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# ARTICLE
# *In Situ* Teaching: Fusing Labs & Lectures in Undergraduate Science Courses to Enhance Immersion in Scientific Research

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Undergraduate courses in the life sciences at most colleges and universities are traditionally composed of two or three weekly sessions in a classroom supplemented with a weekly three-hour session in a laboratory. We have found that many undergraduates can have difficulty making connections and/or transferring knowledge between lab activities and lecture material. Consequently, we are actively developing ways to decrease the physical and intellectual divides between lecture and lab to help students make more direct links between what they learn in the classroom and what they learn in the lab. In this article we discuss our experiences teaching fused laboratory biology courses that intentionally blurred the distinctions between lab and lecture to provide undergraduates with immersive experiences in science that promote discovery and understanding.

*Key Words: pedagogy, laboratory, fused courses*

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**Exposure is not enough: Immersion and discovery are the essence of scientific discovery**

Many scientists and educators have repeatedly pointed out that the way scientists do science and the way scientists teach science are not aligned (National Research Council, 2003; Brewer and Smith, 2011; PCAST, 2012). Science is not a list of facts to be memorized, but rather a dynamic means of discovery, using rigorous information, observation, and experimentation to create new knowledge that can be verified and updated (Moore, 1993; Alberts, 2012). Scientists spend their time asking questions, performing experiments, grappling with problems, trouble-shooting methods, and engaging with other scientists through conversations and primary literature. So why then do most undergraduate science courses ask students to sit still and listen to expanding collections of facts that scientists have discovered?

Lectures, as pedagogical devices, were created in an age where information and access to knowledge was limited. Instructors had special training, experiences, and unique access to information. In the twenty-first century, instructors continue to have special training and experience when compared to their students, but the playing field has been leveled regarding access to information. Instructors are undoubtedly still necessary to help most students navigate information and develop knowledge, but the idea that the instructor is the sole source of information is fully outdated. Investigations into the effectiveness of lectures also reveal that the amount of information retained by students in a standard 50-minute lecture is astonishingly low (Menges, 1988; McKeachie et al., 1990) and students describe traditional lectures as “frustrating and not engaging” (Brewer and Smith, 2011). Consequently, some argue that lecturing is a familiar but old-fashioned and ineffective means of education that needs to be reimagined. Some undergraduate science educators are now shifting away from lectures and embracing more student-centered pedagogies with demonstrated success via a variety of active teaching approaches (Crouch and Mazur 2001; Handelsman et al., 2004; Knight and Wood, 2005; Mazur, 2009; Nilson, 2010; Brewer and Smith, 2011).

No athletic coach would ever train a young player primarily by talking about the sport or showing a series of beautifully crafted slides. Instead, good coaches immerse their players in the types of scenarios their players will face on game days. Young athletes may certainly read about the game and listen to lectures or watch films, but they primarily learn the game through a combination of active drills, practices, scrimmages, and competitions. Interestingly, the newest and youngest athletes experience the most immersion in the actions of the sport, with lectures and theory added to the training program at more advanced levels. So why then do scientists train undergraduates in an inverse fashion? Consider that as instructors we train many of our young scientists initially through readings and lectures, perhaps with a few contrived laboratory exercises or instructor demonstrations. Only after an undergraduate proves herself capable in introductory and intermediate coursework, is she then able to begin to gain access to the research lab, the playing field of scientists. When asked what one change she would make to improve science education in the United States, Nobel laureate Elizabeth Blackburn responded:

> *I think the thing science educators have to do is teach one important lesson: that science requires immersion. A lot of teaching is about setting up these little projects. But real science happens when you’re really immersed in a question. The way we teach it [science] now, with an hour of instruction here and a laboratory class there, it doesn’t allow for what has been my experience: that immersion is the essence of scientific discovery. Science just isn’t something you can do in one-hour-and-a-half bits. Digging deep is what makes people actually productive.*
>
> (Dreifus, 2013)

So how can this critical idea of immersion be built into an undergraduate science curriculum? Why are most undergraduate science labs simple or discrete exercises that fit neatly into a single weekly afternoon period? Why do so many undergraduates dislike or misunderstand the purpose of lab sessions (Russell et al., 2008)?

In this article we describe lessons learned in our initial attempts to fuse lecture and lab learning both spatially and temporally with the goal of creating more authentic and engaging research experiences within a laboratory course format. At Davidson College we transitioned two upper-level courses from a traditional format with distinct lectures and labs into fused courses where lab and lecture times were not distinguished. The experiences we describe arise from JR's teaching of BIO333 Cellular and Molecular Neuroscience in 2011 and 2013 and BL's teaching of BIO306 Developmental Biology in 2014. We argue, however, that the approach and lessons learned are not specific to these subjects and can be generalized to nearly any undergraduate science course.

