THINKING OUTSIDE OF THE LAB: SPECIAL CONSIDERATIONS FOR LAB COURSE REDESIGN

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She has a passion for learning and considers herself a lifelong learner who is perpetually trying to discover new things and new ways of doing the things that she has already made a part of her life. Teaching and learning are both very enjoyable for Amy and she is greatly interested in transitioning blended and online course materials as a standard way of teaching instead of as a new or emerging type of instruction.

As the primary investigator for the Transforming Instructional Laboratories project, Amy has developed an expertise in laboratory redesign practices using best pedagogical methodologies. Amy is recognized as the go-to person on the S&T campus for learning about instructional design of laboratory courses, including DELTA labs, which strive for the goal of delivering experiential labs to all.

Abstract

Course redesign has traditionally focused on lecture-style courses, while laboratory courses have received comparatively little attention. The Missouri University of Science and Technology's Delivering Experiential Labs to All initiative is a model for redesigning lab courses to more effectively present lessons in contexts where use of specialized equipment is impractical or unnecessary through the use of blended and online laboratory courses. Special considerations arise when applying redesign strategies to such laboratory environments. This paper focuses on several details of instructional design that differ in laboratory courses when compared to the creation of blended and online lecture materials. While focusing on the practical issues that enable implementation, the author also emphasizes that the willingness to experiment and adapt over the course of multiple attempts are the key qualities that will help other programs with their own redesign efforts.

KEY WORDS: online, laboratory, experiential, Missouri, technology, science, curriculum

1. INTRODUCTION

Lecture course redesign is old news; many institutions have redesigned lecture courses. At the Missouri University of Science and Technology (S&T), efforts have been made to think outside of the box by thinking outside of the lab. The Delivering Experiential Labs to All (DELTA) initiative is driving laboratory course redesigns in several departments across campus, and has resulted in some great changes and improvements in the way the university's labs are being designed and delivered.

The project began in late 2013, when instructional designers first approached faculty with the idea to form blended and online labs. Many were initially hesitant. What they had seen of course redesign in the past typically included large, gateway lecture courses that were filled to capacity. The redesign of lecture courses was simple and well documented, and such redesigns had been done successfully for quite some time by campuses across the country, including Missouri S&T. What faculty were being asked to do, though, was to look at highly customized lab courses in their field of expertise and make changes based on the advice of an instructional designer who had little or no subject-matter expertise.

Branding of the redesigned labs was the first potential setback in Missouri S&T's endeavor to transform the way laboratory courses are delivered. The project needed an "elevator speech" to pitch to faculty, and it was not sufficient to merely state that the campus needed to create online labs, because "online" was not a term faculty were willing to accept for experiential learning activities.

The result was DELTA: courses that could be online, blended, flipped, or presented via any other appropriate delivery mode. The defining characteristic is that these labs are what they need to be, not what they always have been.

Labeling the new labs DELTA courses changed perceptions and smoothed the pathway to begin redesigning additional lab courses. It also drove home a lesson to the instructional design team—in the words of Ken Robinson in his 2006 TED Talk titled *How Schools Kill Creativity*, "If you are not prepared to be wrong, you will never come up with anything original" (Robinson, 2006). This became a guiding principle behind all of the lab redesigns: try something, and if the effort is unsuccessful, try it in a different way. But never be afraid to try.

Through this process, several other lessons specific to laboratory course redesign have been discovered as well. These findings and considerations are outlined below. There is no definitive hierarchy to this list, though some considerations are more urgent than others.

2. PEDAGOGY DRIVES COURSE DESIGN

At the center of many traditional laboratory activities are specialized pieces of laboratory equipment. For example, the Missouri S&T Mechanics of Materials course involves bending, stretching, and breaking various metals. This experimentation is not easily done at home. In this example, the technology available in the laboratory, rather than pedagogy, has traditionally driven instruction. Accordingly, when the redesign process began, a number of important questions related to laboratory were considered, including the following:

- Do the labs which use this machinery contribute to the course goals?
- Do students need to know how to run the machinery?
- Is this knowledge essential to student advancement in the field?
- Are students actually running the machinery now, or is that the job of the instructor or TA with students simply documenting what they observe or recording numbers?

