenged. Given the wealth of online resources that range from simulations to access to remote instrumentation to citizen science initiatives, is it time to rethink the role, delivery, and purpose of the undergraduate teaching laboratory.

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Teaching laboratories have been a fixture in science education since the mid-1800′s. Considered essential for introducing students to the hands-on techniques and critical thought necessary to become practicing scientists, teaching labs have enjoyed a sacred and untouchable status in higher education. However, teaching labs also represent an investment in time, space, resources and personnel, an investment that in a period of dramatic budget reductions is increasingly being challenged. Make no mistake about it: undergraduate science teaching laboratories are expensive and represent significant investments by the institution, departments, faculty/staff and student. It is surprising, then, that the design, delivery or content of teaching labs frequently receive little or no consideration by departments or institutions. Perhaps even more astonishing is how little thought is given to the horizontal or vertical integration of teaching laboratories within or between science programs. The failure to articulate the pedagogical value and necessity of laboratories or to comprehensively integrate them into the broader science curriculum raises questions about whether today′s laboratories are adequately preparing students in the sciences and ultimately, given their phenomenal use of resources, whether teaching laboratories are good investments. More importantly, it is now time to ask whether there are better alternatives to the traditional bricks and mortar teaching laboratory.

To answer this, faculty and administrators must move beyond the predominant model of laboratory science education, in existence since the late 1800′s, of a "hands-on" learning experience occurring in a laboratory setting. Indeed, it should not be a surprise to see clear examples of laboratory activities conducted today that would be familiar to a student of the 19th century. The fundamental difference, however, is that teaching laboratories of that time tended to be training pathways for students to enter faculty research labs, with the laboratory activities reflecting the types of skills needed to function within a particular research discipline. This model worked well with small numbers of students and where the research to be conducted was, by today′s standards, relatively simple. Unfortunately, this model fails dramatically in today′s environment where large introductory laboratory courses are filled with hundreds, if not thousands, of students. To complicate matters, many of these students are passing through laboratory courses in one department, such as chemistry, as prerequisites to majoring in other disciplines, such as pharmacy or medicine. These students, will generally not spend a single day conducting research within a chemistry laboratory, let alone conducting research with a faculty member within that discipline. And finally, today's faculty research is much more complex and dependent on the use of instrumentation, a situation not reflected in the design or content of contemporary introductory teaching laboratory courses.

As a result of these and other factors, introductory teaching labs, especially at larger institutions have evolved into educational factories; their primary focus to move large numbers of students through what ends up being an artificial version of the laboratory experience that provides limited and often disjointed training and even less opportunity to develop critical thinking skills based on observations and manipulations. Typically, these laboratories consist entirely of repetitive, predefined activities intended to produce predetermined outcomes in two or three hour blocks. They do little to engage the student in the scientific process or to capture the excitement of research and discovery. Given this status quo, how do we effectively move away from the predominant factory model to one that incorporates alternative laboratory teaching strategies and that more effectively reflects science in the 2010's and beyond?

Myles G. Boylan of the National Science Foundation stated in 2007 that *"In almost every discipline, I could point to a variety of really effective, wonderful sets of instructional materials and instructional practices, and say that if we could magically click our fingers and get everybody using them, there would be a huge improvement in undergraduate education that would happen instantaneously, but we're nowhere near that."* (Chronicle of Higher Education, *The Tough Road to Better Science Teaching*, August 3, 2007). To understand why this is so and to effectively develop alternative models for the undergraduate teaching lab, it is critical to recognize some of the factors that make change difficult. To begin with, many universities have developed a significant infrastructure to support the traditional model of the teaching laboratory and its focus on processing large numbers of students through laboratory activities. Everything from prepping the labs, running the labs, to ordering supplies and handling lab waste has been optimized over time for the relentless march of students through the laboratory. In addition, as with any institutionalized system, an entire bureaucracy and economy has developed around this laboratory infrastructure. For example, at some institutions TA support is distributed centrally. If a given department has a large number of students taking a large number of required labs, that department has a higher probability of receiving TA support. Offering a TA position to potential graduate or advanced undergraduate students is a significant recruitment tool for attracting these students into your department and supporting institutional research mandates. Maintaining the teaching laboratory infrastructure along with financial support for graduate students are powerful incentives for not changing the status quo. This is further supported through required introductory science courses, such as introductory chemistry, that students across the sciences are obligated to take. These service courses dramatically inflate the student numbers within a particular department, bolstering arguments for the need of additional resources.

Laboratory fees represent another reason for maintaining the current laboratory model. That is, whether by design or by default, laboratory fees collected from large introductory laboratory sections are often used to subsidize the smaller more costly advanced labs taken by upper level majors or for supporting departmental instrumentation that many introductory level students will never use. In addition, bulk purchasing of chemicals, supplies, glassware and other consumable materials for use in multiple courses makes it difficult to track the use of supplies or provide an exact accounting of who is paying for what. In this case, the status quo provides an effective means of laundering laboratory fees. Only a very small percentage of students taking introductory laboratories, such as general chemistry, go on to become majors in that discipline. This lower level subsidy of upper level courses by the majority of non-major students often makes a significant difference in the types and quality of labs that can be offered to students within those majors. This, in turn, creates a strong incentive to maintain the status quo. Why remove a relatively flexible source of income, lab fees, from your budget by changing the way introductory labs are taught or by eliminating labs altogether?

