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An article in the Two-Year Community column on page 17 describes a dual-enrollment program that gives high school students an opportunity to experience college science in a supported environment, along with lessons learned and challenges faced by faculty when setting up such a program. On page 34, read how one group of investigators examined whether short “Kahn style” video lectures, assigned as homework, could replace live classroom lectures in the presentation of buffer theory and problem solving. And see page 97 for an article on the development and evaluation of graduate teaching assistant learning communities to enhance the implementation of inquiry experiences in undergraduate laboratories.

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Did violence shape our faces?

What contributed to the evolution of faces in the ape-like ancestors of humans? According to new research, the cause might be the prehistoric version of a bar fight—over women, resources, and other slug-worthy disagreements.

Biologist David Carrier and physician Michael H. Morgan contend that human faces—especially those of our australopith ancestors—evolved to minimize injury from punches to the face during fights between males. The findings present an alternative to the previous, long-held hypothesis that the evolution of the robust faces of our early ancestors resulted largely from the need to chew hard-to-crush foods such as nuts.

“The australopiths were characterized by a suite of traits that may have improved fighting ability, including hand proportions that allow formation of a fist, effectively turning the delicate musculoskeletal system of the hand into a club effective for striking,” says Carrier, lead author of the study. “If indeed the evolution of our hand proportions were associated with selection for fighting behavior, you might expect the primary target, the face, to have undergone evolution to better protect it from injury when punched.”

The rationale for the research conclusions came from determining a number of different elements, said Carrier.

“As the Moon cooled and solidified, tidal forces became frozen in place. The sculpting effects of tidal and rotational forces became frozen in place. The idea of a frozen tidal-rotational bulge, which indicates that violence played a greater role in human evolution than is generally accepted by many anthropologists. In recent years, Carrier has investigated the short legs of great apes, the habitual bipedal posture of hominins, and the hand proportions of hominins. He’s currently working on a study on foot posture of great apes that also relates to evolution and fighting ability.

Research on the evolution of creatures in the genus Australopithecus—immediate predecessors of the human genus Homo—remains relevant today as scientists continue to look for clues into how and why humans evolved into who they are now from predecessors who inhabited the Earth about 4 to 5 million years ago.

Carrier says his newly published research both “provides an alternative explanation for the evolution of the hominin face” and also “addresses the debate over whether or not our distant past was violent.”

“The hypothesis that our early ancestors were aggressive could be falsified if we found that the anatomical characters that distinguish us from other primates did not improve fighting ability. What our research has been showing is that many of the anatomical characters of great apes and our ancestors, the early hominins (such as bipedal posture, the proportions of our hands and the shape of our faces) do, in fact, improve fighting performance,” he says.

Morgan added that the new study brings interesting elements to the ongoing conversation about the role of violence in evolution. He says, “Our research is about peace. We seek to explore, understand, and confront humankind’s violent and aggressive tendencies. Peace begins with ourselves and is ultimately achieved through disciplined self-analysis and an understanding of where we’ve come from as a species. Through our research we hope to look ourselves in the mirror and begin the difficult work of changing ourselves for the better.”

(University of Utah)

Tidal forces gave Moon its shape

The shape of the Moon deviates from a simple sphere in ways that scientists have struggled to explain. A new study shows that most of the Moon’s overall shape can be explained by taking into account tidal effects acting early in the Moon’s history. The results provide insights into the Moon’s early history, orbital evolution, and current orientation in the sky, according to lead author Ian Garrick-Bethell.

As the Moon cooled and solidified more than 4 billion years ago, the sculpting effects of tidal and rotational forces became frozen in place. The idea of a frozen tidal-rotational bulge,
known as the fossil bulge hypothesis, was first described in 1898. “If you imagine spinning a water balloon, it will start to flatten at the poles and bulge at the equator,” Garrick-Bethell explains. “On top of that you have tides due to the gravitational pull of the Earth, and that creates sort of a lemon shape with the long axis of the lemon pointing at the Earth.”

But this fossil-bulge process cannot fully account for the current shape of the Moon. In the new paper, Garrick-Bethell and his coauthors incorporated other tidal effects into their analysis. They also took into account the large impact basins that have shaped the Moon’s topography, and they considered the Moon’s gravity field together with its topography.

Efforts to analyze the Moon’s overall shape are complicated by the large basins and craters created by powerful impacts that deformed the lunar crust and ejected large amounts of material. “When we try to analyze the global shape of the Moon using spherical harmonics, the craters are like gaps in the data,” Garrick-Bethell says. “We did a lot of work to estimate the uncertainties in the analysis that result from those gaps.”

Their results indicate that variations in the thickness of the Moon’s crust caused by tidal heating during its formation can account for most of the Moon’s large-scale topography, while the remainder is consistent with a frozen tidal-rotational bulge that formed later.

Tidal heating and tidal-rotational deformation had similar effects on the Moon’s overall shape, giving it a slight lemon shape with a bulge on the side facing the Earth and another bulge on the opposite side. The two processes left distinct signatures, however, in the Moon’s gravity field. Because the crust is lighter than the underlying mantle, gravity signals reveal variations in the thickness of the crust that were caused by tidal heating.

Interestingly, the researchers found that the Moon’s overall gravity field is no longer aligned with the topography, as it would have been when the tidal bulges were frozen into the Moon’s shape. The principal axis of the Moon’s overall shape (the long axis of the lemon) is now separated from the gravity principal axis by about 34°. (Excluding the large basins from the data, the difference is still about 30°.)

“The Moon that faced us a long time ago has shifted, so we’re no longer looking at the primordial face of the Moon,” Garrick-Bethell says. “Changes in the mass distribution shifted the orientation of the Moon. The craters removed some mass, and there were also internal changes, probably related to when the Moon became volcanically active.”

The details and timing of these processes are still uncertain. But Garrick-Bethell said the new analysis should help efforts to work out the details of the Moon’s early history. (University of California, Santa Cruz)

**How flies escape looming predators**

When a fruit fly detects an approaching predator, the fly can launch itself into the air and soar gracefully to safety in a fraction of a second. But there’s not always time for that. Some threats demand a quicker getaway. New research reveals how a quick-escape circuit in the fly’s brain overrides the fly’s slower, more controlled behavior when a threat becomes urgent.

“The fly’s rapid takeoff is, on average, eight milliseconds faster than its more controlled takeoff,” says group leader Gwyneth Card. “Eight milliseconds could be the difference between life and death.”

Card and her colleagues discovered two neural circuits mediate fruit flies’ slow-and-stable or quick-but-clumsy escape behaviors. Card and her colleagues find that a spike of activity in a key neuron in the quick-escape circuit can override the slower escape, prompting the fly to spring to safety when a threat gets too near.

A pair of neurons—called giant fibers—in the fruit fly brain has long been suspected to trigger escape. Researchers can provoke this behavior by artificially activating the giant fiber neurons, but no one has actually demonstrated that those neurons responded to visual cues associated with an approaching predator, Card says. She was curious how the neurons could be involved in the natural behavior if they didn’t seem to respond to the relevant sensory cues, so she decided to test their role.

Card’s team switched the giant fiber neurons on or off and then observed how flies responded to a predator-like stimulus. By analyzing more than 4,000 flies, Card and her colleagues discovered two distinct responses to the simulated predator: long and short escapes. To prepare for a steady takeoff, flies took the time to raise their wings fully. Quicker escapes, in contrast, eliminated this step, shaving time off the takeoff but often causing the...
fly to tumble through the air.

When the scientists switched off the giant fiber neurons, preventing them from firing, flies still managed to complete their escape sequence. “On a surface level evaluation, silencing the neuron had absolutely no effect,” Card says. “You can do away with this neuron that people thought was fundamental to this escape behavior, and flies still escape.” Shorter escapes, however, were completely eliminated. Flies without active giant fiber neurons invariably opted for the slower, steadier escape. In contrast, when the scientists switched giant fiber neurons on in the absence of a predator-like stimulus, flies enacted their quick-escape behavior. The evidence suggested the giant fiber neurons were involved only in short escapes, while a separate circuit mediated the long escapes.

Card and her colleagues wanted to understand how flies decide when to sacrifice stability in favor of a quicker response. To learn more, von Reyn set up experiments in which she could directly monitor activity in the giant fiber neurons. She discovered that the giant fibers were active not only in short-mode escape, but also during some of the long-mode escapes. The situation was more complicated than their genetic experiments had suggested. “Seeing the dynamics of the electrophysiology allowed us to understand that the timing of the spike is important in determining the fly’s choice of escape behavior,” Card says.

On the basis of their data, Card and one of her colleagues propose that a looming stimulus first activates a circuit in the brain that initiates a slow escape, beginning with a controlled lift of the wings. When the object looms closer, filling more of the fly’s field of view, the giant fiber activates, prompting a more urgent escape. “What determines whether a fly does a long-mode or a short-mode escape is how soon after the wings go up the fly kicks its legs and it starts to take off,” Card says. “The giant fiber can fire at any point during that sequence. It might not fire at all—in which case you get this nice long, beautifully choreographed takeoff. It might fire right away, in which case you get an abbreviated escape.” The more quickly an object approaches, the sooner the giant fiber is likely to fire, increasing the probability of a short escape. (Howard Hughes Medical Institute)
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Other topics of interest include, but are by no means limited to, the following:

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- Professional development for college science faculty
- Gender and diversity issues in the college science classroom
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- Innovative use of technology in the classroom or laboratory
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All manuscripts deemed suitable for consideration will be double-blind peer-reviewed by members of the Research and Teaching Review Board. Each of these reviewers is an expert in the area of science education research.

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Case Studies: Dr. Clyde Freeman Herreid, Director of the National Center for Case Study Teaching in Science, edits the Case Studies column published in JCST. The column publishes original articles on innovations in case study teaching, assessment of the method, as well as case studies themselves along with teaching notes for classroom instruction. All material is peer-reviewed in a double-blind process. Submissions should be limited to 2,500 words and submitted directly to herreid@buffalo.edu.

The Two-Year Community: Dr. David M. Majerich, in the Design and Intelligence Laboratory at the Georgia Institute of Technology, edits the Two-Year Community column published in JCST. Successful contributions to this column center on aspects of teaching and learning of special importance in the community college environment. Coordination of science education efforts in the community college classroom with subsequent educational and/or workforce expectations and professional issues of science instructors at community colleges are of particular interest.

Submissions are limited to 3,000 words exclusive of tables, figures, and references. Submissions reporting on investigations or those that review other literature will be double-blind peer-reviewed. Editorial submissions will be assessed for their level of novel contribution. Accepted editorials will be designated as such (and therefore nonpeer-reviewed) in the journal and should be limited to 1,000 words. Submissions should be submitted directly to dmajerich@nsta.org.

Point of View: JCST serves as a point of professional contact and community discussion for instructors of college level science. The Point of View column published in most issues of JCST presents considered reflections or thoughtful opinions on issues of broad interest to the community.

Unlike other columns and feature articles in each issue, submissions to Point of View are not peer-reviewed. The Field Editor chooses to publish submissions based upon their relevancy, and upon the level of potential contribution to the conversation on teaching and learning in college-level science. Submissions should be limited to 900 words and submitted directly to our electronic submission system (http://mc.manuscriptcentral.com/nsta) with an indication that the manuscript is to be considered for the Point of View column.
The Two-Year Community section of the *Journal of College Science Teaching*, edited by Dr. David M. Majerich, invites submissions on aspects of teaching and learning of special importance in the community college environment. Coordination of science education efforts in the community college classroom with subsequent educational and/or workforce expectations and professional issues of science instructors at community colleges are of particular interest. Some broad topics of interest include the following:

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- Professional development for two-year faculty
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- Innovative technology adoption and curricular integration in the classroom or laboratory
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Prospective contributors are encouraged to contact the column editor by e-mail to discuss the suitability of a given idea for this column. Submissions are limited to 3,000 words exclusive of tables, figures, and references. Submissions reporting on investigations or those that review other literature will be double-blind peer-reviewed. Editorial submissions will be assessed for their level of novel contribution. Accepted editorials will be designated as such (and therefore nonpeer-reviewed) in the journal and should be limited to 1,000 words.

Inquiries concerning the suitability of possible contributions to the Two-Year Community column should be sent by e-mail directly to:

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Considerations and Recommendations for Implementing a Dual-Enrollment Program: Bridging the Gap Between High School and College Level Science

By Laura A. Lukes

Dual-enrollment (DE) science courses offer a way to strengthen the science, technology, engineering, and mathematics pipeline between high school and college. These courses offer high school students the opportunity to experience college science in a more supported environment, allowing them to adjust to the different academic and social demands of a college learning environment. Evidence suggests that the DE model may better prepare students to be academically successful in college both in terms of performance (e.g., GPA) and time to graduation (number of years it takes a student to graduate with a college degree). DE programs have many stakeholders and require advanced planning in order to be successful. This article describes the successful coordination and implementation of a DE geology program (consisting of two lecture and two lab courses). The lessons learned and challenges faced can provide insights to both high school and college instructors interested in organizing and implementing their own DE science programs.

The term dual enrollment (DE) is used to describe a course in which a student is enrolled to receive credit as both a high school student and a college student. In the broader perspective, DE programs are viewed as college transition programs by the U.S. Department of Education (2003). DE is seen as a way to bridge the gap between high school achievement and college readiness (Hofman, 2012). Because of the variation in college and state policies, DE programs can be located on college campuses or in high schools. Regardless of physical location, the intent behind DE programs is to “keep talented students challenged, help smooth the transition between high school and college, develop vocational readiness, and give students momentum toward a college degree” (Klopfenstein & Lively, 2012, p. 60). As more attention in higher education is being paid to the low rates of student success in college (Karp, 2012) and the role of community colleges in strengthening the science, technology, engineering, and mathematics (STEM) pipeline, it is important to share best practices and lessons learned about building partnerships between high school and college institutions, as well as how to effectively implement STEM DE programs.

Benefits of dual enrollment
A DE program has many stakeholders: students, parents, college faculty and administrators, high school faculty and administrators, as well as universities that accept DE credit during student transfers. Research has indicated that students who participate in DE courses take less time to earn a college degree and have better college academic performance (as measured by college GPA; Allen & Dadgar, 2012). Additionally, students who participate in DE programs have higher rates of nonperformance college readiness because they have learned new ways of behaving, thinking, and interacting with others through the college student role rehearsal provided by DE (Karp, 2012). Although the tendency is to focus on benefits to students, there are other stakeholders involved in our DE program who benefit from participation (see Table 1 for benefits by stakeholder group).