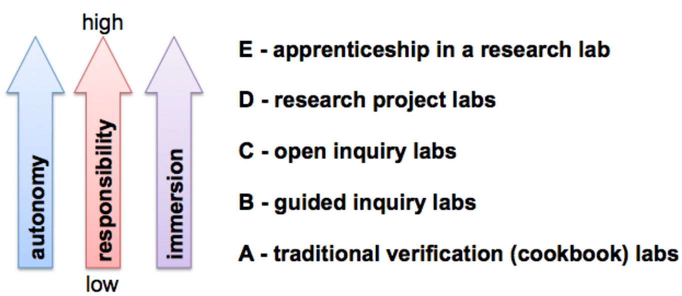


*Figure 1.* A Continuum of Autonomy, Responsibility, and Immersion in Undergraduate Laboratory Experiences. Undergraduate laboratory experiences vary along a continuum from traditional verification labs *(A)* with expected outcomes often called "cookbook" labs to apprenticeships in research labs *(E)* through research or thesis courses and internships. The levels of autonomy, responsibility, and immersion are highest in the apprenticeship situations *(E)*. Although these research apprenticeships are well known as effective tools to teach young scientists, relatively few students can participate in such experiences. Continuum adapted from Weaver et al. (2008) and Wood (2009).

## Where does immersion in scientific discovery happen in undergraduate science curricula?

Immersing students in the process of scientific discovery can take multiple forms and typically occurs at multiple points within an undergraduate science curriculum (Fig. 1*A*). Lab courses are highly dependent on institutional culture, resources, and support in many dimensions. We recognize that there is no single way to teach science and a full spectrum of ways in which students can experience scientific discovery. Any science course that includes a laboratory component likely has the goal of engaging a student directly in the processes of scientific discovery and experimentation through hands-on activities. Most science lab sessions offer traditional exercises where reagents, supplies, and equipment are all carefully laid out for the students with a list of specific steps to guide students toward an expected outcome - all comfortably within a typical three-hour lab session. While such "cookbook" labs unquestionably provide important exposure to scientific ideas, instruments, samples, and procedures, these lab experiences usually do not immerse students in original research questions. Moreover, cookbook labs give students relatively little autonomy, agency, or responsibility. Consequently, student engagement can be minimal. It is not unusual to overhear some students actively dreading lab sessions, to observe some students passively avoiding engagement (allowing labmates to do all the work), or to witness a student racing through a lab exercise, eager to be dismissed early.

Many initiatives in recent years have focused on shifting these cookbook labs into more investigative formats where student autonomy and responsibility are enhanced to provide a slightly more authentic and immersive scientific experience (Wood, 2003; Weaver et al., 2008; Wood, 2009; Russell et al., 2010; Kloser et al., 2011; Hanauer and Dolan 2014; Moore and Teter, 2014). Creating lab experiences that increase student agency by requiring students to select a variable to test (guided inquiry; Fig. 1*B*) or design an experiment (open inquiry; Fig. 1*C*) within specific parameters allows students to gain more insight into doing science. These inquiry-based methods, while partially cookbook in nature, are inevitably more authentic scientific research experiences than traditional verification labs. Students receive some input into the question and/or methods that lead to less predictable and more open-ended results, which allows for more authentic experiences in data analysis and communication.

Some lab sessions that meet in a traditional once per week format can be remarkably immersive in the scientific discovery process by focusing on research projects that span multiple weeks or even the full semester (Fig. 1*D*). In these examples the full class may engage in a single research question or small groups may be addressing interrelated questions. Whatever the format, the potential to do "real" research provides a highly authentic scientific experience and often enhances student excitement and engagement. Trouble-shooting, replication, and data analysis are essential integral experiences when lab sessions are focused on novel research questions. Often the specific research questions are naturally aligned with the instructor's research interests, expertise, and innate enthusiasm. Student motivation can be enhanced dramatically because lab is something "real" that may be risky but also rewarding, original, and meaningful. Ideally, the outcomes of course-based research can produce preliminary data, contribute to an ongoing body of work, and/or result in peer-reviewed publications. Such course-based research inherently prioritizes immersion in the scientific process while following the traditional framework of a weekly lab schedule. Student autonomy, responsibility, and engagement are likewise strongly elevated over more traditional lab experiences.