Ultimately, the guiding question is: if the students aren't actually doing anything, are they learning optimally? Research dictates that active-learning techniques presented in learning environments such as lab courses lead to higher overall scores when compared to lecture-based courses, and active learning strategies lead to learning on deeper levels (Hackathorn et al., 2011). Furthermore, some engineering experts believe that advanced instrumentation and data acquisition procedures can lead to a feeling of detachment by students from the needed experimentation (Muscat and Mollicone, 2012). In an effort to enhance learning in the Mechanics of Materials course at the University of Malta, experimentation practices were evaluated and the determination was made to provide students with the opportunity to design and implement their own experiential learning. The results presented with a high level of student satisfaction (Muscat and Mollicone, 2012).

For the Mechanics of Materials course at Missouri S&T, it was determined by the instructor that each lab conducted in class could be conducted using different materials purchased mostly from hardware, convenience, and/or grocery stores (Table 1). The resulting design innovations inspired a lab kit (Fig. 1) that students who are not on campus can use to do science anywhere. And, because this equipment is found at local stores, students can easily purchase their supplies from a list provided by the instructor.

TABLE **1:** Sample kit components: Mechanics of Materials

Experiment names	Items needed	Approximate cost
Spring Constants, Linear Regression	Springs	$53
	Weight Set (purchased online)	
	Caliper (purchased online)	
	Hook	

Direct Sheer Stress, Bearing Stress	Cookie cutter set	$9
	Play-Doh	
	Modeling clay	

FIG. 1: Mechanics of materials spring constants and linear regression kit components; photo courtesy Jeff Thomas, Missouri S&T

The aforementioned list of supplies was cautiously designed. Students are not expected to purchase costly materials for a singular use. Each lab attempts to include materials that will be beneficial for the student in one of two ways, namely, the materials may be used in more than one lab or the kit might include items that the student will actually need after graduating, such as calipers and weight sets. The nature of this course prevents concerns for disposal of materials and waste. In other courses, however, disposal and waste play a key role in the lab design.

3. LABORATORY SAFETY AND MATERIAL DISPOSAL

The first semester General Chemistry lab on the S&T campus is blended. Students attend half of the scheduled class sessions in the traditional lab where they perform experiments that cannot be transformed for delivery outside of such a controlled environment, typically due to safety concerns. The remaining half of each student's coursework is completed using kits that the students take to common areas on campus, often dorm facilities. These kits are designed to allow students to perform experiments that do not necessarily need to be conducted in a lab. To use an example from the equipment issue discussed above, General Chemistry students do not need expensive laboratory spectroscopes to learn spectroscopy (Fig. 2). Instead, they can build their own spectroscopes for just over $1 using a small piece of plastic tubing, black paper, and a polarizing filter. In designing their own equipment, students are also learning more about how the spectroscope works. Student learning in such instances is actually increased by eliminating the more expensive technology.

FIG. 2: General Chemistry cell phone spectroscope

The notion of labs conducted in common areas led to the next point of concern. On hearing of chemistry occurring outside of classroom lab spaces, the Environmental Health and Safety office quickly responded to the instructors with inquiries about the course. The two key concerns were student safety during the activity (for students conducting the lab as well as students who may be in the common areas for other reasons) and disposal of waste after the completion of the activities.

First, the safety for each lab activity was individually considered. If a lab activity required specialized safety equipment that could not be reasonably provided outside of the lab, then that particular lab was completed in the traditional lab environment. Several lab activities, however, were transformed to be conducted outside of the traditional space. Two examples of labs that provide fundamental skills but do not necessarily require a structured lab environment are the spectroscopy lab mentioned previously, and the paper chromatography lab. However, oftentimes, these examples of safer labs still include waste components. In larger quantities, these wastes could pose a hazard, and each potential risk needed to be analyzed separately.

For example, both the General Chemistry kits and the General Biology kits used at Missouri S&T are at least partially created by a vendor, which produces microscale quantities for students to use for experimentation outside of the lab (see Fig. 3). The difference between how the two courses have been designed, however, has created a need for distinct disposal procedures.