Setting up a DE course
I taught Earth and Space Science courses (geared toward high school
freshman) during the day and Geology courses at two local community colleges in the evening. I wanted a way to expand access for my high school students who expressed interest in the geology sections of the classes I taught. I also wanted them to have access to the equipment and resources available at the community college. Learning about DE from a teacher in another district during a professional development workshop, I recognized DE as a win–win way to move forward with increasing access to geology in high school. I then led the efforts to establish a geology DE program at a public high school in a suburb of a major city in Arizona. The high school partnered with the nearest community college, which is part of a larger countywide community college system. The program offered a Physical Geology lecture and lab in the fall and Historical Geology lecture and lab in the spring (4 credit hours total each semester). Table 2 contains a list of the weekly course topics for the Physical Geology course.

Setting: The high school

The high school averages about 1,400 enrolled students in a given year. In terms of meeting state standards, the school’s Arizona Instrument to Measure Standards (AIMS) scores have varied during the reported period of 2010–2013: 61%–72% passing in math, 84%–89% passing in reading, and 71%–83% passing in writing (Arizona Department of Education, 2012). Additionally, the 4-year graduation rate is reported at 89.9%. In terms of diversity, 21% of students qualify for reduced lunch, 76% of the student population is reported as White, and the largest underrepresented group is reported as Hispanic (14.3%; National Center for Education Statistics, n.d.).

Setting: The community college

The community college has an enrollment of approximately 11,000 students. In terms of diversity, 63.9% of the student population is reported as White, with the largest underrepresented group reported as Hispanic (13.6%; National Center for Education Statistics, n.d.). In 2011, 37% of the full-time enrolled students were federal Pell grant recipients (Scottsdale Community College, n.d.). Part-time and full-time retention rates were 37% and 56%, respectively, in 2011. Thirty-two percent of students transferred out in 2009, and the 3-year graduation rate was 17% for students entering in fall 2009.

Step 1: Establishing interest

Anyone who has taught at a high school or community college has experienced the nerve-racking period of the semester in which students register for classes for the follow-

### TABLE 1

<table>
<thead>
<tr>
<th>Stakeholder group</th>
<th>Benefits</th>
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| Students and parents | • Challenge of college level that students may not be receiving in traditional levels  
| | • Practicing college in a more scaffolded environment, easing the academic transition  
| | • College credit for less (saves time and money spent at a university); students have the opportunity to earn college credit at a reduced rate (compared with the average university per credit cost)  
| | • Exposure to the college norms, reducing novelty space/culture shock of college transition  
| | • Credit toward diploma |
| K–12 district administrators (e.g., district administrators, high school principals, department chair) | • Allows them to offer advanced courses that they might not otherwise have the budget for  
| | • Makes open enrollment schools more attractive to prospective students by offering unique opportunities  
| | • Provides money for lab equipment that is otherwise unavailable |
| College administrators (e.g., DE coordinators, Science Department administrators and faculty) | • Increased enrollment  
| | • Potential for continued enrollment  
| | • Lower overhead if class is taught on high school campus |
| DE instructors | • Opportunity to teach specialty or advanced classes not offered because of district costs  
| | • Opportunity to finance equipment for use in other classes beyond the DE course  
| | • Potential for other partnerships with community college (e.g., guest speakers, equipment loans) |
ing semester or year. If one’s class doesn’t reach a critical cutoff enrollment value (which varies by institution), the class will be cancelled. Although the reasons why students sign up for classes varies, students have to go out of their way to enroll in a DE course because there is extra paperwork and cost. Over half the students who enrolled in the DE geology courses had taken Earth and Space Science with me; they stated that they had enjoyed both the subject and my teaching style in that course. Three of the students indicated they were considering a geology major in college. The rest indicated they planned to enter college on graduation as non-STEM majors and that they wanted to “get their science lab credit out of the way” by taking it as a DE course.

When thinking of a DE class, it is easy to focus on the student interests and benefits. If students are interested, it seems to reason that the program will happen. But in the setup of a DE program, others (see Table 1) need to express interest in order for the program to come to fruition. Buy-in is needed from parents, instructors, department chairs, high school administrators, district administrators, college DE coordinators, and college department faculty.

Parents were interested because of the financial and academic advantages that DE could offer. The high school Science Department chair was interested because the DE courses brought money to the department for supplies (in this DE program, the high school receives funds from the college the following school year) with no additional costs on their end. In addition, such advance course offerings bring prestige and diversification to the Science Department’s portfolio. Administrators concerned about budgets were interested in how DE could increase schoolwide enrollment numbers. As this particular high school is an open-enrollment school, enrollment numbers can potentially be increased by attracting students from other schools by offering unique opportunities (such as DE courses), which are not offered at their home schools. Similarly, college department chairs and instructors were interested because students enrolled in a DE course may be interested in taking future courses in geology from instructors on campus, thereby building their enrollment and program. College DE coordinators interested in building collegewide enrollment find DE courses to be a student gateway to their on-campus programs.

Step 2: Considerations, planning, and setup

To initially launch a DE science course, a school must meet the mandated enrollment numbers. Besides listing the course in the college/high school registration books, the school must receive district approval. This requires advance planning, as this typically takes place in the fall of the year prior. To meet the district paperwork deadlines, commitments need to be confirmed from all involved: the community college DE coordinator, the college Science Department/faculty sponsor, the high school principal, the high school Science Department chair, and the DE instructor.

In order to secure a commitment from the college, the future DE instructor has to have met the qualifications and applied to teach as an adjunct faculty member at the college. Oftentimes, community colleges require that instructors have 20 or more graduate-level credit hours

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<th>Week 1</th>
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in the subject being taught. I already had a master’s degree in geological sciences and a master’s degree in 7–12 science education, meeting the 20 graduate-level credit hour requirement in geology. Because not all high school science teachers meet these credit requirements, someone planning to set up a DE science course needs to consider the qualifications of the potential DE instructor. In addition to meeting the required qualifications, I was already teaching in the county-wide college system. My previously submitted application from one college transferred readily to the DE college. This saved a tremendous amount of time and paperwork, allowing the program to move forward under tight high school district deadlines. The college department was also familiar with my teaching abilities. Some departments require DE instructors to teach a semester on campus as a traditional adjunct before they are allowed to teach a DE course. If this is the case, the DE teacher potentially would need to complete that teaching experience 2 years prior to the proposed start date for the DE course.

The course syllabus needs approval from the DE coordinator and the college Science Department. Even though there were format requirements unique to this college, because I had already taught this course at another community college, the process went quickly. DE instructors new to teaching in a college setting may need to allow for time for revisions according to the college’s specific course requirements.

As discussed earlier, for there to be commitment from the district and from the high school, the DE instructor must be able to communicate the benefits for the school and district of offering the course. At the high school level, it is important to consider the general science staffing needs of the Science Department. If the DE instructor is the only teacher certified to teach specific classes, he or she may be unavailable to teach the DE science course. There were other teachers certified to teach Earth and Space Science at the high school, so for me this wasn’t a limiting factor.

Another issue to consider in advanced planning is the location of the courses. Will both the lecture and the lab be offered on the college campus? The high school campus? The college we worked with wanted at least one of the courses to meet on the college campus (to familiarize the students with campus and potentially inspire them to take other classes there). I acted as a liaison between the district and the college to sort out options. In the end, it was determined that transportation issues and student scheduling conflicts would reduce the potential enrollment numbers. The compromise was to pilot the science DE program on the high school campus and move it to the college campus in the following years if course enrollment stayed strong.

Once the courses are listed in the registration systems in both the college and high school, students register through their high school systems. They must also enroll as students in the college and meet the semester registration and fee deadlines. To streamline this process in our situation, the DE coordinator for the college made special arrangements with the college registrar. Because the majority of the students are minors, parental permissions were needed. Two informational sessions were offered with myself and the DE coordinator from the college. Parents and students received additional information, completed paperwork, and registered with ease.

**Step 3: Implementation**

Because I had already taught similar courses at the college level, an approved curriculum was available. For others considering their own programs, a curriculum must be developed, which can require a large time commitment. The difficulty in implementation came in the form of lab equipment and supplies. Because of the year’s lag time between DE implementation and the provision of college monies for supplies, alternative arrangements had to be made. These arrangements are described later in the manuscript.

In addition to normal pedagogy, the college side of a DE program requires DE instructors to be observed and evaluated. In our case, a member of the college’s geology faculty completed the task. Advanced planning by the DE instructor is required to obtain necessary high school administrator approval to have a visitor on campus.

**Step 4: Sustaining the program**

The last step to a DE program is to sustain student interest and enrollment. For our courses, there was approximately a 25% drop in student enrollment between fall and spring semesters. Anecdotally, three of the students who chose not to enroll in the historical geology courses in the spring semester indicated that the workload was too much, but difficulty level was fine. End-of-semester student evaluations for both courses were positive, and lab activities involving fossil samples and virtual field experiences were identified as favorite activities. To recruit students for the following school year, flyers and information sessions publicized the program. The courses did have high enough enrollment to be offered the following...
year (again, the majority of the students had me as their instructor for Earth and Space Science). A change of DE instructor over the summer (because of my participation in the Albert Einstein Distinguished Educator Fellowship Program) resulted in a continuation of the program, but with a change in topic from geology to physical geography. This change in topic was due to the qualifications of the staff available to teach the courses. The final enrollment numbers for the second DE year are unavailable. The program was discontinued the following year. Without a formal evaluation process in place, it is difficult to say why the program was not sustained. See the lessons learned for more discussion of mitigating these challenges.

Lessons learned: What worked well

Professional networks and relationships make the process smoother. Professional partnerships already existed between the high school instructor (who at that time taught Earth and Space Science at the high school and geology at another community college in the countywide system) and the college geology instructor. This preexisting professional relationship facilitated the communication needed to navigate the logistical coordination process of identifying and reaching out to the key administrators in both the community college and high school systems. The high school and community college instructors were able to work through the paperwork on both ends and meet in the middle, rather than one of them trying to coordinate both, saving time and frustration. As mentioned previously, the DE coordinator also played a critical role by streamlining the paperwork for the students and their parents, without which several students likely would not have registered.

Communication of opportunity is key, but so is timing. The program was successful at meeting enrollment requirements because we started the communication process early, namely before the registration period even began. I advertised the course using flyers posted around the school, highlighting the student benefits. Other science instructors who taught courses with the target student population also announced the course offering in their courses, again before registration started. Additionally, parents played an important role in communicating the value of their child taking a DE course to other parents. During the informational session that the high school instructor offered, several parents indicated that they had learned about DE programs from other parents and were interested because of what they had heard.

It helps to have a DE instructor who has already taught at the community college level. I had already taught geology at the community college level for a few years before implementing this program. This proved to be advantageous because I already had a well-developed curriculum at the appropriate content level, so more time was available to mitigate the equipment and paperwork challenges that came up during the courses. This is particularly relevant to consider if you are a community college instructor looking for a high school teacher to partner with. Many high school teachers have multiple courses to prepare for, so teaching another course—particularly if they haven’t taught the course before—may become overwhelming.

Lessons learned: Challenges

The money to purchase equipment and supplies is dispensed the following academic year. Because of the financial arrangement between the community college and the K–12 school district, the instructor had no supplies or equipment to run the necessary labs for the course. These challenges were overcome through sample access partnerships with the high school’s grant-funded Rock and Mineral Museum and partnerships with the community college’s Geology Department (samples and maps were loaned to the high school on an “as needed and available basis”). Without these partnerships, many of the labs would have been difficult to do. But as illustrated, careful planning and making use of professional networks and outside funding sources can overcome such a challenge.

High school teaching staffing is constantly changing. In order to sustain the program, more than one qualified DE instructor in the subject area is needed on the staff. I relocated the following year, and no one at the high school met the community college’s requirements to teach the courses. The students who had enrolled for the year following the pilot year had the option to take a DE Physical Geography course instead of Physical and Historical Geology. The Physical Geography course met enrollment numbers but was dropped from the course listings the following year, likely because of low enrollment numbers.

DE credit doesn’t transfer to all universities. The majority of students enrolled in the geology DE courses were planning to attend in-state universities after high school graduation. The major in-state universities in Arizona have a streamlined transfer credit system with the countywide system...
two-year community college system. However, there were some students who were planning to apply to out-of-state schools, and it was far less clear whether the credits would transfer. Students/parents had to contact the universities to determine this and often expressed conflicting information and frustration. It is unclear how many students didn’t enroll because of this issue.

Conclusion
DE programs offer numerous benefits to students, teachers, and partnering institutions. To be successful, however, as illustrated by the four-step example described, programs require advance planning, community support, and a consistent instructor pool. Beyond offering college courses at a high school, DE programs serve to build bridges between high school and college communities. These partnerships increase communication between high school and college levels and have the potential to lessen the leaks in the STEM pipeline by helping students successfully transfer from high school to college through a supportive experience.

Acknowledgments
I am grateful for the interest and support that I received from administers and faculty of both the K–12 and college systems, as well as from the participating students and parents.

References

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Proposal Deadline: 1/15/2015

2016 National Conference

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How Does Undergraduate Research Experience Impact Career Trajectories and Level of Career Satisfaction: A Comparative Survey

By Kirsten Yaffe, Carol Bender, and Lee Sechrest

The immediate benefits of research experiences for undergraduates have been documented. However, little has appeared about the long-term impacts of these experiences on participants’ career trajectories and their level of career satisfaction. In addition, many studies of undergraduate research lack a comparison group. This article reports a comparison of results from a survey of participants in the University of Arizona (UA) Undergraduate Biology Research Program (UBRP) with those of a comparable group drawn from the UA College of Medicine who did not participate in UBRP.

Findings indicate that exposure to undergraduate research clarifies career paths and demonstrates to many students that they have an aptitude for scientific research that has a strong effect on their professional development.

Participation in research for many who pursue medical careers tends to be “instrumental” in that it is seen as a means of becoming a more competitive medical school applicant. Both the UBRP group and the College of Medicine group indicated that mentors were key to determining and achieving their professional success. Response rates suggest that an organized undergraduate research program fosters a feeling of community and engenders an enduring sense of loyalty within a large institution.

A literature review on the value of undergraduate research found few examples of well-designed program evaluations (Seymour, Hunter, Laursen, & Deantoni, 2004). Nine articles supported claims of benefits of undergraduate research; 45 articles failed to show adequate support for expected benefits. A subsequent controlled, 3-year study by the same authors at four liberal arts colleges reported seven sorts of benefits arising from undergraduate research experience, and few negative, ambivalent, or qualified assessments were voiced. An ongoing study, the Survey of Undergraduate Research Experiences (SURE), relies on an online survey of self-reported learning gains from undergraduate research experience (Lopatto, 2004, 2007). The survey allows programs to compare self-reported learning gains by their students with those reported by students in undergraduate research programs elsewhere in the country.