For an undergraduate, the most authentic scientific experience is an apprenticeship (Fig. 1*E*) in a research lab where the student conducts novel research and assumes maximal responsibility for designing, conducting, interpreting, and communicating that research. It is unquestionably full immersion, often configured as a paid summer internship or a thesis project that awards course credit. This apprenticeship form of scientific training has been a long-standing tradition in undergraduate education that can be very effective (Hathaway et al., 2002; Lopatto, 2004; Hunter et al., 2006; Lopatto, 2007; Russell et al., 2007; Linn et al., 2015). Unfortunately, apprenticeships in established research labs are accessible to a relatively small number of undergraduates, most of whom gain access via previously demonstrated excellence in less immersive forms of scientific training. Even the most generous research labs have practical constraints (personnel, time, funding, priorities, etc.) that limit their abilities to provide time-intensive mentoring to undergraduates. Consequently, many institutions find it logistically impossible to require a research apprenticeship as part of an undergraduate science curriculum, regardless of the value of such immersive research experiences. In addition, undergraduates experience limiting factors (schedule, stipend, motivation, mentoring, etc.) that make immersion in a research lab challenging. Thus, authentic research experiences are often unavailable to many undergraduate science students.

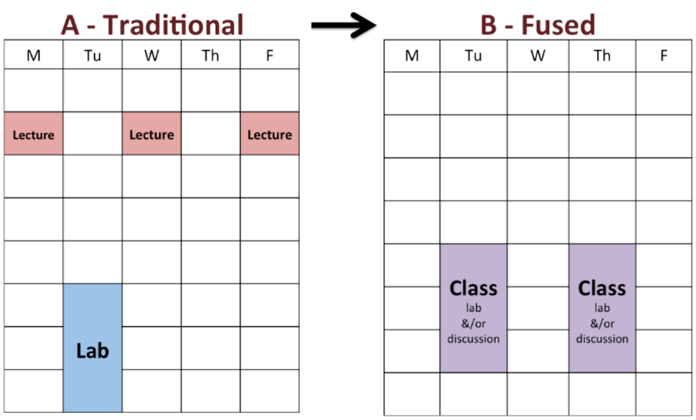


*Figure 2.* Traditional versus Fused Course Schedule. *A)* Traditional undergraduate science courses typically meet two or three times per week for lectures in a traditional classroom and also break into smaller weekly laboratory sections that are separate. This model provides approximately six in-class hours per week per student. *B)* In the fused course students also experience approximately six hours of instruction each week, but that time is combined into two three-hour sessions that allow discussions and lab experiences to be planned and executed in a more flexible format to prioritize learning goals.

**Fusing lecture and lab temporally**

To maximize the number of undergraduates immersed in scientific research experiences, we were attracted to lab course models that include inquiry-based exercises and research projects. In our experiences, guided inquiry labs are generally more appropriate for introductory lab courses and open inquiry or research project labs are generally more amenable to upper-level lab courses. While some topics and methods can use traditional weekly lab sessions to address novel research questions, we found that the questions we were most excited to bring to our research students and the lab methods most frequently used in our scholarship did not transport readily to our upper-level lab courses (Developmental Biology; Cellular & Molecular Neuroscience). Importantly, multi-day techniques such as culturing cells or immunostaining could not be conveniently deployed in lab sessions that met once per week in a traditional format (Fig. 2*A*).

We were inspired by successful and well-tested strategies in undergraduate physics education that intentionally blended classroom and laboratory activities together via innovative models called Studio Physics, Peer Instruction (PI), Workshop Physics, and/or SCALE-UP (Belcher, 2001; Jackson et al., 2003; Gaffney et al., 2008). During a class period students do a combination of active learning strategies that include problem solving, small group discussions, demonstrations, and/or experiments. Lecture and lab time are not distinct in time or space in these courses. Many instructors reconfigured their classroom and laboratory spaces to facilitate clusters of students who collaborate during class times; the front of the classroom disappeared and the instructor transitioned from a lecturer to a roving consultant available to help groups of students as they work through the material. The physicists pioneering these strategies reported enhanced gains in student attendance, performance, and retention in the major (Hake, 1998; Crouch and Mazur, 2001, Watkins and Mazur, 2013).

We transitioned our Developmental Biology and Cellular & Molecular Neurobiology courses into fused courses by abandoning the traditional formula of 150 minutes of lecture per week (3 x 50 minutes MWF or 2 x 75 minutes TuTh) plus a weekly three-hour lab section. We speculate that this course formula separating lab and lecture has persisted for so long because of tradition, convenience, architecture, and scheduling. In some situations the instructors for the two components may differ as well as the semester in which the students enroll in the lab or lecture, further distancing what a student learns in lab from what s/he learns in lecture. This traditional formula does not accurately reflect how a scientist works or thinks and does not promote immersion in scientific inquiry. Moreover, we found that some students have considerable difficulty making meaningful links between what they learn in lecture and what they do in lab.

To minimize divides between lecture and lab learning, we reconfigured our courses to meet in two 160-minute (TuTh) or two 170-minute (MW) blocks per week (2 x 3hr; Fig. 2*B*). These blocks aligned neatly within our institution's weekly course schedule, minimizing conflicts with other courses. Although we did not consider three 110-minute class sessions per week due to the specific lab procedures prioritized in our learning goals, some fused courses will likely work well if offered three times per week. Regardless of the specific temporal reconfiguration (2 hr x 3 days/week or 3 hr x 2 days/week), students experience the same amount of instructional time in a traditional or a fused laboratory course.