FIG. 3: General Biology macromolecules lab, hands-on labs; photo courtesy Terry Wilson, Missouri S&T

The General Biology kits are sent directly to the student and are designed to be completed by an individual. The biology class is also a low enrollment course (approximately 20 students in a full section). Because any chemicals in need of disposal are being done so in microscale quantities by one individual, there is not a strong concern for disposal. An entirely different scenario unfolds in the General Chemistry lab course.

On the S&T campus, General Chemistry serves over 1200 students from various departments per year. As a freshman-level course, General Chemistry typically includes students who are also living in residential housing on campus. The safety burden arises when several hundred students are completing their lab experiments in the dorms during the same week. The safely disposable microscale quantities may pose a greater risk if several hundred students are disposing of them in the same dormitory facility.

The solution for the General Chemistry lab is uncomplicated. Because this course is blended, the students do come to the traditional lab every other week throughout the semester. After completion, students return the entirety of the used kit, including waste materials, gloves, and all packaging, to the lab. Students are required not only to submit a lab report, but they also must properly dispose of all waste materials. This disposal procedure prevents larger quantities of waste elimination in the dorms while it serves to reinforce the proper disposal techniques that students are required to learn using guidelines set forth by the American Chemical Society.

The return of the chemistry equipment also serves to fulfill another goal, i.e., reduction of waste and promotion of environmentally sound practices. By returning the kits, all non-consumable materials that might be reused, such as glassware, are also returned. As a result, the Chemistry Department is able to reduce purchasing costs by filling kits with non-consumable materials from previous semesters. This leads to the discussion of responsibility for the purchase of materials in redesigned DELTA courses.

4. PURCHASE AND DISTRIBUTION OF LAB MATERIALS

Currently, it is up to each academic department to determine a purchasing model for their laboratory components. For DELTA labs, there is interest in having the student pay, and there is also interest in departmental payment—but who actually purchases the materials is not just about financing. Some of the redesign factors previously discussed influence this decision as well.

The General Biology lab course was the first to consider using kits for a fully online DELTA lab. In this case, the students are using the kit as a replacement to the lab manual that was traditionally used. Because students are no longer purchasing a lab manual, those in the online section of the General Biology lab are purchasing their own kits directly from the vendor.

This method of kit delivery was selected for various reasons. First, instructors prefer to keep the cost of the kits as low as possible. Using a secondary vendor on campus, such as the academic department or bookstore, would increase costs as well as promote storage concerns—these kits are not all small enough to fit on a bookshelf or in current storage facilities. The second reason is due to the very nature of these kits. Many kits contain perishable materials. If an overabundance of kits is purchased to meet the needs of a course for any given semester, kit components may not be easily preserved until the following semester. Finally, lab kit vendors update the documentation for their kits frequently. If the kits are purchased directly from the vendor, any updates that occur during the progression of the semester can be more easily communicated to the students by the vendor.

When the General Chemistry redesign began, a different purchasing model was adopted. Because the course is blended, the department is saving classroom space and reducing purchasing costs by replacing some of the larger machinery and equipment with modestly priced kit components. As a result, the Chemistry Department was able to use these cost savings as one reason to justify the departmental purchase of the kits. Other arguments in support of departmental acquisition of the kits were revealed in the early stages of the redesign as well.

One factor involves the vendor distribution processes. Vendors that produce lab kits for out-of-the-lab experimentation produce them to be shipped to the students as entire semester kits. Because the chemistry students in the blended lab at Missouri S&T need to acquire the individual lab exercises one at a time from the department, the prepackaged kits have to be deconstructed by chemistry department staff before distribution to the students. This additional process requires much more manpower and time than the model used by the Biology Department, where the kits are shipped directly from the vendor to the students. The deconstruction and reassembly is also only possible if the Chemistry Department purchases the kits. Also, if this step were eliminated and the kits were shipped directly to students, the concerns of the Environmental Health and Safety office on campus would potentially become realized with students living in residential housing on campus.

Another aspect of the chemistry kits that is important to note is that because the kits are being dissected into individual labs, it is obvious that each kit presented to students does not encompass an entire course. The notion that a kit is not an entire course is more difficult to distinguish in the biology kits, which are shipped in their entirety to the students. The next lab redesign consideration addresses whether the kit alone is, in fact, the course.