Both Lopatto (2004, 2007) and Seymour et al. (2004) noted limitations of their studies, including lack of a comparison group and data on long-term impact. Our study addresses these limitations by the inclusion of a comparison group and an attempt to study the long-term benefits of undergraduate research. The proximate value of undergraduate research includes retention in the major to degree completion, development of problem-solving and critical-thinking skills, and preparation for graduate and professional school (Adedokun et al., 2012; Fechheimer, Webber, & Kleiber, 2011; Harsh, Maltese, & Tai, 2011; Taraban & Logue, 2012; Thiry, Laursen, & Hunter, 2011). This paper describes an exploration of the lasting effects of participating in undergraduate research on the career development and satisfaction of University of Arizona (UA) students.

UA is a land-grant research university with 40,000 students. It provides a supportive environment for undergraduate researchers and since 1988 has hosted the Undergraduate Biology Research Program (UBRP). In 1997, UA, largely on the strength of UBRP, was one of 10 institutions that received a National Science Foundation Recognition Award for Integration of Research and Education (RAIRE). UBRP supports over 100 students per year who often enter the program in their freshman year. More than 82% of UBRP students do research for more than a year with opportunities to publish or present their work at conferences (for a more in-depth description of UBRP, refer to Bender, Ward, & Wells, 1994).

Study description

Participants

Our study involved an online survey followed by phone interviews with a subset of volunteers. Subjects were drawn from two groups—UBRP participants between 1988 and 2010 and,
for comparison, medical students who attended the UA College of Medicine (COM) during the same interval. COM students were chosen for comparison because they had academic credentials and interests similar to many UBRP participants, but not all did undergraduate research. Overlap between the groups was limited, but students who participated in UBRP and later attended the UA COM were included in the UBRP group; those who did not participate in UBRP were counted among the COM group.

**Research methods**

The information we sought was multifaceted, and the questionnaire grew rapidly. To minimize response burden, we opted for closed-ended questions with checkboxes for responses. An “escape hatch” for open-ended responses was included for most questions by including an “other” option with space for free text. We assumed that we would have unanswered questions after the survey and included an option for respondents to volunteer for a future follow-up phone interview. The survey was developed in-house by a consensus of five people knowledgeable about the issues (an evaluation specialist from the UA Psychology Department, the UBRP director, a life sciences professor, an IT specialist, and a biostatistics graduate student). The survey was pilot tested by the UA Evaluation Group for Assessment of Data (EGAD) and refined prior to dissemination.

Prospective UBRP subjects received an e-mail that introduced the study and asked for participants. The e-mail included a link to the web-based survey and contained wording indicating the voluntary nature of the research, consistent with consent forms. The study was approved by the UA Human Subjects’ Protection Program in an expedited review. For privacy, subjects from the COM group were contacted by COM staff. The survey was distributed to individuals from each class of the COM that corresponded to each year since the inception of UBRP, to draw a similar distribution of survey respondents from each group.

**Survey responses**

Survey respondents included 423 current UA students and alumni who participate(d) in the UBRP program and 73 who attended the UA COM. The request for volunteers for follow-up phone interviews resulted in 23 interviews, 14 UBRP respondents and 9 COM respondents. The interviews focused on specific issues, primarily respondents’ experience with mentors, and those findings are reported elsewhere (Yaffe, Bender, & Sechrest, 2012); however, some interviews raised issues relevant to the topics addressed in this article. Where appropriate, interview information is included.

**Findings**

A higher proportion from the UBRP group responded to the individual

![FIGURE 1](image)

**Distribution of reported ages of survey respondents. Response rates:** Undergraduate Biology Research Program (UBRP) = 88%; College of Medicine (COM) = 23%.

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<th>Age</th>
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<tr>
<td>47</td>
<td>44</td>
<td>37</td>
</tr>
<tr>
<td>48</td>
<td>45</td>
<td>38</td>
</tr>
<tr>
<td>49</td>
<td>46</td>
<td>39</td>
</tr>
<tr>
<td>50</td>
<td>47</td>
<td>40</td>
</tr>
<tr>
<td>51</td>
<td>48</td>
<td>41</td>
</tr>
</tbody>
</table>

![TABLE 1](image)

**TABLE 1**

Demographic information of survey respondents.

<table>
<thead>
<tr>
<th>Sex</th>
<th>UBRP</th>
<th>COM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>235</td>
<td>(60%)</td>
</tr>
<tr>
<td>Male</td>
<td>159</td>
<td>(40%)</td>
</tr>
<tr>
<td>Number responding</td>
<td>394 (92%)</td>
<td>53 (73%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ethnic minority status</th>
<th>UBRP</th>
<th>COM</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>269</td>
<td>(68%)</td>
</tr>
<tr>
<td>Yes</td>
<td>124</td>
<td>(32%)</td>
</tr>
<tr>
<td>Number responding</td>
<td>393 (92%)</td>
<td>52 (71%)</td>
</tr>
</tbody>
</table>

*Note: UBRP = Undergraduate Biology Research Program; COM = College of Medicine.*
Impact of Undergraduate Research Experience

survey questions. The percentages showing the distribution of responses to each item use the number of respondents to each question in the denominators to facilitate comparisons between groups. The total number responding (and corresponding response rates) for each question is also shown.

UBRP respondents to the survey were younger and more likely to be female and still working on a degree than were the COM participants. This is not surprising because the UBRP group included current undergraduates and those who recently received a bachelor’s degree, whereas the COM group included only those who had already completed a bachelor’s degree. Moreover, more females than males major in the biological sciences. Nationally, more males than females matriculate at medical schools (Association of American Medical Colleges, 2012); however, since 2003, the UA medical school has enrolled more females than males (Figure 1 and Table 1).

Among survey respondents were 191 from the UBRP group who were currently working toward a degree (mostly advanced degrees), representing 60% of the UBRP group who provided education information. Among those who were no longer students, eight UBRP respondents indicated that they planned to return to school to pursue another degree; 20 UBRP alumni indicated that they would not return to school. In contrast, no one from the COM responded to the question regarding pursuing education in the future; however, one respondent from the COM specified that he or she left medical practice and was currently working toward a different degree. Table 2 shows the degrees either received or in progress reported by the survey respondents.

We asked respondents to indicate the primary reason they chose the program that they most recently completed (or were currently enrolled in). Few respondents (36) answered this question, and all were from the UBRP group. The majority (77%) reported choosing their degree program because it matched their interests and abilities. Five (14%) stated that they were following advice given by their mentor or a friend. One respondent wanted to improve chances for career advancement. Two respondents reported an “other” reason, only one of whom specified further that he or she wanted to improve his or her earning potential.

Career path trajectory

Few UBRP respondents and no COM respondents answered a question regarding their level of satis-

### TABLE 2

Degrees pursued by survey respondents (received or in progress).

<table>
<thead>
<tr>
<th>Degree</th>
<th>UBRP</th>
<th>COM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Received</td>
<td>In progress</td>
</tr>
<tr>
<td>MD/PHD</td>
<td>8 (3%)</td>
<td>13 (4%)</td>
</tr>
<tr>
<td>MD/MPH</td>
<td>4 (1%)</td>
<td>1 (0%)</td>
</tr>
<tr>
<td>MD/MBA</td>
<td>1 (0%)</td>
<td>1 (0%)</td>
</tr>
<tr>
<td>MD</td>
<td>57 (18%)</td>
<td>35 (11%)</td>
</tr>
<tr>
<td>DO</td>
<td>2 (1%)</td>
<td>3 (1%)</td>
</tr>
<tr>
<td>PhD</td>
<td>92 (29%)</td>
<td>52 (16%)</td>
</tr>
<tr>
<td>Other professional</td>
<td>19 (6%)</td>
<td>13 (4%)</td>
</tr>
<tr>
<td>Other health provider</td>
<td>1 (0%)</td>
<td>3 (1%)</td>
</tr>
<tr>
<td>MPH</td>
<td>9 (3%)</td>
<td>5 (2%)</td>
</tr>
<tr>
<td>Other masters degrees</td>
<td>63 (20%)</td>
<td>10 (3%)</td>
</tr>
<tr>
<td>Undergraduate</td>
<td>251 (78%)</td>
<td>47 (15%)</td>
</tr>
<tr>
<td>Other (associates degrees, second undergraduate majors, other postbaccalaureate degrees, etc.)</td>
<td>22 (7%)</td>
<td>8 (3%)</td>
</tr>
<tr>
<td>Number responding</td>
<td>320 (76%)</td>
<td>59 (81%)</td>
</tr>
</tbody>
</table>

Note: UBRP = Undergraduate Biology Research Program; COM = College of Medicine.
faction with their career choice. We explored this further during follow-up interviews. In addition to asking about interviewees’ career satisfaction, we asked interviewees to speculate on possible reasons why someone would choose to not answer this question. Curiously, although some interviewees speculated about possible reasons for not answering this question, most saw no compelling reason to skip it, and no one refused to answer during the interviews. All who were interviewed felt certain they would have responded to that question on the survey. We suspect that the low response rate was an artifact of either the online survey layout (i.e., this question was simply missed by most who completed the survey) or there was a computer error that did not allow the responses to these questions to be recorded for most of the surveys other than for the 36 UBRP individuals whose responses appeared. This demonstrates one of the risks of using internet surveys.

Of the 36 responses from the UBRP alumni whose responses were recorded, 80% were either “pretty satisfied” or “completely satisfied” with their careers. Only one individual reported feeling that he or she had made some serious mistakes (Table 3).

In addition to a question concerning the choice of degree program, a separate question asked what led respondents to their current career path. Overwhelmingly the largest proportion of respondents in both groups specified that they were pursuing careers in which they had a personal interest. The second most reported reason for pursuing a particular career for both groups was the influence of a mentor. Among UBRP respondents, the next three most reported reasons were related to undergraduate or earlier experiences, including presenting research. Among the COM respondents, the third most reported reason was following a friend or family member’s career choice (Table 4).

Although parental influence was not identified by respondents in either group to be a large influence on career path (8% for UBRP group and 3% for COM group), it is interesting to note that COM respondents were more likely to have a parent who had an MD than were UBRP respondents. UBRP respondents were more likely to have a parent who had a PhD (Tables 5 and 6).

We wondered if financial limitations had an effect on choices respondents made and if they would have done things differently had money not been an issue. This question was left open-ended. The majority of UBRP respondents (281 or 66%) answered this question, as did 28 (38%) of the COM respondents. More than two thirds of those responding indicated that they faced issues because of finances that detracted from their educational experience. Many of these issues had long-term conse-

---

### TABLE 3

Ratings of career satisfaction among a subset of survey respondents.

<table>
<thead>
<tr>
<th>Level of satisfaction with career</th>
<th>UBRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>I'm completely satisfied</td>
<td>16 (44%)</td>
</tr>
<tr>
<td>I'm pretty satisfied</td>
<td>13 (36%)</td>
</tr>
<tr>
<td>I wish I had done a few things differently</td>
<td>6 (17%)</td>
</tr>
<tr>
<td>I have made some serious mistakes</td>
<td>1 (3%)</td>
</tr>
</tbody>
</table>

Number responding* 36 (8.5%)

Note: UBRP = Undergraduate Biology Research Program.

* Follow-up interviews suggest a data collection issue limited the number of responses to this question.

### TABLE 4

Influence on selection of career path.

<table>
<thead>
<tr>
<th>Influence on selection of career path</th>
<th>UBRP</th>
<th>COM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Following parent(s) wishes</td>
<td>33 (8%)</td>
<td>2 (3%)</td>
</tr>
<tr>
<td>Undergraduate experience presenting or publishing research</td>
<td>101 (24%)</td>
<td>2 (3%)</td>
</tr>
<tr>
<td>Influence of a mentor</td>
<td>147 (35%)</td>
<td>9 (17%)</td>
</tr>
<tr>
<td>Following a family member or friend's career choices</td>
<td>41 (10%)</td>
<td>6 (12%)</td>
</tr>
<tr>
<td>Personal interest</td>
<td>343 (81%)</td>
<td>45 (62%)</td>
</tr>
<tr>
<td>A teacher or classroom experience before college</td>
<td>91 (22%)</td>
<td>3 (4%)</td>
</tr>
<tr>
<td>Influence of someone else in research group</td>
<td>26 (6%)</td>
<td>0</td>
</tr>
<tr>
<td>Other UG experience</td>
<td>76 (18%)</td>
<td>4 (5%)</td>
</tr>
<tr>
<td>Other experience</td>
<td>38 (9%)</td>
<td>4 (5%)</td>
</tr>
</tbody>
</table>

Note: UBRP = Undergraduate Biology Research Program; COM = College of Medicine; UG = undergraduate.
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sequences. Responses were grouped into categories and are presented in Table 7.

Respondents from both groups reported similar concerns, although the emphases were somewhat different in each group. For UBRP respondents, financial constraints most commonly affected career-related education or training (19%). For the COM group, most financial concerns kept them from taking additional classes or pursuing a second major to be more well rounded (25%). The second most frequently mentioned experience on which financial constraints impinged for both groups was study abroad (15% for the UBRP group; 18% for the COM group).

Responses of several individuals in both groups suggested that they felt trapped by the cost of their education. This was particularly true of those who went to medical school. One respondent stated that she would have left medical school but was unable to because of the debt she had already incurred. She continued, increasing her debt, hoping to pay off her debt once she entered medical practice. Others commented that they were unable to enter a medical sub-specialty because of the cost of additional training. Some indicated that they would leave medical practice entirely but were unable to do so because of the residual financial burden they carried from the debt they still had from medical school.

**Sustained effects of undergraduate research**

Most of the UBRP group felt their research experience had an effect on their choice of career and level of career satisfaction. Over 80% believed that their undergraduate research experience had a substantial effect, including 46% who felt that it was critical in their career choice. Almost all (94%) of the UBRP respondents reported that it had at least some effect on their level of career satisfaction; over one third said that it had a very great effect.

In contrast, one third of the COM respondents did not have any undergraduate research experience. Among those who reported having undergraduate research experience, half reported that it had very little or no effect on their choice of careers, and two thirds said that it had very little or no effect on their level of career satisfaction. During follow-up interviews, several individuals who intended to go to medical school noted that they made a point of seeking out research experience during their undergraduate education to improve their chances of being accepted to medical school. For these individuals, it is not surprising that their undergraduate research experience did not contribute to their career choice; in fact, their intended choice of career was what prompted them to seek opportunities to do undergraduate research.