Fused class sessions can theoretically fall at any convenient times on the weekly calendar, but our experiences suggested that afternoons are preferable over mornings. One of us (JR) taught a fused course first as a

TuTh morning course then moved it to an afternoon course in its next offering. Overall, students were more engaged and lively when the fused course was offered in the afternoons. Early morning class sessions that started at 8:15 AM increased tardiness, absences, and students coming to a long class on an empty stomach as compared to class sessions that started at 1:30 PM.


*Figure 3*. Using traditional classroom and laboratory spaces for teaching a fused course. Lab courses may be fused in time and/or space. In the first two fused courses taught the instructor reserved two spaces for the full duration of all meetings: a traditional seminar-style classroom *(A)* and a nearby traditional research lab *(B)*. Students moved back and forth between these two teaching spaces in a given class period as the day's activities necessitated.

**Course ceilings**

In our situation this temporal reconfiguration from traditional to fused format necessarily decreased class size. A traditional lab course at our institution enrolls up to 32 students in lecture. These 32 students then split into with two different lab sections of 16 each, typically meeting on two different afternoons. Our teaching laboratories were built to accommodate a maximum of 16 students, which thereby reduced the cap on a fused course to the laboratory size. We also note that we targeted BIO306 and BIO333 for fusion in part because student demand was consistent but had not reached capacity in recent years. If a fused course can be taught in a classroom space or two adjoining lab spaces then the ceiling may not need to be reduced.

**Fusing lecture and lab spatially**

As mentioned above, many courses with "dry" labs such as introductory physics or computer science have successfully transitioned their hands-on activities from the laboratory into traditional or slightly modified classroom spaces. Others have designed studio classrooms with areas within one room that resemble both traditional classrooms (with moveable desks or tables) and traditional teaching laboratories (with benches and instruments). Biology and neuroscience laboratory methods normally require animals, chemicals, and/or specialized instrumentation making learning goals inherently "wetter" and necessitating lab spaces. Consequently, moving lab activities into classrooms was impossible for our courses. In our first two offerings of fused lab courses we relied on existing teaching spaces. We simultaneously reserved a traditional biology teaching laboratory (Fig. 3*B*; 4*A*) and the nearest traditional classroom (Fig. 3*A*) which was located on a different floor in an adjoined building. With chronically limited classroom space, this dual reservation required us to convince administrators that a single innovative course model merited the reservation of two distinct teaching spaces. Having full flexibility to move between a classroom and a teaching lab allowed the instructor and students to spend as much or as little time in lab mode or discussion mode on a given day as the learning goals dictated. For example, students can set up a procedure in lab and then move to the classroom during an incubation period and return to the lab at the end of that incubation. The drawbacks of using two separate teaching spaces included inefficient transitions from one space to the other, ambiguity of starting location, and the instructor's inability to be in both teaching spaces at once when some students were working in the classroom and others were working in the lab.

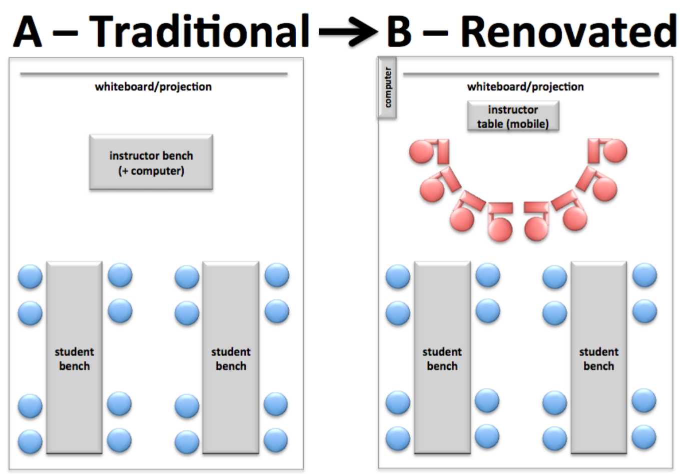


*Figure 4.* Converting a Traditional Teaching Laboratory into a Laboratory that Can Host a Fused Class. After two iterations of the fused course model that alternated between a traditional classroom and a traditional teaching lab, we lightly remodeled an existing traditional teaching lab *(A)* into a space that could accommodate both laboratory work and class discussions *(B)*. The renovations included relocating the computer and projection system, replacing the instructor's bench with a mobile table, and adding eight mobile student desks (red).