5. DESIGNING A COURSE USING KIT COMPONENTS

If the laboratory kit model is selected, it is very important to note that a kit does not make a course. Kits, whether designed by a vendor or an instructor, contain materials and procedures. A course contains goals, learning objectives, and instructions for achievement. In order to measure the quality of a course, instructors and instructional designers at Missouri S&T have developed a course evaluation guide. The guide is based on the Quality Matters rubric, but tailored to our specific campus needs. No kit that has ever been tested fully meets all of the components of the Missouri S&T course evaluation guide. Accordingly, the course goals and learning objectives, which are developed before any instructor ever even looks at any kits, are measured against the kits provided by vendors. Gaps are identified and new content is created to fill those gaps.

For example, the General Biology kits offered by Hands-On Labs do not offer a satisfactory and cost-efficient microscopy unit. Because the General Biology DELTA course is for nonmajors, it also is not feasible to have those students purchase their own microscope. With the assistance of a graduate student, the instructor found plans for a $10 smartphone microscope on Instructables (Instructables, 2015) (see Fig. 4). In practice, the students have rarely been able to build this microscope for $10 (the typical cost is around $14), but when compared with the microscopes in the traditional lab, the instructor and students were very pleased with its performance. This small addition to the vendor's kit has received recognition from numerous sources and has been featured in publications including Campus Technology (2014), Eduwire (2015), and Lab Manager (2015).

FIG. 4: $10 microscope used in General Biology laboratory course

Another more recent example of kit customization is the development of a $1 spectroscope for General Chemistry (see Figs. 5 and 6). Like the $10 microscope, the spectroscope uses a smartphone as a platform for data collection. The spectroscope is being built from polarized film and inexpensive tubing and the spectrum is viewed using the camera on a phone or tablet. This innovation did not stem from a gap in the kit contents, but innovations by the redesign team led to the discovery of a way to modify a component in the kit and make it more affordable. Initially putting the spectroscopy activity into a kit cut the cost dramatically, and now, because of continued brainstorming and development, the cost for the exercise has been decreased for a second time.

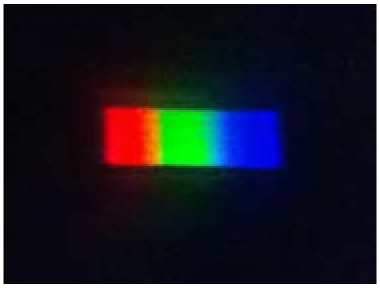

FIG. 5: Halogen light spectroscope image; courtesy Klaus Woelk, Missouri S&T

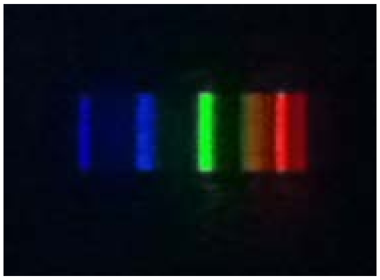

FIG. 6: Compact fluorescent light spectroscope image; courtesy Klaus Woelk, Missouri S&T

6. ADA COMPLIANCE

As new ideas are developed, it is essential to understand that some students are more technically savvy than others and some are similarly more adept at manipulating tools and machinery to effectively build their own lab equipment. Not everyone can be expected to build these additions to the vendors' kits. Consider students with disabilities. What if a student has fine motor skill impairment? If such a student receives instructions for creating experimental equipment (such as the $10 microscope or the inexpensive spectroscope) and they are physically unable to do so, the university has done this student a disservice.

DELTA labs strive to deliver to all. Considerations for disabilities in course design, as with all other courses, are essential. There are several different aspects to disability support that must be recognized. As mentioned above, if a student has a fine motor skill impairment, accommodations must be made. How does that student build or manipulate equipment outside of the lab? Does he need a partner? Does this partner need to be enrolled in the class, or is a family member or roommate sufficient? What if the student is blind? Does a particular disability only require extra time for completion of assignments? What if there is a set time for a procedure or the need for measurable milestones along a timeline? What is done in these situations and how will these issues be addressed?

There are numerous questions surrounding disability and it is impossible to predict all of them in advance. One idea under contemplation relates back to the safety issues mentioned before. The General Chemistry instructors have made it clear to their students that it is not safe to do chemistry experiments alone. Each chemistry student is assigned a partner. Disability accommodations can often be alleviated by doing lab work with a partner, as long as the student with the disability is willing to share this information.