The proportions of responses concerning the effect of undergraduate research on both career choice and satisfaction within both groups did not change when the answers were limited to only those respondents who currently perform research (results not presented; Figure 2). Among the UBRP group, three positive aspects of the research experience were selected by two thirds of the respondents: (a) finding science “fun and exciting,” (b) having a mentor who was a positive role model, and (c) having a good experience in a lab. The next most identified positive experience was presenting experimental results, either at a conference or in a publication. Noteworthy is that 45% felt that having the structure of the undergraduate research program provided the needed foundation to pursue a science education.

Among the COM respondents, the ranking of positive effects of undergraduate research was similar to that of the UBRP respondents, although fewer respondents identified them (Table 8). One exception is having had a mentor who served as a positive role model. Seventy-one percent of the COM respondents indicated that they had a mentor who had been an

### Table 5

Reported medical degrees obtained by the parents of survey respondents.

<table>
<thead>
<tr>
<th>Has MD</th>
<th>UBRP</th>
<th>COM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Father only</td>
<td>18 (4%)</td>
<td>8 (11%)</td>
</tr>
<tr>
<td>Mother only</td>
<td>8 (2%)</td>
<td>0</td>
</tr>
<tr>
<td>Both</td>
<td>5 (1%)</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Neither</td>
<td>392 (93%)</td>
<td>64 (88%)</td>
</tr>
</tbody>
</table>

*Note: UBRP = Undergraduate Biology Research Program; COM = College of Medicine.*

### Table 6

Reported doctoral degrees obtained by parents of survey respondents.

<table>
<thead>
<tr>
<th>Has PhD</th>
<th>UBRP</th>
<th>COM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Father only</td>
<td>47 (11%)</td>
<td>2 (3%)</td>
</tr>
<tr>
<td>Mother only</td>
<td>9 (2%)</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Both</td>
<td>9 (2%)</td>
<td>1 (1%)</td>
</tr>
<tr>
<td>Neither</td>
<td>359 (85%)</td>
<td>69 (95%)</td>
</tr>
</tbody>
</table>

*Note: UBRP = Undergraduate Biology Research Program; COM = College of Medicine.*
influential role model.

Twenty-one percent of UBRP respondents reported negative aspects of undergraduate research. Among this group, having a discouraging mentor was selected by one third, followed by a general sense of disinterest in the work itself. Among the one fourth of the COM respondents who reported negative effects of undergraduate research, the most frequently selected was that the experience generated little interest in a career that included research, particularly as compared with other options (Table 9).

Effects of UBRP versus other research experience

The effects of undergraduate research on choice of career was also examined by comparing members of the COM group who had and did not have undergraduate research experience, respectively, and members of

### TABLE 7
Financial limitations and their effects among survey respondents.

<table>
<thead>
<tr>
<th>What would you have done with unlimited finances to spend on your education?</th>
<th>UBRP</th>
<th>COM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number who responded to the question</td>
<td>281 (66%)</td>
<td>20 (38%)</td>
</tr>
<tr>
<td>Number of those responding to the question who had faced financial constraints</td>
<td>195 (69%)</td>
<td>20 (71%)</td>
</tr>
<tr>
<td>Nothing</td>
<td>86 (31%)</td>
<td>8 (29%)</td>
</tr>
<tr>
<td>Studied abroad</td>
<td>43 (15%)</td>
<td>5 (18%)</td>
</tr>
<tr>
<td>Pursued a different career (financial constraints affected choice of career or education trajectory)</td>
<td>24 (9%)</td>
<td>1 (4%)</td>
</tr>
<tr>
<td>Pursued more education—would have taken additional classes or pursued a second major to be more well-rounded</td>
<td>37 (13%)</td>
<td>7 (25%)</td>
</tr>
<tr>
<td>Would have reduced concerns due to financial security (needed to work, not been in debt)</td>
<td>19 (7%)</td>
<td>3 (11%)</td>
</tr>
<tr>
<td>Would have taken more time to complete education</td>
<td>20 (7%)</td>
<td>2 (7%)</td>
</tr>
<tr>
<td>Would have applied to or attended a more expensive university (either before, after, or instead of UA)</td>
<td>38 (14%)</td>
<td>3 (11%)</td>
</tr>
<tr>
<td>Would have pursued additional career-related education or training</td>
<td>53 (19%)</td>
<td>3 (11%)</td>
</tr>
</tbody>
</table>

Note: UBRP = Undergraduate Biology Research Program; COM = College of Medicine; UA = undergraduate.

*Some individuals’ responses are counted in more than one category above.

### TABLE 8
Noteworthy positive effects of undergraduate research experience among survey respondents.

<table>
<thead>
<tr>
<th>Positive effects of undergraduate research</th>
<th>UBRP</th>
<th>COM</th>
</tr>
</thead>
<tbody>
<tr>
<td>I saw how fun and exciting science could be</td>
<td>253 (66%)</td>
<td>6 (35%)</td>
</tr>
<tr>
<td>My mentor was a terrific role model</td>
<td>251 (66%)</td>
<td>12 (71%)</td>
</tr>
<tr>
<td>My experience in the lab was wonderful</td>
<td>250 (65%)</td>
<td>9 (53%)</td>
</tr>
<tr>
<td>Contact I made with other science students</td>
<td>170 (45%)</td>
<td>3 (18%)</td>
</tr>
<tr>
<td>I realized that “I really can do it!”</td>
<td>146 (38%)</td>
<td>2 (12%)</td>
</tr>
<tr>
<td>Having the structure of the program gave me the foundation I needed to enter a science program</td>
<td>172 (45%)</td>
<td>3 (18%)</td>
</tr>
<tr>
<td>The experience of publishing and/or presenting my work at a conference gave me a great feeling</td>
<td>193 (51%)</td>
<td>6 (35%)</td>
</tr>
<tr>
<td>Other</td>
<td>64 (17%)</td>
<td>2 (12%)</td>
</tr>
<tr>
<td>Number reporting any positive effects</td>
<td>382 (90%)</td>
<td>17 (23%)</td>
</tr>
<tr>
<td>Number reporting only positive effects</td>
<td>304 (72%)</td>
<td>10 (14%)</td>
</tr>
</tbody>
</table>

Note: UBRP = Undergraduate Biology Research Program; COM = College of Medicine.
the UBRP group who practiced medicine. Within the COM, the influence of UG research appears somewhat limited. Several reported that the experience of presenting research influenced their choice of career. However, fewer cited personal interest as an influence.

Comparing career influences of the UBRP group to those from the COM group with undergraduate research experience suggests that some of the positive influence of research was a result of the UBRP experience as a whole (e.g., being part of a community of undergraduate researchers), rather than just the effects of performing research as undergraduates (Figure 3).

Only five COM respondents, including two who expressed a desire for better mentorship or a different career path, made additional comments. In contrast, 68 UBRP respondents provided overwhelmingly positive comments, some of which clarified answers to earlier survey questions. Several comments indicating the importance of the research experience included the following:

My experience with UBRP can’t be matched. I am an absolute supporter of the program and believe it changes lives. In my opinion, there are too few opportunities for children and young adults to be exposed to science and engineering at a time when the world needs more decisions based on sound reason and judgment . . . UBRP helps to create an indispensable population of critical thinkers.

I am still grateful for the opportunity to be part of the UA’s research community . . . it offered me a greater sense of direction and will inform my future educational and vocational pursuits.

The UBRP Program had the most significant impact on my professional life of all my life experiences. It gave me the tools I needed . . . I do not think that a girl who grew up in a blue collar, middle-class family could have achieved my level of accomplishment had it not been for UBRP. Thank you for changing my life.

Conclusions

The higher rate of response to this survey by UBRP participants compared with COM participants suggests that an organized undergraduate research program positively fosters identification with the institution. It also is clear from the UBRP respondents’ comments that engaged learning in the form of undergraduate research is a valued part of students’ education even when they do not continue on to science careers. The impact of mentors was important to both groups, but the COM respondents identified mentors as having an impact on their career development even more often than did the UBRP respondents.

Undergraduate research appears for many students to be a transformative experience. That is, participation in an actual, ongoing research group helps students to clarify their career paths. Part of that clarification involves the discovery of the excitement of science, along with its challenges. They learn

### TABLE 9

**Noteworthy negative effects of undergraduate research experience among survey respondents.**

<table>
<thead>
<tr>
<th>Negative effects of undergraduate research</th>
<th>UBRP</th>
<th>COM</th>
</tr>
</thead>
<tbody>
<tr>
<td>It didn’t give me any great insight into the benefit of pursuing a career in science</td>
<td>5</td>
<td>(6%)</td>
</tr>
<tr>
<td>I wasn’t involved long enough for it to have had any special effect</td>
<td>12</td>
<td>(13%)</td>
</tr>
<tr>
<td>My experience just wasn’t that interesting to me, especially compared to other options</td>
<td>17</td>
<td>(19%)</td>
</tr>
<tr>
<td>My relationship with my mentor was not very encouraging for me</td>
<td>32</td>
<td>(36%)</td>
</tr>
<tr>
<td>After trying my hand at science, I realized I didn’t want to continue</td>
<td>11</td>
<td>(12%)</td>
</tr>
<tr>
<td>I didn’t seem to be “getting it,” so I decided to choose another field</td>
<td>1</td>
<td>(1%)</td>
</tr>
<tr>
<td>I really didn’t think I’d be able to afford the costs of going for a higher degree</td>
<td>6</td>
<td>(7%)</td>
</tr>
<tr>
<td>I didn’t like the lab I was in or the people who were around me</td>
<td>7</td>
<td>(8%)</td>
</tr>
<tr>
<td>Other</td>
<td>29</td>
<td>(33%)</td>
</tr>
<tr>
<td>Number reporting any negative effects</td>
<td>89</td>
<td>(21%)</td>
</tr>
<tr>
<td>Number reporting only negative effects</td>
<td>11</td>
<td>(3%)</td>
</tr>
</tbody>
</table>

*Note: UBRP = Undergraduate Biology Research Program; COM = College of Medicine.*
that science can be “fun,” but they also discover by observing those around them that it can be a career.

Another way that research participation can be transformative is when students realize they have the talent to do research. In some ways, from a broader human standpoint, it is also fortunate that some students are able to discover early that they are, for whatever reasons, not suited for scientific careers, allowing them to pursue other options before they become enmeshed in unsatisfying (for them) educational requirements.

The basic sciences are different from medicine, the latter being far more about applications of science than doing science. Most medical students start their college years as premedical students, knowing that they eventually want entrance into medical school. Probably most of them have had instigation for their career choice by way of personal medical experiences, countless exposures to “medicine” in the media, or by personal acquaintance with a physician. Their interest in undergraduate research tends to be “strictly instrumental,” concerned with the value of that experience in their quest for admission to a medical school.

Basic science students have probably had much less instigation toward the choice of a career in science and have a lot less knowledge about what scientists do (premed students probably do not know what doctors really do!). Hence, their early experiences with research are more informative and are likely to be more influential in determining the directions their careers take. Even if a basic science student’s early experience with research is instrumental (e.g., is a way of earning money), that experience may add to the student’s information about careers and about his or her suitability for a science career. Although the present study was limited to students in the life sciences (broadly defined), we would guess that the same sorts of responses would be obtained from persons in other scientific fields if they were asked about their undergraduate research experiences. Students in chemistry, physics, or hydrology labs would gain knowledge about the nature of scientific work and of the activities of career scientists. They would have experiences that would help them to gauge their own interests and abilities for performing such work.

One unexpected finding from our survey was the extent of the effects of the financial burden of receiving an education in the United States. Although we did not set out to study the impact of educational costs on career choices, the cost, particularly of medical education, cannot be ignored. Students with early career interests in other applied science fields (e.g., clinical psychology, occupational therapy) might have an instrumental

![Figure 2](image-url)
view of early research experience much like that of medical students (i.e., how it might enhance their prospects for entry into doctoral programs leading to practice). Further research along such lines would be of interest and perhaps useful in planning educational curricula and in student guidance.

Note: For all the survey results, see the unpublished report by Yaffe, Bender, and Sechrest (2013) at https://ubrp.arizona.edu/wp-content/uploads/2013/12/Undergraduate_Research_Survey_Results.pdf.

Acknowledgments
This study was funded in part by a grant to the University of Arizona by the Howard Hughes Medical Institute (HHMI 52006942). We also thank Linda Don for her cooperation in contacting the College of Medicine study participants and Matthew Knatz for his assistance with our web-based questionnaire.

References


Kirsten Yaffe is a graduate student in the Department of Biostatistics, Carol Bender (bender@email.arizona.edu) is University Distinguished Outreach Professor, and Lee Sechrest is Professor Emeritus in the Department of Psychology, all at the University of Arizona in Tucson.
New technological developments have minimized training, hardware expense, and distribution problems for the production and use of instructional videos, and any science instructor can now make instructional videos for their classes. We created short “Khan style” videos for the topic of buffers in biochemistry and assigned them as homework, followed by group problem-solving sessions in class. We tested the hypothesis that “inverting the classroom” (a popular terminology for the new format) could replace traditional live lectures, which are typically followed by assigning homework problems (traditionally, mostly solved by students working alone). Using the inverted classroom method, we found that most of our students achieved mastery in solving buffer problems on an exam, without any live lecture (the class averages were ~80%). Our survey data showed that both students and faculty reviewers considered the new format to be an effective teaching tool. To validate our results, we included six survey questions concerning rigor and fairness: positive data were obtained in this regard, with a mean of ~4, on a 5-point scale. We included three separate classes in our study with grade data from 67 students and survey data from 42 students.

For well-trained specialists using expensive hardware, the possibilities for video instruction have been with us for many decades. Very recently, there has arisen a combination of inexpensive hardware (a ~$60.00 drawing tablet), free software, and free universal access to video storage and retrieval sites on the internet. These developments have now put video production into the hands of any interested party with minimal training (Gannod, Burge, & Helmick, 2007). Salman Khan (director of the Khan Academy website) has created hundreds of science instructional videos that share certain characteristics. They are short (~15 minutes or less) and consist of a black background with extensive use of color for formulas and drawings. The teacher’s voice is synchronized to the activity appearing on the computer screen. At no time does the teacher’s face or hands appear in the video. The end result is somewhat mesmerizing (a Kahn video example on the topic of buffers can be found at http://www.youtube.com/watch?v=HzmI7A578ss).