In the third iteration of our fused course model we addressed these drawbacks by making minor renovations to a traditional teaching laboratory (Fig. 4). The original layout included a large, fixed instructor's bench at the front of the teaching laboratory with two perpendicular benches providing seating for 16 students (Fig. 4*A*). The primary function of the instructor's bench was to house computer projection equipment. Because computer technology has reduced in size considerably in recent years, we relocated the instructor's computer to the laboratory wall and removed the large, fixed bench from the front of the teaching lab. We replaced the instructor's bench with a small, wheeled table and added eight mobile student seats with desks (Fig. 4*B*). The cost to remodel and purchase new seating was modest (<$5K), but powerful because the space now accommodated multiple functions more logically.

In the renovated teaching laboratory when class time emphasized experiments, students used the 16 seats at the benches (Fig. 5*A*). When class time emphasized discussion, students used the eight mobile seats at the front of the classroom as well as the front eight bench seats (Fig. 5*B*). Because the benches were counter height, sight lines easily permitted students sitting at the lab bench to see over classmates seated in lower desks up front. Larger instruments such as microscopes and computer monitors were located on benches at the back of the room to minimize obscuring sight lines to the front of the room for discussions (Fig. 5*B*).

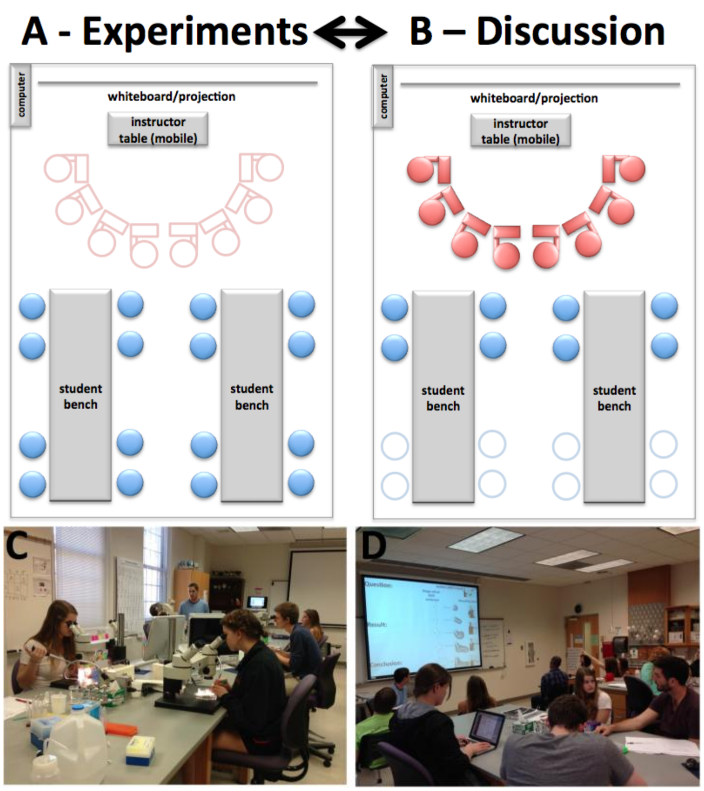


*Figure 5.* Modified laboratory space allows for both class discussions and lab activities. When class time focused on laboratory work, students used the 16 bench seats *(A, C)*; and when class time focused on discussions, students used the desks and front lab seats *(B, D)*. Larger equipment such as computer monitors and microscopes were concentrated at the back of the benches to maximize sight lines. This modest reconfiguration of a teaching laboratory allows students to engage in research projects *(A, C)* as well as active class discussions *(B, D)* in the same room.

**Crafting a flexible, skills-oriented syllabus for a fused course**

Our experiences suggest that reconfiguring a course's meeting times and/or teachings spaces are important but insufficient steps to achieving a course where students can become more immersed in research questions. Instructors who have the interest and ability to attempt a fused laboratory course should not simply transpose the syllabus from a traditional, segregated lab course onto the fused format. Instead we strongly recommend the instructor carefully craft a fused course syllabus using backward design focusing on learning goals, research questions, student skills, and laboratory techniques (Wiggins and McTighe, 1998; Kerchner et al., 2012). Centering the syllabus on what the students will do and the skills they will acquire is best practice for a successful fused course syllabus starting point. We also recommend that an instructor focus on original, engaging, contemporary scientific questions in which the instructor has some expertise and/or strong interest, paying particular attention to opportunities where theory and practice can be taught in unique proximity. Whatever the topic of the fused course, we caution that most instructors will need to overcome the natural tendency to emphasize content coverage. In our experiences we have found that a fused course's reading material can center either on a traditional textbook (BIO 306) with primary literature sprinkled throughout or it can center fully on primary research literature (BIO333). Moreover, a flipped lecture approach was also very compatible with the active and fluid nature of a fused course (BIO306). It even allowed some of the lab content to be flipped. For example, a recording on creating scale bars supplemented with examples of strong and weak embryo images was the most frequently viewed flipped lecture.