Finally, laboratories, even as cook book labs, are generally difficult to bring into production. A thousand and one things can and do go wrong. To paraphrase the late Art Linkletter, "students do the darndest things." From mixing the wrong chemicals to the inevitable spills to being involved in serious accidents, almost anything can and does happen in a lab full of students. To be sure, this is part of learning how to function in a laboratory environment but, it also means that instructors tend to stick with well-established labs that minimize the potential for chaos. This generally means that labs are designed and written as simply as possible, providing students with step by step instructions throughout each experiment right to the experimental conclusion. If the solution turns red you did the experiment right if not, repeat steps 1 through 5. This is far removed from the trial and error associated with real labs. The control and predictability of step by step laboratory protocols has a further advantage of limiting student complaints, an important consideration for the tenure and promotion process. Students do not like uncertainty and often reflect this in course evaluations. Real science is full of uncertainty. The closer teaching labs get to "real labs" the greater the uncertainty in experimental outcomes. Students following traditional laboratory instructions have become comfortable knowing what they have to do to get a grade. Being graded on an outcome based on a defined process provides students a level of comfort. These factors make it difficult for faculty to change the types of labs offered and the way labs are taught. Generally speaking, new labs take a lot of effort to design, test and implement and are usually associated with a higher number of student complaints, especially if they are problem based or open ended. In other words, the rewards for changing labs are few while the penalties can be significant, including poor tenure review and havingless time for research and grant writing among them. Indeed, looking at the cost benefit ratio, the costs of changing labs are often significant relative to the benefits gained by a faculty member for doing so.

So, where does all of this leave us? First of all, change may come despite many of the issues just described with perhaps the biggest driver of change being the length and depth of the "Great Recession." Indeed, the *Chronicle* has highlighted a number of these moves (Chronicle of Higher Education, *Budget Cuts Force Chemistry Department to Hold Some Labs Online*, Oct. 8, 2010) and as the impact of the recession continues, we will likely see other forced changes to the science laboratory curriculum. But is this all bad? As the saying goes, "crisis creates opportunity for change," and nowhere is there more opportunity or need for change than in the way laboratory-based science is taught. However, the problem with crisis driven change is that more often than not, the change we see is in efficiencies — that is, doing the same or similar things only cheaper. Rarely does this result in the types of change that bring about a fundamentally new paradigm, in this case a new way of teaching laboratory science. This is particularly true given that the current bricks and mortar model of laboratory education represents the gold standard by which all possible alternatives must be judged. And it is true that few, if any, of the alternative strategies for laboratory-based education, such as the use of lab kits, remote instrumentation, virtual and online labs, can replicate the traditional "hands-on" laboratory. But should they? Is it really desirable to replicate traditional "hands-on" labs using these alternative strategies or should educators be trying to use these approaches to create an entirely new laboratory teaching and learning paradigm?

In rethinking the traditional views of science education, educators and administrators should be focusing on the things these alternate strategies make possible. For example, a significant advantage of an online remote laboratory experience that incorporates remote instrumentation over its brick-and-mortar counterpart is that online laboratories do not have to be confined within defined timeframes (typically two- or three-hour time blocks). This means that online laboratory activities can be less prescriptive in nature, delivered with greater flexibility, and can provide multiple opportunities for students to consider and modify experimental conditions, reinterpret results, and reflect on experimental outcomes. The ability to repeat, reinterpret, and reflect allows the online laboratory experience to be more representative of the way science is actually conducted. The use of prepackaged science kits that allow students to conduct experiments at home or in the dorm has been shown to draw family members and roommates into the experiments activities. This begs the question: can conducting labs outside the traditional bricks and mortar laboratory be a pathway to greater science literacy for non-scientists?

The bottom line is that instead of replicating traditional labs, these strategies can and should be used in new and/or complementary ways to reshape education and training in the sciences and provide largely untapped opportunities to engage students in ways that go far beyond what is possible in traditional labs. Embracing the capabilities made possible by these alternative strategies represent a significant departure from the traditional belief that science must be taught as a series of predetermined "hands-on" activities conducted within restricted spaces and defined timeframes. Rather than simply moving students through a series of traditional "cookbook-style" activities, in our view the teaching laboratory has the potential to be shifted to one of providing students with a "laboratory experience" designed around associated learning goals and resources. This new paradigm includes access to and us of laboratory kits, remote instrumentation, virtual simulations and other web-based resources, as well as the use of a variety of social networking tools that promote collaboration, information sharing, timely feedback on student learning and on-going assessment. This model of science education incorporates the collective resources and tools available outside the traditional teaching laboratory to engage students in the scientific process, support their learning needs, and promote a culture of scientific research, learning and discovery.

However, designers and users of alternative lab strategies should also avoid the temptation of offering students too much. From YouTube videos, to podcasts, to virtual simulations, to Second Life activities and beyond, it is important to remain cautious about how we conduct educational labs while at the same time fully exploiting the available resources to effectively engage our students. The instructor's role and responsibility for creating and implementing a quality laboratory experience is an essential element of this change. As far back as 1886, Ira Remsen, the first Chemistry Department Chair at Johns Hopkins University and later its President, stated, "It behooves those who are convinced of the great advantages to be derived from good laboratory courses to see to it that these courses are conscientiously conducted." Translated using today's educational language, this statement underscores the importance that teaching laboratories have clear learning objectives, thoughtful instructional design, pedagogically relevant activities, and appropriate evaluation and assessment processes — Crucial elements frequently missing from the traditional teaching laboratories of today. Considering the enormous pressures on undergraduate science programs, should we continue to provide life support for the undergraduate teaching laboratory with its traditions, infrastructure costs, and hidden economies or is it time to change the status quo and seriously consider alternatives?