As university biochemistry professors, we were particularly interested in scientific videos that involve the presentation of complex quantitative topics (Eick & King, 2012). Buffers are one example of a problematic quantitative topic, and experience has taught us that this subject area is particularly difficult for our students to master. Other faculty members agree (Orgill & Sutherland, 2008). Our working hypothesis in this study was that video lectures, assigned as homework, could replace live classroom lectures in the presentation of buffer theory and problem solving (He, Swenson, & Lent, 2012; Prober & Health, 2012), particularly when combined with a collaborative learning environment (Case, Stevens, & Cooper, 2007; Johnson & Johnson, 1974). The preceding assertions need some “case study” documentation if they are to be adopted on a wide scale by understandably skeptical, and traditionally cautious, academics (Bell, 2012).

“Inversion of the classroom” has some inherently appealing characteristics. We have noted that students have less and less appetite for individually working difficult problems on homework assignments, and their response to a long “live lecture” is to tune it out (Deslauriers, Schelew, & Wieman, 2011). We have also noted that lecturing has a long, well-documented (and frequently ignored) history of failure as a problem-teaching tool (Powell, 2003). Group problem solving in the classroom means that both the group and the teacher are available to help but has been criticized as too time-consuming, leaving little time for lecture. Our video lecture homework can be viewed from anywhere and
at any time students prefer—hopefully when they feel attentive and focused. The videos can be repeatedly rewound and reviewed. They do not consume class time, creating a window for group problem-solving sessions during class.

Khan videos are less available for upper division science classes, and we became interested in converting a junior-level biochemistry survey class (enrolling mostly biology majors) to the inverted classroom format. In the past, the topic of buffers often seemed to produce test anxiety (and failure) in our student population. Chemistry II buffer lectures (>90%) were the most common type of preparation for our students, and very few students had taken analytical chemistry prior to taking biochemistry.

**Methods**

A number of methods were used. First, over a 3-week period, students watched seven buffer videos by receiving e-mail links to YouTube videos with a specific class day set for completion. Second, on the due date and without further explanation, they arrived in class and were asked to go to the board in groups of four or five and work a buffer problem to a final solution; collaborative problem solving is a very important part of our method (Klionsky, 2001; Paulson, 1999). Three different buffer problems were given to four to five students randomly assigned to six groups so that each problem was worked by two groups. After allowing 15 minutes to work the problems, the students were asked to “shift” to one of the other two problems and either complete the problem or certify a correct solution. Note that after two shifts, every student had seen every problem, and there were two solutions to each of the identical problems on the board for comparison. The process was time-consuming, requiring approximately 45 minutes, but it led to completely correct solutions (with the instructor’s assistance). Students were encouraged to ask for help when the group stopped making progress. Third, the above method was repeated on three other class days. On test day, students were given buffer problems that were similar, but not identical, to the video problems and classroom work. Fourth, the tests were graded by the principal investigator (PI) and scanned into a PDF file such that the student’s names were anonymous. The PDF file was sent for review to the biochemistry faculty listed as co-authors on this article. After watching the six relevant videos and reviewing the graded results, the biochemistry faculty completed a six-question survey. After students performed group work to proof a detailed test key for errors, their graded exams were returned to them. After receiving the grades, students were asked to fill out an anonymous survey, containing the same questions that were asked of faculty reviewers. The survey questions began with “the usefulness of the videos” and continued onto a series of “validation questions” about the rigor and fairness of the grading. The class labels are not chronological; Class 3 preceded the surveyed classes. We added “Class 3” to the “majors” and “grades” Figures 1 and 2 at the request of reviewers. The class labels and chronology are not important; they are essentially three separate experiments using three separate classes.

The survey questions are listed here in an abbreviated form: The answers were given on a Likert-type scale; a positive-response format of 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree.

**FIGURE 1**

Composition of the class by majors. The y-axis shows the percentage of students in each major.
agree, with 5 always the most positive response. The questions were as follows:

1. The videos were useful in preparing students for the test?
2. The test problems were difficult?
3. The test grades reflected mastery?
4. Other faculty would have graded the problems similarly?
5. The grading was consistent?
6. The grading was fair?

The most important question is Question 1, because it alone will validate or refute our hypothesis. Questions 2–6 were intended to establish that there was a reasonable level of difficulty to the problems, and competent and fair grading ensued to make sure that any conclusions drawn from Question 1 would be valid.

We used the following two buffer problems for the Class 1 test, (Class 2 answered very similar problems), and the reader can judge the level of rigor and difficulty posed by the test:

**Buffer Problem 1:** We need 600 ml of phosphate buffer that is 600 millimolar total phosphate species at pH 7.00. We have available phosphoric acid (H₃PO₄) and all three sodium salts, NaH₂PO₄, Na₂HPO₄, Na₃PO₄. Choose the correct A (acid) and B (base) pair in order to make a buffer at pH 7.00. Phosphate pKₐs are: pKₐ₁ = 2.12; pKₐ₂ = 7.21; pKₐ₃ = 12.67. Identify and label A and B by their formulas, and calculate the grams of A and B that must be dissolved in 600 ml of water to make the buffer. (Note: A periodic chart of atomic weights was available.)

**Buffer Problem 2:** We need 300 ml of HEPES buffer that is 300 millimolar total HEPES at pH 7.11. We have available only the crystalline zwitterionic form of HEPES (which is an onium sulfonate), and we have 1.00 M HCl and 1.00 M NaOH solutions available, if needed. The pKₐ of HEPES is 7.56; FW = 238.1. (A) Calculate the grams of HEPES that are needed. (B) Calculate the milliliters of HCl or NaOH that need to be added. (C) Calculate the amount of water that needs to be added to achieve a total volume of 300 ml.

It was thought that the first problem would be somewhat easier. It is a straightforward matter of identifying the two components in the buffer equation, pH = pKₐ + log B/A, recognizing that B and A can be construed as mole ratios (the students practiced this type of problem), then doing an algebraic substitution so that individual moles of A and B can be calculated from the total moles (B + A = total moles buffer). Buffer Problem 2 seemed more difficult because the students had been taught that when only one buffer component is available, they must identify the pH of the solution, so students had to perform a weak acid calculation, obtain pH, then add enough base to convert some A to B. The students were allowed to make an approximation that if pH was more than one pH unit below the pKₐ of the relevant A/B pair, then the initial solution could be considered to be ~100% A.

**Data and results**

Figure 1 shows the detailed composition of the three classes with re-
solving in class during group work (as described in the Methods section). Buffer 1 and Buffer 2 yielded approximately the same grades and almost exactly the same average grade. There was very little difference between the two classes, which were two semesters apart.

Figure 3 shows the response to student and faculty surveys. All questions on the survey were asked with 5 as the most positive response; for example, to a question about “difficulty of the problems,” a 5 would have indicated that the “problems were ‘extremely difficult.’” The questions are listed in the methods section, and students and faculty answered the same six questions. In both classes students and faculty thought the videos were at least “useful” as preparation for the buffer test. Questions 2–6 were essentially validations of the test itself. These questions were intended to establish that the buffer problems were reasonably difficult and that the grading was consistent and fair, so that a successful outcome could be interpreted as a true success and was not due to an overly easy exam, or overly generous grading.

**Discussion**

Not all the students necessarily viewed the videos “on time.” On two separate occasions, one third of the class had not viewed the video by the homework deadline. We were counting on peer pressure to help alleviate this situation and created a rule wherein a group could eject a member that could not help to solve the problem because he or she had not seen the video (no ejections actually occurred). By test day, there were over 30 viewings on every buffer video, in
a class where 27 students took the test; we surmise that at some point most students viewed all the videos. We could observe the total number of viewings on the videos, but we were not able to associate a particular student with a viewing. In our study, no points were awarded for video watching. Compelling upper division university students to do homework and offering points is a controversial topic, but it might be a useful carrot to award a few points for watching.

Both students and faculty agreed that the videos were (at least) “useful” in preparing students for the test, with survey scores always being greater than 3.6 on this question (see Figure 3, Question 1). We confirmed our hypothesis. It is indeed possible for most students to master complex quantitative problems by learning from videos (without any live lecture), followed by group problem work in class (see also the grade averages shown in Figure 2). Readers are encouraged to judge for themselves whether the level of difficulty of the problems (shown in the Methods section) is sufficiently rigorous for a biochemistry course. It was somewhat surprising that the students did not consider the problems to be extremely difficult (Figure 3, Question 2 was scored as neutral for that question); we conclude that our method was successful, making the problems appear to be simple.

Our success is real; validation of the grading by the faculty reviewers and students confirmed that the tests were scored fairly and consistently and that handing out “easy grades” was not the reason for overall student success. The PI (Barreto) saw the faculty survey results only in aggregate, and the faculty respondents knew that anonymity from the PI was part of the design, so objective answers were more likely than not. Note also that there were very few declared chemistry majors (Figure 1), so that an advanced background in buffers cannot explain the overall student success.

Interestingly, both the standard deviation and magnitude of the means were remarkably consistent when comparing student and faculty responses (see Figure 3). We expected more divergence in the standard deviations because some students did not do well, and we thought this might polarize the responses, particularly to validation questions about problem difficulty or fairness. Faculty members have no such potential ‘built-in’ bias because they did not take the test for a grade. Excellent agreement was achieved in two separate classes (Figures 2 and 3), showing that the results are reproducible. The true trial number for grades (Figure 2) is 67 students, and for survey data (Figure 3) it is 42 students; overall compliance was >95% for the survey data.

Note that all of our data were based on a combination of class group problem solving and video viewing. We believe that these activities are synergistic, but we did not test the variables separately (that would raise serious ethical considerations by creating a treatment group that we believe would cripple student success). As an example, we predicted that video viewing alone would lead to catastrophically low problem scores, because students initially made many mistakes at the board (after viewing the videos without practice). Over a 3-week period, with weekly assignments of two to three different videos (a total of seven), each showing different buffers and buffer types and leading to the buffer problem exam in Week 4 of the semester, problem solving did improve with practice.

Finally, consider the student survey responses to Question 1 (Figure 3, Bar 1: “The videos were useful”) where a minimum score of 2.0 would have indicated a student perception of “somewhat useful,” and higher scores would indicate an increasing level of “usefulness.” With the preceding scale in mind, we note that for Question 1 (the most important survey question), we achieved high positive responses from the students: Class 1 = 4.1 and Class 2 = 3.6.

Conclusion

Inverting the classroom by combining video homework and group problem solving in class leads to overall student success, with relatively low attrition for a difficult, quantitative buffer exam. Problem-based laboratory instruction might also benefit from this method (Barreto et al., 2007).

Acknowledgments

We thank Patricia Barreto for her help in editing the buffer videos, graphing figures, and proofing this manuscript. Florida Gulf Coast University IRB approval was obtained for this study, Case 2012-54.

References


Teaching Biochemical Buffer Problems Using Videos and Group Work


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This article describes factors that influence the success of collaborations involving science, technology, engineering, and mathematics (STEM) and Education faculty at research-focused universities who work toward postsecondary STEM education improvement. We provide insight into how interdisciplinary faculty may successfully collaborate given their different disciplinary backgrounds. We explore the importance of education research brokers, individuals credited with helping STEM faculty understand, respond to, and recognize the importance of education research and theory. In addition, we discuss the advantages of appointments of brokers within STEM versus Education Departments. We identify key characteristics that help build and sustain interdisciplinary collaboration and establish the critical roles of brokers at institutions that strive to improve education.

Postsecondary faculty members are expanding a movement to improve science, technology, engineering, and mathematics (STEM) teaching and learning in dynamic and diverse ways (Bouwma-Gearhart, 2012a; Bush et al., 2008; Foster et al., 2010; Hamos et al., 2009; Handelsmann et al., 2004). Faculty efforts to improve postsecondary STEM education are increasingly involving collaborations between faculty from STEM departments, typically based in Colleges of Arts and Sciences (hereafter STEM faculty), and those from Departments and Colleges of Education (hereafter Education faculty), where pedagogy specialists are often located. The effects of collaborations of this sort have been the topic of recent studies (Bouwma-Gearhart, 2012a; Bouwma-Gearhart & Adumat, 2011; Foster et al., 2010; Frank & Shapiro, 2007; Hamos et al., 2009; Westat, 2009).

Yet the research literature concerning these collaborations, in fact concerning faculty work in general, most notably focuses on barriers and typically provides few practical recommendations that work within the current realities of modern universities (Bouwma-Gearhart, 2012b; Bouwma-Gearhart & Adumat, 2011; O’Meara, Terosky, & Neumann, 2008). The many barriers to successful interdisciplinary collaborations between postsecondary educators include the overwhelming power of discipline and department in faculty members’ professional identity (Levine, 1993) and professional advancement (Holley, 2009), as well as philosophical and cultural differences between disciplines that impede collaborations (Braxton & Hargens, 1996; Frank & Shapiro, 2007; Hora, Millar, & Ramaley, 2010).

This article explores factors influencing the success of collaborative endeavors that meaningfully involve STEM and Education faculty at large public land-grant universities in the United States, institutions that produce 50% of STEM baccalaureates (C. Keller, personal communication, November 23, 2011) and are known for disproportionately rewarding faculty for research over teaching and teaching improvement activities (Bess, 1997; Healey, 2005; LaPointe, 2005).

Methodology
Setting and research focus

We studied five research-focused universities to examine how these institutions were successfully implementing undergraduate education reform, more broadly speaking,
and specifically via active and successful interdisciplinary collaborations. Institutions demonstrated the following:

- evidence that postsecondary STEM reform initiatives were well underway and were making progress toward improving undergraduate STEM education, and
- potential to inform our interests regarding the professional realities of postsecondary faculty and instructors from different disciplines.

We sought to identify practices underlying successful reform that involved STEM and Education faculty in order to explore: How do STEM and Education faculty successfully collaborate to improve undergraduate education?

**Research tools and methods**

We created a semistructured interview tool to allow interviewees to recall, reflect on, and synthesize their experiences (Lattuca & Creamer, 2005; Livingston, 1997), specifically toward providing insight into the success and challenges of STEM reform initiatives from a systems perspective (see Appendix). Institutional Review Board approval was secured, and the study was determined exempt.

Institutional liaisons were asked to identify successful initiatives that involved important roles for STEM and Education faculty. (Note: The purpose of this research is not to explore the achievements of the actual initiatives, but the processes and factors underlying their perceived success.) Given their role in STEM reform initiatives on their campuses, institutional liaisons also served as interviewees. Institutional research participants were recruited via personal e-mail with a description of the study and invitation to participate. Thus, the sample was purposeful and one of convenience (Stake, 1995).