If the goal is to immerse the student in a semi-realistic research experience where they have some ownership over decisions, there will be an element of controlled chaos that is best accomplished by a fluid and flexible syllabus and instructor attitude. Not every lab experience in a fused course needs to work flawlessly. Trouble-shooting, repetition, and revision are all inherent to the scientific research process and good lessons for students to learn firsthand. To accommodate such lessons a fused syllabus needs to be planned in such a way that it can be dynamic, living document capable of adapting rapidly if needed. The lab goals can be more ambitious than a traditional course in that they can thoughtfully incorporate multi-day or even semester-long lab activities and collaborative experiments. We argue that a flexible syllabus is more realistic reflection of the research process where few projects proceed precisely on schedule or according to initial plans. For example, BIO333 focused on culturing neurons, immunostaining neurons with antibodies that the instructor had not before used, Western blotting, and RNAi – all of which are complex, multi-day or multi-week procedures with many opportunities for missteps and unexpected setbacks. As another example, the BIO306 syllabus focused on experiments that exposed developing embryos of various species to potential teratogens during different windows of development then measured gross morphological features. Students assumed considerable responsibility for determining appropriate doses, windows, and morphological measurements for each of the experiments they performed.

Although our syllabi were dynamic, we did, however, hold some firm deadlines for students. We kept quiz and exam dates as written on the syllabus to enhance students' abilities to anticipate and plan their work accordingly. On testing days we assessed the material and skills that the students had covered thus far, not necessarily what the original schedule may have prescribed.

**Engaging students in a fused course: setting the tone**

We found that the instructor's enthusiasm and investment in the fused format are both necessary and contagious. An instructor successfully implementing any atypical teaching method needs to lead by example and provide the rationale guiding her pedagogical choices. While an instructor in a fused course will necessarily need to relinquish some control in order to facilitate lab projects that are more ambitious, more original, and less predictable than traditional labs, students must be made aware that they will be more active and more in control in a fused course than in their traditional laboratory learning experiences. Consequently, mentioning the fused format in the catalog description and course syllabus then discussing it during first day of class are particularly important steps to enhance student buy-in and minimize potential misunderstandings and apprehension. Furthermore, we recommend that the instructor dive right into an active teaching method in the first few minutes of the first day; something as simple as a think-pair-share exercise can set the tone that students cannot be passive spectators during class time. This strategy may scare away a few students who prefer to hide in the back of the room, but we found this to be a wise investment in optimizing future classroom dynamics. We also recommend that the instructor invest time during the first meeting explaining why she chose to fuse the course, what her goals are, and why she is so excited about this new format. We suggest that she provide evidence from active learning strategies in her previous courses, even if only anecdotal data are available. If the instructor has no first-hand experience, borrowing data from other instructors at the institution or elsewhere showing increases in test scores can be very convincing to students. A sincere personal touch can also be persuasive. For example, an instructor might explain a particularly painful undergraduate course experience and contrast it with an exciting research experience that opened her eyes and changed her motivation. The coaching analogy mentioned above can also work (e.g., "You wouldn't expect to learn how to ride a bike by sitting in a lecture, so why would you expect to learn science that way?").

In our experience describing the fused format does not require considerable data or explanation and does not come in a right or a wrong format. Conveying the rationale for the fused format up front is essential to stimulate student buy-in, particularly for students who have specific expectations for how they receive information, intolerance for ambiguity, or are not self-reflective. In addition to a thoughtful and positive introduction to the fused format, it is also important to remind students throughout the duration of the course that it is OK if experiments are not executed perfectly or if the data are messy and ambiguous. Reflection and questions are powerful learning tools. The lesson that scientists can learn more from their ignorance and failure than from their mastery or success is a potent experience that is particularly appropriate within the fused course format (Schwartz, 2008; Firestein, 2012).

**Coordinating student attention in a fused course**

Our experiences indicated that giving students a road map for the day was helpful. We often listed the day's objectives on the board or first slide and estimated the time each component might take so the students could see the pattern of the day. These patterns varied, some days included more lecture/discussion components and some days included more (or all) lab components. We found that three hours is too long for any one activity, particularly lecture or discussion based activities, so we recommend that every class meeting include a laboratory component even if it is a short, dry activity such as finding sources, analyzing data, or constructing a poster. In addition we generally found it easier to place lecture and discussion elements earlier in the three-hour meeting because students were more likely to be working at similar paces. Hands-on elements with lab techniques generally worked better in the later components of the class session because students could work at their own speeds and not worry about holding up the class or being unable to leave when they finished their task. The flexibility to rearrange the schedule was a significant benefit for techniques that required incubation times because this underused lab time could be redirected to discussions. Similarly, when we were unsure how long it would take students to complete a laboratory task, we would place that activity at the start of the class session and use the remaining time to get as far as allowable with discussion or lecture.