The students who are completing their work off campus and without a partner may have additional disability support issues. Because preparations cannot be made for every situation, it is important to have a general plan in place. Currently, discussions occur with each instructor in regard to the accommodations they would feel comfortable with. In the event that a student would approach them with a disability concern, the instructor can then be prepared with some ideas for accommodations that might be acceptable.

There are also several course design practices that instructional designers help to apply to all of the course redesigns at Missouri S&T, both lecture and lab, to help with disability concerns. Instructors are encouraged to use online tools that meet disability standards. Such tools include the learning management system (LMS), online homework platforms, and supplemental sites provided by textbook publishers or lab kit companies. The Educational Technology department also offers a service to closed caption any video content created by the instructor. Experience with captioning for disability support has proven that it is much simpler to do so in advance, even if an immediate need is not present, than it is to modify the content once a need is identified.

Another benefit of video captioning has become evident as well. The international student population at Missouri S&T is growing rapidly. Feedback from international students confirms that this population of learners greatly appreciates the captioned video content. These students are able to hear and see the words, which is extremely helpful when engaging with new content, especially if the content is not in a learner's native language.

Disability and communication concerns definitely present a "last, but not least" area of focus for any course redesign project. A culture of acceptance on college campuses has led to a great deal of innovation to provide educational opportunities for those with disabilities. What higher education is looking for now is innovation in all areas of education—a mass movement, if you will—to provide accessibility of all types of courses to all populations of learners. That is what DELTA is doing, delivering experiential labs to all.

7. CONCLUSIONS

Several conclusions emerged from the experimentation described. First, laboratory redesign does not require use of existing laboratory facilities. Laboratory activities that do not require specialized equipment are, in fact, often better able to accomplish course goals when conducted outside of the traditional lab classroom. Second, costs of laboratory delivery can be significantly reduced through the use of innovations such as the replacement of instrumentation with inexpensive alternatives from hardware stores or methods that utilize smartphones and tablets. Such methods make use of technology that is readily available to most students and little assistance is needed for students to master the learning requirements created when smartphone devices are used for learning. Third, laboratory kits work well and can be used at home to augment online instruction, thus truly making laboratory activities available to an expanded audience of learners. Fourth, continued experimentation is needed for the laboratory redesign. Each redesign project must be evaluated annually to determine if new methods and technologies can replace former lab components.

8. THE FUTURE OF LABORATORY INNOVATION

In *The True Believ*er, Eric Hoffer (1951) described the nature of mass movements—who is involved, what roles they might play, and what outcomes can be expected. The principles of mass movement described by Hoffer are applicable in this arena all too clearly. Hoffer said, "Fear of the future causes us to lean against and cling to the present, while faith in the future renders us receptive to change" (Hoffer, 1951, p. 9). Change is significant in the evolution of laboratory course design. In science, what is the symbol for change? The answer is Δ.

The delta symbol is the accepted symbol for change, so it was the logical place to begin this revolutionary journey. Using best pedagogical practices, Missouri S&T is evaluating courses and discovering new pathways for accomplishing the course goals in all redesigned courses, not just the lectures.

As innovative course design drives change in online education, keep in mind, "Nothing so bolsters our self-confidence and reconciles us with ourselves as the continuous ability to create; to see things grow and develop under our hand, day in, day out" (Hoffer, 1951, p. 38). At Missouri S&T, the processes used to create DELTA labs have been documented in order to create a collection of redesign guide sheets. This collection is being piloted at Missouri S&T and will eventually serve as a course redesign handbook for use by any instructor or instructional designer interested in laboratory course redesign.

These guides provide templates for each process of the redesign from the development of course goals and outcomes to the analysis and evaluation of the redesigned lab. Throughout the redesign process, instructors are provided with customized reports and steps for completion of pedagogical necessities.

As the development of DELTA labs continues at Missouri S&T and the handbook of guide sheets is completed, knowledge sharing with other STEM institutions will play a pivotal role. Expansion of the collection of knowledge resulting from successful practices developed by this project will serve to expand the reach and educational potential of multiple institutions, and truly result in delivering experiential labs to all.

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