Data presented in this article are from interviews with 35 STEM faculty/instructors, chairs, and deans; 12 Education faculty/instructors, chairs, and deans; and 7 project leaders, coordinators/managers, or administrators of STEM reform initiatives. Interviews, ranging from 11 to 17 per campus, were completed during a 2- to 3-day site visit to each institution and lasted 1 to 2.5 hours each, all within a 3-week time frame in 2011. Interviews were conducted with small groups or individuals dependent on research participants’ scheduling requests.

Data analysis was initially inductive pertaining to the research questions across interviewees’ interview transcripts. The first author on this paper used grounded theory techniques, operating with as few a priori assumptions as possible (Glaser & Strauss, 1967; Strauss & Corbin, 1998) and building an inductive codebook via first analysis. All coding was done using NVIVO 9 qualitative analysis software. A constant comparison method was used during all data analysis—the “grounding” of grounded theory—allowing emerging conclusions or theory to inform the subsequent analysis of data (Glaser & Strauss, 1967; Strauss & Corbin, 1998) and uncovering evermore nuanced patterns under the factors appearing most salient (deemed per number of interviewees making a claim and percentage of all text coded under these factors). NVIVO cluster analysis identified relative factor (code) overlap to uncover pertinent relationships between factors across interviews for further qualitative analysis. During data analysis, we noted resonance of data patterns with a preespoused social science theory, brokering. The first author did a final round of analysis with consultation with the second author to confirm resonance of the theory with data.

**Analytical framework**

Brokering typically occurs in contexts of difference, in which the participating parties have differing experiences or bodies of knowledge (Hall & Guéry, 2010). In the field of education, brokering is frequently examined in contexts of students’ migration and focuses on translation and interpretation for individuals who are unfamiliar with a new language and/or circumstances (e.g., Mazak, 2006; Orellana, Reynolds, et al., 2003; Perry, 2009). Regardless of context, brokers provide “recourse to multiple sources of linguistic and cultural knowledge in order to create meaning, negotiate a task, or solve a problem” (Vasquez, Pease-Alvarez, & Shannon, 1994, p. 96). In other words, brokers bridge the knowledge and experience gaps of those struggling with unfamiliar content or practices, often in informal ways during everyday situations or activities that do not necessarily have this bridging as an explicit focus.

Derived from the field of anthropology, the construct of brokering attends to bridging the knowledge between participants from different cultures (Hall & Guéry, 2010), such as the cultures of the STEM disciplines and the field of education. Brokering, thus, is more complex than the concept of “translation” would suggest, as brokers may be providing or interpreting knowledge related to culture (e.g., Gentemann & Whitehead, 1983; Trickett, Sorani, & Birman, 2010) or specific genres (Perry, 2009), both of which would include differences between STEM (natural science) and education (social science) research. Hall and Guéry (2010) noted that brokers may perform in complex ways, and (unlike professional translators who attempt to interpret verbatim and
without adding influence to a situation) have “both an overview and influence in a mediation activity [and operate with] more independence in initiating or promoting negotiation” (p. 32).

Early work in brokering that primarily focused on translation assumed that those who receive brokering assistance lack knowledge and that brokers solely possess and supply the necessary expertise (e.g., Chu, 1998; Gentemann & Whitehead, 1983). More recent scholarship has challenged this unilinear expertise model of brokering, demonstrating that both (or all) participants bring some sort of expertise to the brokering event and that the process involves the mutually beneficial negotiation of different bodies of knowledge, including learning opportunities for both brokers and those who seek brokering (Dorner, Orellana, & Jiménez, 2008; Mazak, 2006; Orellana, Reynolds, et al., 2003).

Our research moves beyond consideration of individual actors and their actions in the process of brokering and considers how these individuals and processes might inform organizational change. We build on related scholarship that emphasizes network structures, and related social capital, needed for change and innovation in organizations (see Burt, 2005; Fligstein, 2005; Kondra & Hinings, 1988; Lin, 2001; Marsden, 1982; Powell & Colyvas, 2007; Shah & Waldstrom, 2009; Tatarynowicz & Lomi, 2009). Thus, our research benefits from and elaborates on both micro (individual) and macro (organizational) perspectives, situating brokering in light of attempted and secured organizational change.

Findings

We documented main characteristics/strategies associated with successful postsecondary STEM education improvement initiatives, all of which attend to the importance and key characteristics of brokering toward facilitating productive collaboration between STEM and Education faculty.

Successful collaborations recognize the value of others’ expertise and that those involved in postsecondary improvement activities are at different points in their appreciation of interdisciplinary knowledge and work.

STEM and Education interviewees described their own evolution in perception regarding research and expertise from those working in disciplines and departments other than their own. This evolution process often began with a mutual suspicion of others’ discipline, noted most on the part of STEM faculty concerning Education faculty and research. Over time, enhanced interpersonal trust and familiarity with others’ disciplinary research allowed reform participants to evolve to a second stage of, as one interviewee described it, “simple awareness and respect for other types of knowledge.” Given enough time and collaborative work, a third stage afforded perception that others’ research was of value regarding pedagogical problems of pressing concern. Comments alluding to this state included “[we] STEM faculty valued what School of Education people do and that it has impact” and “[regarding] people from the School of Education, I realized they had something important to say.” The fourth and final stage was acknowledgement of other discipline’s bodies of knowledge as expertise and their researchers as experts. One participant remarked on the prevalence of ego in academia and summarized the importance of this stage to the success of interdisciplinary collaborations: “[When in] a collaboration with someone who knows something about something more than you, you are taking them serious professionally.” This evolution was facilitated by key individuals who understood associated realities and had the expertise necessary to broker events critical to this evolution.

These findings are aligned with Hall & Guéry (2010), who found brokers in other contexts were recognized as having the expertise to foster mutually beneficial, goal-oriented collaborations (Hall & Guéry, 2010). The brokering events described by our participants, some of whom were brokers themselves, were more complex than a more simple concept of “translation” would suggest. The brokers who helped faculty in their evolution provided or interpreted knowledge related to the different cultures represented in STEM and education research. In addition, brokering often included multiple events, often over significant periods of time (semesters or years).

The end result of this evolution was indicative of the most successful interdisciplinary collaborations, that being each party’s recognition of the other’s expertise and associated felt respect for the other’s contribution to the improvement endeavor. This evolution was most experienced by STEM faculty with respect to the field of education and its researchers. However, the valuing of STEM participants’ expertise by education experts was also deemed necessary to achieve successful STEM education improvement (as discussed next).

Successful collaborations occur when participants recognize that faculty and instructors are likely to be on numerous paths, and at different points in their trajectories, with respect to pedagogical (improvement) issues.

Many STEM faculty members admitted feeling some insecurity with
respect to their practices concerning teaching and learning, especially regarding their earliest experiences teaching. This was not surprising, given the typical scant attention paid to developing preservice STEM faculty as educators. One interviewee offered, “We don’t really learn to teach except by standing in front of a class, but there is actually a lot of literature about that. I learned about the taxonomy of learning objectives and it was an eye-opener for me. And this is a simple thing that changed my practice but I was never exposed to this.” The importance of opportunities for STEM faculty to revise teaching practice via building understanding of education research and theory has been highlighted by education and STEM discipline-based researchers alike (Alberts, 2009; Anderson et al., 2011; Bouwma-Gearhart, 2012a, 2012b; Handelsman et al., 2004; Mathieu, Pfund, & Gillian-Daniel, 2009).

Many of our STEM interviewees were engaged in real-time, data-driven projects informed by education theory and research. Although many had been engaged with education research and theory for some time through their involvement in education improvement projects, they typically desired more exposure. A midcareer STEM faculty member lamented: “I am embarrassed to say I still didn’t know how rich that literature was.” Interviewees found themselves desiring, at various points in their career and education improvement initiative work, more activity to help move them to “the next step.” For some, this step translated into moving from an exploration of education research into “actually quantifying what a teaching effect is.”

The brokering events our interviewees discussed concerned real-world, goal-oriented activities (Hall & Guéry, 2010; Vasquez, Pease-Alvarez & Shannon, 1994). Movement along pedagogical improvement trajectories required significant time and assistance; even those most familiar with education research and theory lamented the difficulty they initially had in deciphering this relatively new literacy and “helping to shift the disciplinary language and show there can be scholarship behind teaching.” Brokers challenged STEM faculty to engage with education research findings and practices incrementally, by “starting simple, so that they don’t feel bombarded, changing just one thing in their course as we want them to actually do it well and continue doing it.”

Successful collaborations recognize the critical and nuanced roles of brokers of education research and theory in the collaboration.

STEM faculty and instructors stated that a primary way to support their engagement with education research and theory was via connection with those more knowledgeable about it as it applies to their discipline. Additionally, STEM faculty and instructors’ social connections with those serving as brokers of education research and theory motivated their continued commitment to education improvement work. STEM faculty linked these impacts to the following characteristics they commended brokers for:

• translating education research and theory into forms understandable and usable by STEM faculty and instructors;
• having a strong ability to speak and unite the languages of both STEM and Education, with respect to disciplinary ways of knowing and processes;
• conveying enthusiasm and means for improving STEM education through rigorous education research;
• treating all participants as intellectual peers and not inferior with respect to their pedagogical knowledge and practices;
• meeting STEM faculty and instructors “where they are” on their trajectory with respect to knowing and understanding pedagogical research and how this may translate to practice.

These findings reflect aspects of brokering research and theory that show the strong mediational and promotional roles brokers may take, as well as the complex functions they perform (e.g., Hall & Guéry, 2010), such as treating all participants as knowledgeable and important, understanding and facilitating different developmental trajectories, all the while speaking and operating across the languages and cultures of different disciplines and fields. One STEM interviewee stated, “There are many different routes to developing expertise in something like biology education research or for teaching and learning in biology. One way is bringing people with different expertise to partner, [specifically] bringing in those of dual or hybrid identity spanning STEM and Education.”

Successful brokers were housed in either STEM or Education departments. Each lent different strengths to collaborative endeavors. Individuals from “both sides of campus” fulfilled key roles of brokering and helped others to access and actually understand the new literacy of education research and theory, albeit via nuanced means. Those with disciplinary appointments in STEM departments, notably holding STEM doctorates, were often recognized as “having proved themselves in the STEM world and now in the world of education.” These people fulfilled others’ calls for distinguished STEM researchers to highlight the false incompatibility
of STEM research and education reform activity (Anderson et al., 2011; Handelsman et al., 2004). Yet STEM faculty brokers were not just the Nobel Laureates and National Academy members among the group. In fact some were not even in a typical tenure-track line. Regardless of exact position, their brokering abilities to make education research and theory accessible and understandable allowed them to serve as very powerful change agents, exerting what some STEM faculty deemed “peer pressure” in pushing their STEM colleagues and departments toward consideration of STEM education problems. Moving beyond brokering concerning knowledge and experience with education research and theory, brokering of social capital (Burt, 2005; Fligstein, 1997; Lin, 2001) was also made obvious via our interviewees’ talk with respect to these STEM discipline-situated brokers. “If given space to care [by these individuals] you are held more responsible.” Via these individuals, autonomy was granted (sometimes required) to engage with education research and theory and associated improvement endeavors.

Somewhat surprising, however, was the identification of another group of brokers who were deemed just as powerful. These individuals had their academic appointments in Education Departments, held doctorates in Education, and often held bachelor’s or master’s degrees in a STEM discipline. These individuals were most credited with increasing STEM individuals’ and improvement teams’ collective competencies as well as perceived importance regarding education research and theory. STEM faculty and instructors also credited, although less so, budding pedagogy experts like learning assistants and postdoctoral teaching fellows who helped improve curriculum.

Successful brokers frame education research and theory in relation to typical STEM research and teaching practices and acknowledged expertise.

Education research and theory experts acted as brokers by making a somewhat foreign body of knowledge accessible to STEM faculty and instructors seeking support. Key to this was framing education research and theory in relation to typical STEM research and teaching practices. Most important, brokers recognized STEM research and teaching practices as important expertise that could inform pedagogical reform. The most gifted brokers moved beyond simply recognizing that all participants bring some sort of expertise to the brokering event (Dorner et al., 2008; Orellana, Reynolds et al., 2003; Mazak, 2006) and actively scaffolded on this disciplinary expertise.

Interdisciplinary, broker-rich faculty groups help catalyze institutional change.

During the interviews, many mentioned the importance of interdisciplinary faculty groups to foster collaboration and action. Teams involving brokers from both STEM and Education were particularly strong in both granting autonomy to engage with education research and theory and in increasing the team’s related collective competencies.

In addition, teams with this composition were reported to have the collective power to foster, and potentially institutionalize, widespread undergraduate education improvement work based on research-confirmed means. Interviewees spoke of institutional change resulting from “creating a population who actually knows what good teaching looks like.” Often, brokers’ roles were complex (Hall & Guéry, 2010), as they were also credited with initially getting an initiative off of the ground by encouraging others to join and truly engage in the effort’s work. As was said of one broker, “He is the Pied Piper in the department.” These individuals were recognized as shouldering a significant amount of work with respect to the continuation of some reform initiatives. Similar to other findings in education brokering research, this work was not necessarily seen as a burden among interviewees (e.g., Perry, 2014; Orellana, Dorner, & Pulido, 2003), even as they assumed the extra challenging work of lessening the “separation between A&S and Education . . . before this person, there was not much interest to really bridge the gap with some unapproachable on both sides of the fence.” Still, these individuals were described as having endless energy and as seemingly capable of handling the various aspects of the reform initiatives that they juggled. And some, notably staff, had job descriptions explicit to the management of an initiative or multiple initiatives and were recognized as doing their somewhat prescribed job amazingly well, especially in terms of recruiting others to the initiative.

Interviewees noted that brokers were very powerful in their ability to inspire more widespread reform, eventually comprising a “choir” of sorts, formed within departments, colleges, and at universities. Yet beyond just “preaching to the choir” made up of others just like them, they wielded the power to expand the choir through their recruiting efforts. From there, these individuals, known among interviewees for fostering trust and respect, were key in “making sure the choir is still singing the same tune. Then it resonates with structure around you that starts vibrating. We are shifting from being a voluntary effort of lone heroes to one that is institutionally rewarded for it with the university saying this is what you are here for.” As emphasized in related scholarship, brokers
capitalized and created network structures and related social capital needed for change in their organizations (Burt, 2005; Fligstein, 1997; Kondra & Hinings, 1988; Lin, 2001; Marsden, 1982; Powell & Colyvas, 2007; Shah & Waldstrom, 2009; Tataryowicz & Lomi, 2009).