In the fused format we found ourselves needing to get students attention in very direct ways (e.g., "Everyone please stop what you are doing for a moment, we need to focus our attention on…" or "Each group needs to find a good stopping point in your data analysis in the next five minutes so we can discuss today's reading."). We also found that we needed to make very obvious links between class activities, explicitly reinforcing connections between techniques and concepts (e.g., "We saw immunostaining in the paper we read on cortical neurons *in vivo*, now let's consider what antibodies we want to use to identify the neurons we are culturing").

**Benefits of fused courses**

Our experiences as instructors revealed many unique benefits of the fused course format. The first was that we were not tied to a tight 50- or 75-minute time block; the freedom to worry less about the clock and let the discussion or trouble-shooting or hands-on activities take as long as the students needed (within three hours) allowed us to focus on quality and depth of learning. We also particularly appreciated the ability to put theory and practice in close proximity. We found that we could scaffold theoretical and practical skills in more places and ways throughout the course than we had accomplished in traditional lecture/lab configurations. We could read primary literature, execute the techniques, analyze data, and pose experimental design and analysis questions in class and on exams. The fused format also allowed us to emphasize a collaborative approach and spirit. We perceived that our students in fused courses identified more strongly as a cohesive team that supported each other in their learning. The fused format also allowed us to use lab meeting and journal club formats to give students a more authentic taste of how research teams organize their meetings together.

In a fused format that prioritizes student collaboration, we found it especially important to reassign groups at various points throughout the semester so that students did not work with the same lab partner(s) for the full length of the course. We often used a mixture of selection methods so that students sometimes worked with preferred partners and sometimes worked with new partners. The fused class format also lent itself well to the use of primary literature as foundational reading material. We prioritized students' ability to read research papers, analyze data, and propose experiments, and we assessed these skills via conceptual quizzes, exams, and assignments that asked students to apply what they knew to new situations.

The fused format also allowed students to see many of the critical but behind-the-scenes aspects of research that are not evident in cookbook laboratory exercise where all reagents are neatly prepared for their use by someone else in advance. Some of the more entertaining and memorable moments occurred when we allowed students to perform routine lab maintenance tasks such as making their own solutions, calculating dilutions, and autoclaving waste. Students learned to appreciate the considerable work that goes into most research questions while being forced to confront significant shortcomings in their basic laboratory skill sets.

The fused format also allowed students to be curious and inquisitive. With some control over research questions we encouraged students to be self-motivated, expecting them to look things up and build their own knowledge in ways that most research scientists do. We found that experiments with even a small original component were more motivating and engaging than doing a cookbook lab.

**Challenges of fused courses**

Teaching a fused course requires considerable thought into configuring class meetings to ensure variety and engagement; three hours of any one element gets too long for students and instructors. With emphasis on original research questions, the odds that a complex, multi-day procedure will not work are considerably high. Fused course instructors need to be prepared for plans to change and the syllabus to be fluid and dynamic. Students may need time and repetition to develop technical competence, experimental designs may need to be reconsidered, and results may be negative for a variety of (very discussable) reasons. Any fused course instructor needs to have contingencies in mind when the science does not go as planned. Most importantly, the instructor must not appear disappointed or uncomfortable with experiments gone awry, instead reminding students that failure and redirection is an essential element of immersion in scientific inquiry and directing them toward what they learned.

Another challenge of fused courses is designing situations where the speedier students do not get so far ahead of the slower students that one group is bored and off topic while another other group is lost and anxious. Students in the same class will inevitably work at a variety of speeds. Thus, it is important to design class activities that can expand or contract to meet the time allowed. For example, have an additional small task in mind for students who finish ahead of the others. Such tasks could ask them to look up relevant references, find a video, double-check analysis, tidy up, etc. Another strategy is to give students a list of questions or tasks that will take longer than the allotted time. If their starts are staggered at different points on the list, then at least one student will hit each item on the list, but no student will get to everything. This strategy allows students to work at their own speeds and get as far as they are able in ways that minimize pressure and anxiety of being the slow pokes.

"It really cemented the fact that science is not some isolated event that you go to a separate lab to complete."

"Lab didn't become something that I dreaded and I felt like it backed up the things we were learning about in lecture."

"It kept me actively engaged throughout the class and gave us the opportunity to see what we just learned."

"Sometimes it was hard to stay focused and engaged during lectures when I was looking forward to the lab activity."

*Figure 6.* What students say about a fused course. The quotes above represent four of sixteen student responses from the most recent fused course offering (BIO306) to the prompt, "Describe your experiences with "fused" format where lab and lecture activities occurred on the same day in the same space. What were the advantages and disadvantages of this unique course format?".