Interviews also revealed that institutional leaders can play an important role in education reform through provision of resources and creation of supportive environments. “It’s nice to have a chair next to you saying ‘we really want you to try these changes in your courses.’” Yet from the perspective of interviewees, change was only minimally attributed to top-down mandates of provosts, deans, or department chairs. Most salient to even administrators was faculty and instructor action, driven by interdisciplinary groups that helped to ensure collaborative understanding across disciplinary paradigms. “My role as chair is primarily a facilitator, sometimes identifier of potential innovations; more often innovations percolate up from people and my primary role tends to be responding to that with ‘that seems like a good idea’ so I can make that happen.”

Conclusion and recommendations

There are many voices calling for postsecondary STEM education improvement, and the importance of involving both key STEM departmental members and higher level administrators is well established (see Anderson et al., 2011; Handelsman et al., 2004). We contribute to this discourse through articulation of strategies that strengthen collaboration across disciplines to improve postsecondary education. Critical to this is the identification and empowerment of individuals who can act as brokers between seemingly disparate disciplines in terms of research, theory, and practices and norms, and who can do so in ways that support and capitalize on the diverse experiences and expertise other individuals bring to the table.

We recommend that organizations of postsecondary education promote the development of highly skilled brokers and secure their much-needed participation in efforts to improve STEM education. Local brokers of education research and theory who already have these skills should be identified and supported in their translational roles via buy-outs of their time and/or additional external motivations to secure their participation. Institutions that do not have skilled brokers should consider hiring those with these skills or putting concerted effort behind growing their own. Readers interested in what brokers should have in their training background may wish to see Bouwma-Gearhart (2012a) for a more lengthy discussion, Bush et al. (2008) for a discussion of fostering and retaining STEM department-based faculty with education specialties, and Mathieu et al. (2009) for a description of a center-based model for fostering education research and theory experts.

In addition, professional development opportunities for STEM faculty and instructors should explicitly allow for interdisciplinary connections between veteran brokers of education research and theory from STEM Departments (the grantors of autonomy) and Education Departments (the growers of competency) and academics who are newer to education reform.

Acknowledgments

This work was supported by a National Science Foundation/RETA grant, “Promoting Institutional Change to Strengthen Science Teacher Preparation” (#0839150), to the Association of Public and Land-Grant Universities (APLU).

References

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**Appendix**

**Interview Protocol**

INTRODUCTION: As you know [either 1. through your direct involvement in our SMTI learning community or 2. via contact with our learning community representative], our SMTI working group is studying the question: How can undergraduate STEM education be improved for all students while attending to the realities faced by STEM faculty and instructors? In hopes of answering this, we are asking you to share your experiences of initiatives/projects related to postsecondary STEM education reform so that we may begin to uncover what works with respect to best involving STEM faculty and instructors in a positive and realistic way towards postsecondary STEM education improvement. For purposes of this interview, we define STEM faculty and instructors as individuals with advanced training in the STEM disciplines, usually with a terminal degree in the STEM disciplines, usually a doctorate.

[This set of questions can be asked multiple times to elicit interviewee's responses with respect to multiple initiatives.]

1. Please tell me about the nature of your position at your university.

2. Please tell me about an initiative related to STEM education reform with which you are personally familiar (institutional, departmental, individual . . . any level) [if not addressed, check for information regarding any secondary teacher training initiatives]

3. What led those involved in the initiative to undertake this initiative? [to check rationale]. [if needed] What problem(s)/challenges is the initiative intended to address?

4. What factors have been key to the success of this initiative?

5. What have been the major challenge(s) to carrying through with this initiative?

6. What evidence do you have for effectiveness of the initiative . . . or what plans do you have for assessing effectiveness?

7. [if necessary] What do you think are the major challenge(s) to improving STEM education at your institution?

8. [if not already emerged through answers above] Please tell me about the role of STEM Faculty in the initiative(s) you’ve described.

9. [if not already emerged through answers above] Please tell me about the role of STEM Faculty in supporting quality secondary-level teacher education . . . from recruitment to professional development and everything in between.

10. How can undergraduate STEM education be improved for all students while attending to the realities faced by STEM faculty?

   a. [if not already discussed] What characteristics of your institution affect the involvement of STEM faculty in undergraduate STEM education?

   b. [if not already discussed] What characteristics regarding the nature of STEM faculty members’ positions affect the involvement of STEM faculty in undergraduate STEM education?

11. How would you summarize the environment/culture at your institution relative to undergraduate STEM education reform?

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A Comparative Study of Instructor-and Student-Led Learning in a Large Nonmajors Biology Course: Student Performance and Perceptions

By Melody J. Bernot and Jennifer Metzler

Traditional lectures have come under increasing criticism as research indicates lectures may be less effective in achieving learning outcomes than other teaching methods. Student engagement and success can potentially be improved by changing traditional lectures to instructional methods using active learning techniques. Active learning refers to instructional techniques that engage students in the learning process and defer the instructional role from the teacher to the student. In spring 2012, we taught two sections of an introductory nonmajors biology course using a traditional lecture approach in one section and an active learning student-led approach in the other section to assess student learning and course perceptions. Performance on content assessments (homework, exams) and course final grades did not differ between students in the “student-led” section relative to students in the “instructor-led” section. However, students in the student-led section completed more optional assignments potentially because of increased autonomous learning. Student perceptions of the student-led technique were consistently negative. Thus, incorporating active learning techniques is likely most effective when independent learning is augmented with instructor-directed classroom activities.

Over the last decade, higher education has been charged with improving the performance and retention of students, particularly in introductory science courses (Haak, HilleRisLambers, Pitre, & Freeman, 2001). In addition, students are demanding more engaging learning opportunities (O’Brien & Hart, 1999; Page & Mukherjee, 2000) where they not only obtain knowledge, but also apply that knowledge and develop skills to succeed in an unpredictable future (Auster & Wylie, 2006). Student engagement and success can potentially be improved by changing traditional introductory lecture courses to use more active learning. Thus, instructors in higher education are increasingly using active learning strategies (Meyers & Jones 1993) to take advantage of its benefits in preparing students (Haywood, 1989; Hegarty, 1985; Russell & Rothschild, 1991).

The traditional approach to higher education across academic levels and disciplines is the lecture (King, 1993), where instructors describe and review introductory science courses (Haak, HilleRisLambers, Pitre, & Freeman, 2001). In addition, students are demanding more engaging learning opportunities (O’Brien & Hart, 1999; Page & Mukherjee, 2000) where they not only obtain knowledge, but also apply that knowledge and develop skills to succeed in an unpredictable future (Auster & Wylie, 2006). Student engagement and success can potentially be improved by changing traditional introductory lecture courses to use more active learning. Thus, instructors in higher education are increasingly using active learning strategies (Meyers & Jones 1993) to take advantage of its benefits in preparing students (Haywood, 1989; Hegarty, 1985; Russell & Rothschild, 1991).

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Active learning refers to instructional techniques that engage students in the learning process and defer the instructional role from the teacher to the student (Prince, 2004). Active learning techniques include (though are not limited to) problem solving, questioning, brainstorming, audience response, case studies, debates, simulations, and student presentations (Steinert & Snell, 1999). Through active learning, students become engaged because they are thinking about what they are doing (Bonwell & Eison, 1991) rather than...
traditional lectures are ineffective in coupled with research suggesting techniques can have on students, Compelled by research suggesting and lecture skills among instructors. (DiLeonardi, 2007), likely because of lecture relative to other methods consensus about the effectiveness exceeds (Smith & Cardaciotto, 2011). However, research offers no strong conceptual learning needed to succeed in other environments (Sivan, Leung, Woon, & Kember, 2000). Further, autonomous learning is a fundamental skill desired by employers of college graduates (Sternberg, 2013).

Active learning techniques can be difficult to integrate into introductory courses that are typically populated by >100 students in many colleges and universities. However, introductory courses are likely critical points in education where outcomes achieved with active learning techniques (e.g., learning skills) are most needed to ensure future student success. Particularly in large lecture introductory courses for nonmajors, the goal should not be simple delivery of content and development of discipline specific skills, but rather development of critical thought and autonomous learning skills that will serve students throughout their education and into their careers. Despite large lecture classes being the typical format for introductory courses, many college freshman likely do not have established memory structures on which to build course material (Cherney, 2008). This, combined with typical exam formats that reinforce memorization, can thwart conceptual learning needed to succeed (Smith & Cardaciotto, 2011). However, research offers no strong consensus about the effectiveness of lecture relative to other methods (DiLeonardi, 2007), likely because of the variation in course structures and lecture skills among instructors. Compelled by research suggesting the potential impact active learning techniques can have on students, coupled with research suggesting traditional lectures are ineffective in large courses, we conducted a direct comparative study on the effect of “instructor-led” and “student-led” learning in a large nonmajors introductory biology course to assess student learning and perceptions of learning techniques.

Course structure
We assessed the influence of lecture in a five-credit, nonmajors biology course at Ball State University, BIO 113 Microbiology for the Clinical Health Sciences, in spring 2012. The course is designed to provide health science majors with the fundamental concepts and measures of practice in microbiology. The course is primarily taken by students in the nursing program during their first year of study and consists largely of traditional undergraduates 18–19 years old. Enrollment in spring semesters has been increasing, with 280 students enrolled in spring 2012. These students were divided into two lecture sections with one section (Section 1, subsequently called student-led, taught by Author 1) enrolling 160 students and meeting for 50 minutes three times each week and the other section (Section 2, subsequently called instructor-led taught by Author 2) having 120 students and meeting for 75 minutes two times each week over the 15-week semester. The course also incorporated a separate laboratory component (~24 students in each laboratory section), and laboratory instructors differed among sections though activities and assessments were comparable across sections. Laboratory performance was not assessed in this study.

The syllabus and assessment tools (i.e., homework, exams) between the two sections were standardized for consistency. Specifically, students from each section completed the same homework assignments; exams, though not identical between sections, were compared and reviewed for consistency in content and rigor. Point-bearing activities associated with the course were also consistent between the course sections. Student grades were determined on the basis of performance associated with four computer-based, multiple-choice lecture exams (100 points each consisting of 50 multiple-choice questions); pre- and post-assessments of knowledge (5 points each consisting of 10 multiple-choice questions); classroom participation via student-response systems (clickers; 50 points over the semester); and weekly online homework (12 points each week totaling 180 points over the semester, consisting of multiple-choice questions, concept mapping, fill-in-the blank responses, and video-based quizzes). Students in both sections also had the opportunity to earn weekly extra credit associated with online activities (possible 42 cumulative points consisting of content similar to weekly homework). Classroom participation points were awarded on the basis of both a response and whether the response was correct. Students were not awarded performance-based scores on the pre- and posttest assessments; rather, students received full credit for completion regardless of score. In conjunction with the online textbook materials, all students had access to study tools including practice quizzes, MP3 recordings, vocabulary cards, concept outlines, and other activities to provide additional materials and support diverse learning styles.

The primary difference between the two course sections was use of lecture during class time. In the student-led section, students did not receive a lecture from the instructor during class time at any point during the semester. Students in the instructor-led section did receive lectures from the instructor during class time. In the student-led section, students were allotted ~40 minutes
to review and discuss among peers the specific learning objectives for a given day (provided prior to class time) and ask the instructor questions regarding the material, followed by ~10 minutes of questions (multiple choice, fill in the blank) administered through the student-response system (iclicker) to allow for students to see responses of all students and receive immediate feedback. Learning objectives ranged from differentiating vocabulary to completing short-answer questions and diagramming processes. In the instructor-led section, students were given a traditional lecture during class time with questions asked intermittently throughout the lecture using the student-response system to assess comprehension.

At the end of the semester, all students were asked to complete an anonymous, online evaluation of the course and the instructor. The online evaluations consisted of 12 statements that students ranked on a 5-point scale (1 point indicating strong disagreement; 5 points indicating strong agreement). The online evaluation also allowed for students to provide anonymous written comments. In the instructor-led section, 63 out of 109 students (58% response rate) completed the evaluation. In the student-led section, 108 out of 162 students (67% response rate) completed the evaluation. Ball State University offers an incentive to students for completing timely course evaluations as access to final grades earlier than students not completing course evaluations. No other incentives were provided for completing the anonymous course evaluation.

The primary goal of eliminating lecture from the course was to better prepare students to be autonomous learners. Content goals were equal between sections with the expectation that students from both sections would build a foundation of microbiology per learning objectives. We evaluated content goals with regular exams and compared results among sections using analysis of variance (ANOVA). Student perceptions were also compared quantitatively using course evaluations and qualitatively with anonymous student feedback.

Results

Student performance

Students in the student-led and those in the instructor-led sections scored comparably on all course exams ($p > .1$; Figure 1), with a mean exam score of 71.1% across sections and exams, consistent with previous semesters for this course (data not shown). Mean exam scores between the sections differed $\leq 2\%$ across all exams. In the student-led section, exam scores ranged from 14% to 100% and in the instructor-led section exam scores ranged from 28% to 100%. Across exams, average
duration for exam completion (50 multiple-choice questions) in the student-led section was 18 minutes, whereas students in the instructor-led section completed exams in an average of 21 minutes (data not shown).

There was no significant difference between the student-led and instructor-led sections in mean scores associated with in-class, student-response questions or homework questions ($p > .1$; Figure 1). Mean in-class student-response score was 89.9% in the student-led section and 84.5% in the instructor-led section. Mean homework score across sections was 79.2%. However, homework scores in the instructor-led section ranged from 44.6% to 97.8%, whereas scores in the student-led section ranged from 69.3% to 91.6%. There was a significant difference in extra credit scores between sections ($p < .01$; 95% CI = 36.2 – 47.7%; Figure 1). Specifically, students in the student-led section had a mean extra credit assignment score of 71.4 ± 0.9%, which was 40.3% higher than the mean score in the instructor-led section (31.1 ± 5.3%). The lower score on extra-credit assignments in the instructor-led section was primarily due to more students opting not to complete the extra-credit assignments.

Consistent with comparable scores on course assessments, overall course grades were not significantly different between the two sections (mean = 79.5%; $p > .1$; Figure 2). Overall course grades were higher for both sections than in previous semesters (data not shown) because more of the course content was associated with online homework than in previous semesters. Pretest scores were not significantly different between sections (mean = 50.3%), suggesting comparable background knowledge of students between the sections. However, posttest scores were 11% higher than pretest scores in the student-led section but not in the instructor-led section ($p = .023$; 95% CI = 9.7 – 12.5%; Figure 2). Specifically, in the student-led section, mean student scores on the assessment improved from 49.5 ± 13.9% on the pretest to 74.2 ± 15.7% on the posttest. In the instructor-led section, mean student scores on the assessment improved from 51 ± 15.1% on the pretest to 63 ± 14.5% on the posttest.