**Supporting fused courses**

As mentioned above, fused courses may need special considerations for the location and or timing of their offering. In addition to structural support, fused courses may also require administrative and staff support (Brownwell and Tanner, 2012). Our students, colleagues, and administration all encouraged our pedagogical experimentation with fused courses. We are fortunate to work at small, undergraduate-focused institutions and recognize this environment facilitates teaching in this resource-intensive fused format that may not be possible at other institutions of different sizes and/or foci. In particular, our departmental culture prioritized the pedagogical continuity provided when a student takes both lab and lecture from the same faculty member in the same semester. We taught our fused courses with the assistance of a lab manager who ordered and prepared instruments, supplies, and reagents on our behalf. While the fused courses were manageable without an assistant, we recommend that instructors utilize available personnel resources. Hiring a laboratory instructor, graduate teaching assistant, undergraduate teaching assistant, or work-study student who can participate during fused class sessions can be extremely helpful. Having an extra pair of hands to help train students on instruments, round up supplies, and answer questions is a remarkably helpful aide, particularly if the class size is large. We also note an important benefit of an additional instructor is that some students may be uncomfortable asking questions or revealing important gaps in their understanding to the instructor who grades their performance. Thus, a course assistant who is not directly responsible for grading student work, but can pass along questions or sticking points to the instructor further allows the course to be flexible and responsive in ways that maximize student learning.

It is also important to emphasize that the fused method of teaching requires substantial instructor preparation. Course loads may appear lighter to administrators when an instructor's contact hours decrease from 12 to nine hours per week. Yet we found that the planning needed to develop and prepare original lab experiences, to sustain multi-day techniques, to develop contingency plans, and to coordinate student-designed experiments exceeded the work needed to teach a second lab section of a traditional cookbook lab. We recommend that instructors discuss options for teaching credit with their department chairs and/or deans in advance. In parallel, we also recommend that instructors think carefully about assessment strategies in advance when offering fused courses. Thoughtful, rigorous assessment will not only help them facilitate a better class experience for their students, but may also help demonstrate benefits of a fused course format to administrators making decisions regarding course scheduling, ceilings, and/or teaching credit.

**Student experiences in fused courses**

So what do students think about fused lab course formats? One student enthusiastically described her experience in a fused neuroscience course as "repetition without redundancy" because "we read it, we did it, and we talked about it." When asked at the end of the course if students preferred the fused lab course format over the traditional compartmentalized lab course format, 24 of 28 (86%) of BIO333 students indicated that they preferred the fused format. Anecdotal evidence suggests that the few students who dislike the fused format tend to be students who are generally less well prepared for class sessions, making the transitions from discussions to experiments to lectures more difficult to follow. BIO 333 students who experienced the fused format did not fare differently from their traditional counterparts with regard to test scores or overall course averages, but were certainly more engaged and enthusiastic about laboratory experiments and also appeared to gain a more realistic understanding of the scientific research process. Moving forward, more thorough assessment is needed to determine if the fused format presents tangible benefits for our students. We are currently developing a scientific literacy assessment tool to determine if students in fused courses fare better with regard to their understanding of the scientific process, as executed in modern biology laboratories. One particularly exciting finding was that a fair number of our students developed a new or renewed interest in pursuing research careers as a result of the fused course experience.

**Increasing immersion when fusion isn't an option**

Our goal in fusing lab and lecture times together was to create new opportunities for an undergraduate lab course to reflect important elements of an immersive research experience. We wanted our students to emerge from the course with scientific experience and knowledge that did not fall neatly into lecture versus lab compartments. We acknowledge that there are many challenges to offering fused or immersive courses, several of which we described above. The most important challenge is worth repeating - that the instructor needs to let go of the urge to cover content and shift to a perspective of emphasizing skills that students will learn in the course and be able to apply in other situations. We were fortunate in many dimensions to be able to experiment with a fused teaching model and acknowledge that not all institutions, departments, instructors, or curricula will be able to transition a course from a traditional to a fused format. We hope that readers will take our experiences as springboards for thinking about alternative ways to help dissolve the artificial boundaries between labs and lectures by enhancing immersion in scientific research. The means to accomplish this goal without a fused course are numerous and include any actions that make more intentional links or enhance continuity between lecture and lab activities such as multi-week experiments, replication or screening experiments, testing an unknown or new variable in parallel with a cookbook variable, using class time to check on an experiment in progress, emphasis on research literature, more places where students have agency and choice in experimental design, and more opportunities for students to design the next experiment.

Finally, we note that our work thus far has focused on fusing upper-level lab courses. Introductory and gateway courses would also benefit from strategies that decrease the intellectual distance between lecture and lab learning. In particular because students are most likely to leave STEM majors during their first or second year of college (Seymour and Hewitt, 1997) even though "a single positive interaction, excitement about a course's teaching and/or context…[can] cause a student to confirm his or her choice to stick with engineering" (Lichtenstein et al., 2007). Given ongoing concerns about STEM's current inability to train a sufficient and diverse next generation of scientists, all attempts to make undergraduate education in the sciences more authentic, compelling, and immersive should be explored.

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