**Student perception**

Overall, the “student-led” technique was not well received by an overwhelming majority of students as determined by student comments over the semester and anonymous course evaluations. Of the 108 course evaluations completed in the student-led section, only three comments were positive with respect to the active learning technique. Some
representative student comments provided from the student-led evaluations include the following:

- She doesn’t teach. Going to class is pointless.
- I do not prefer this style of teaching, or rather lack thereof.
- I’m not paying all this money to teach myself.

Though limited, the positive feedback regarding the student-led technique warrants further note as students that became invested did indicate the technique facilitated its primary goal. This aspect is best illustrated via a student e-mail to Bernot (student-led section instructor) at the end of the semester:

I know you’ve received pushback since the very beginning of the semester with the no lecture tactic that you have been trying out. I was extremely wary at the beginning, just because

I am not used to someone not lecturing to me. That’s how I have learned for 12+ years and for you to say that you weren’t going to really terrified me at the beginning. I can say now, at the end of the semester, that I am a huge supporter of what you have done. Another student and I were discussing how you tackled this class, and we both agree that the skills we have forced ourselves to utilize in your class have transferred to other classes as well. For [my other class] for instance, my professor just reads his PowerPoints for the entire lecture. At the beginning of the semester, I was relying solely on what he talked about in class, and it showed in my 60–70% test scores. I then, after seeing what I was capable of achieving in micro[biology], decided to try and use those same tactics to study. I feel the biggest thing I am taking away from this class is student responsibility. A lot of students who I have talked to don’t enjoy your teaching style because they expect you to just put the information in front of them, and the students don’t have to go search for it. As far as the pushback goes, I really don’t know how to remedy that. Part of me feels like it is impossible, because a lot of students are coming out of high school only knowing lecture as a form of learning. This type of class is essential though, and I really do hope you continue this in the next year.

As highlighted in the above message, students in the student-led section consistently referred to the teaching technique as no lecture as opposed to active learning, which was the term used by the instructor. Thus, even student language about the course suggested their perception was a teaching method lacking a component rather than a teaching method using an alternative technique. In the instructor-led section, student comments were primarily positive. Some representative written comments from the instructor-led section evaluations include the following:

- My instructor is very enthusiastic about what she talks about and makes people want to learn.
- Great at explaining things and encourages excitement for biology.
- Lectures are very interesting.

Quantitatively, course evaluation rankings reflected written student comments. The instructor-led section had 1.1 point higher overall course evaluation scores (mean = 4.31 ± 0.8 out of 5 possible points) relative to the student-led section (mean = 3.20 ± 1.2; \( p = .046 \); 95% CI = 0.31 – 1.9%; Figure 3). In previous
Instructor- and Student-Led Learning in a Large Nonmajors Biology Course

Semesters where traditional lectures were used, the student-led section instructor (Author 1) received an average evaluation score of 4.23 (N = 8 semesters) in this course comparable to the evaluation score of the instructor-led section during this assessment. Interestingly, course evaluations were lower in the student-led section for both instructor assessments and course assessments (Table 1). Evaluation statements regarding the course objectives, assignments, and grading system (which were identical for both sections) were ranked ~1 point lower in the student-led section. Evaluation statements regarding instructor activities were ranked ~2 points lower in the student-led section relative to the instructor-led section.

Instructor perception

Administering the student-led technique in a large lecture class was accompanied by both significant difficulties as well as significant achievements over the course of the semester. Difficulties were primarily associated with time restraints and student and instructor morale. In the student-led section, maintaining or improving student and instructor morale required a significant amount of energy and time not anticipated. Given the continuous student (and sometimes parent) complaints regarding the student-led technique, a great deal of time was devoted to encouraging student investment in the technique. This was done by showing students in the student-led section that they were achieving comparable grades to those of students in the instructor-led section and by highlighting previous studies on the effectiveness of active learning on developing learning skills and aiding future success.

Additionally, after having taught this course for several years, teaching with the new student-led technique required a significant amount of

<table>
<thead>
<tr>
<th>Evaluation statement</th>
<th>Mean student-led score</th>
<th>Mean instructor-led score</th>
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</thead>
<tbody>
<tr>
<td>My instructor explains the course objectives clearly</td>
<td>2.94</td>
<td>4.37</td>
</tr>
<tr>
<td>My instructor explains course content clearly</td>
<td>2.21</td>
<td>4.33</td>
</tr>
<tr>
<td>My instructor uses effective examples and illustrations</td>
<td>2.13</td>
<td>4.40</td>
</tr>
<tr>
<td>My instructor is respectful when I have a question or comment</td>
<td>3.85</td>
<td>4.46</td>
</tr>
<tr>
<td>My instructor provides feedback that helps me improve my performance in class</td>
<td>2.80</td>
<td>4.13</td>
</tr>
<tr>
<td>My instructor is available for consultation</td>
<td>4.15</td>
<td>4.40</td>
</tr>
<tr>
<td>This course has clear objectives</td>
<td>3.55</td>
<td>4.24</td>
</tr>
<tr>
<td>This course is effective in meeting objectives</td>
<td>3.08</td>
<td>4.18</td>
</tr>
<tr>
<td>This course has assignments related to the objectives of the course</td>
<td>3.76</td>
<td>4.22</td>
</tr>
<tr>
<td>This course has a clear grading system</td>
<td>3.42</td>
<td>4.34</td>
</tr>
<tr>
<td>This course broadens my perspective and/or knowledge</td>
<td>3.26</td>
<td>4.37</td>
</tr>
<tr>
<td>Mean evaluation score</td>
<td>3.20 (1.2)</td>
<td>4.31 (0.8)</td>
</tr>
</tbody>
</table>

Note: One hundred eight students completed a course evaluation in the “active” section and 63 students completed a course evaluation in the “lecture” section. Evaluations rank comments on a scale of 1 to 5 with 1 indicating the student strongly disagrees with a statement and 5 indicating a student strongly agrees with a statement. Standard deviation for mean evaluation score is provided in parentheses.
time to prepare class activities and develop in-class student response assessments. It would have been easier and less time-consuming to give lectures that were, for the most part, already prepared. Despite the fact that no formal lectures were being prepared for the student-led section, a great deal of preparation was required to implement the technique. For example, by not giving lectures, intimate knowledge of the material students were using to work through course objectives was necessary, requiring a thorough rereading of the textbook and web-based materials. Additionally, during and after class time, students were asking questions about the material in ways not previously encountered that required different approaches to assist them in working through material. This latter aspect is related to the achievements associated with the technique as students were no longer primarily asking questions for repetition of material or exam content; rather, questions were more content based than in previous semesters.

An additional perceived achievement was the better use of class time by students. Though there were certainly exceptions, the number of students actively working through their textbook and notes during class time was perceptibly higher than in previous semesters when class time was predominantly composed of instructor lecturing. The most significant achievement was undoubtedly that students in the student-led section achieved comparable grades to those of students in the instructor-led section. Further, the primary goal in implementing the student-led technique, to enhance autonomous learning, though difficult to assess, might have been achieved as evidenced by the higher participation in the optional extra credit activities by students in the student-led section relative to students in the instructor-led section.

**Limitations and lessons learned**

One primary limitation of this study is that different instructors taught the two course sections. Thus, instructor variation may have influenced results in addition to the active learning and lecture techniques. However, both instructors have taught this course for several years and have regularly collaborated in teaching approaches. In addition, previous teaching evaluations where active learning was not used by either instructor were comparable between the student-led section instructor (Author 1) and the instructor-led section instructor (Author 2), suggesting that differences observed between course sections are likely predominantly attributable to the instructional technique used. An additional limitation is the lack of a mechanism identified for higher extra credit participation by students in the student-led section. These students may have developed better autonomous learning skills, although they may also have been compelled to complete extra credit for other reasons. For example, students may have perceived their learning during lecture as insufficient for success. Last, the two sections compared in this study were populated by different students in different time slots. Such variation may have also influenced results, though the two sections had comparable “pretest” scores, indicating that any bias among student groups was likely minimal.

After fully committing to the student-led instructional strategy in a large-lecture introductory course for nonmajors over a full semester, we would not recommend executing the strategy without revision in future courses for several reasons. Eliminating lecture entirely from the course did not influence overall student performance. However, it likely also did not exemplify an ideal teaching technique. First, it would have been significantly easier, less stressful, and less time-consuming for the instructor and less stressful for students to have some lecture during class. Second, until student-centered learning is a primary mode of education, student morale will be low and apprehension high about using such techniques, which may inhibit student learning potential. Such apprehension could be alleviated in large-lecture courses if student-centered learning is supported by additional instructors (e.g., teaching assistants) during class time for better management of student needs and enhanced feedback on activities. Third, by not lecturing, the instructor minimized the potential for transferring enthusiasm for a subject to students, which is critical to the educational experience. However, given the success of the students and the potential for significant future impact on student learning, some of the strategies associated with the student-led technique will continue to be used. Specifically, in future semesters we will continue to include student-led learning activities though we will retain time for traditional lecture (~30–50% course). Previous studies have noted that lectures should not be abandoned in efforts to maximize active learning (Nasmith & Steiner, 2001), but rather be complemented by student-centered educational activities. Additionally, future semesters will incorporate more significant structure during active learning to better guide students and achieve desired outcomes and will revise exams to provide students with evaluations that better assess critical-thinking skills. Our experiences support developing a strategy that incorporates multiple techniques not only to serve multiple learning styles, but also to
convey appropriate enthusiasm and motivation as well as instill autonomous learning. Thus, we anticipate greater student performance with combined strategies of lecture and student-centered learning activities. Notably, implementing a student-led technique, either as an entire educational strategy or a part of one, will undoubtedly require support because of the significant student resistance associated with perceptions of appropriate educational activities. We are very thankful to have had supportive administration and colleagues to implement and assess our educational strategies.

References

Melody J. Bernot (mjbernot@bsu.edu) is an associate professor and Jennifer Metzler is an assistant professor, both in the Department of Biology at Ball State University in Muncie, Indiana.
This study examines the implementation of teaching strategies by graduate teaching assistants (GTAs) in inquiry-based introductory geology labs at a large research university. We assess the degree of inquiry present in each Physical Geology lab and compare and contrast the instructional practices of new and experienced GTAs teaching these labs. We demonstrate that GTAs are able to teach these labs consistently but use different instructional strategies. Further, we found that the incorporation of particular teaching strategies was related to prior GTA experience. Experienced GTAs teach in a more reformed, student-centered manner than new GTAs. Teaching practices were assessed through direct classroom observation and the application of the Reformed Teaching Observation Protocol. The lessons learned from this project can be used to inform other science departments seeking to effectively incorporate inquiry-based labs that encourage effective teaching practices from GTAs.

Introductory science labs are often more focused on the needs of individual students than a typical lecture, allowing students to gain practical knowledge of laboratory techniques while also developing conceptual and procedural knowledge and skills (Bybee, 2000; National Research Council, 1996). The unique strength of labs is that they can provide students with opportunities to engage in investigation and inquiry, the process of science (Hofstein & Lunetta, 1982). Further, given their longer duration and more intimate setting than conventional lectures, labs can be formatted to engage students in metacognitive activities that encourage interaction and reflection (Gunstone & Champagne, 1990).

In recent years there has been a focus on inquiry-based reform in science education (e.g., National Research Council, 2000). Used here, the term inquiry follows the definition of the National Research Council (1996, p. 23), as a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. [It] requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.

This definition focuses on the role of the student, and inquiry-based learning should therefore be understood to be student centered. The National Science Education Standards (National Research Council, 2000) emphasized the nature of inquiry as existing along a continuum of learner self-direction. Inquiry-based curricula have been shown to produce higher average student achievement (Schneider, Krajcik, Marx, & Solomon, 2002) and deeper student understanding of the nature of science (National Research Council, 2000). Graduate teaching assistants (GTAs) instruct the majority of labs at research institutions (Luft, Kurdziel, Roehrig, & Turner, 2004; Sundberg, Armstrong, & Wischusen, 2005; Travers, 1989) and are frequently expected to make instructional decisions, including how information should be presented, which concepts should be emphasized, and how to evaluate student work. This is often done with little direct guidance from faculty (Kurdziel & Libarkin, 2003). Unless GTAs are given the training and resources to teach effectively, introductory students may not reap the benefits of inquiry-based laboratory activities. Academic cultural norms may encourage GTAs to teach as they were taught (Halpern & Hakel, 2002). This often leads to science content, regardless of the
lesson design, being delivered using methods at odds with those recommended by agencies advocating educational reforms to maximize student achievement and interest (American Association for the Advancement of Science, 1990; National Research Council, 1996, 2000).

We revised our introductory geology labs to include multiple inquiry activities. This article describes our effort to assess how much inquiry is present in each lab and to determine how GTAs approached teaching these activities. The goals of this study were to

• measure the level of inquiry in each lab;
• determine if GTAs will teach lab activities effectively, given a course designed around inquiry labs requiring student-centered pedagogy; and
• describe variations in teaching practices used by new and experienced GTAs in reformed introductory geology labs.

Inquiry and reformed teaching

In an inquiry science lab, content is often presented through real-world problems designed to positively stimulate students’ attitude toward science and their natural interest in the world around them (Hofstein & Lunetta, 2004). Positive attitudes toward, and experiences with, science may also have a direct bearing on retention rates (Moskal, Lurie, & Cooper, 2004). Although it would appear that labs are an ideal setting for inquiry, many college science labs are characterized by few or no inquiry activities. Buck, Bretz, and Towns (2008) developed a quantitative rubric to characterize levels of inquiry in college science laboratories (Table 1). Their rubric described five levels of inquiry with the lowest level (Confirmation) providing students with the necessary problem/question, background information, procedures, method of analysis, and means of communicating the results. Conclusions gained from these activities are apparent to students. For example, students may be asked to identify the elevations of several prominent features on a local area map. They are given explicit instructions on how to read the contour lines and where on the map to find the contour interval. A fill-in-the-blank answer sheet tells students how to communicate their results. Higher level activities remove some of this guidance, encouraging students to analyze results, design procedures, or even craft their own research question (Table 1). For example, in an Open activity, students may be asked to use a physical model to test a hypothesis that earthquakes are time predictable. They design the experiment and decide how to communicate their results. Higher level activities incorporate many of the elements of the inquiry definition and more closely replicate the scientific method.

Buck et al. (2008) evaluated 386 laboratory experiments (activities) from a variety of undergraduate science laboratory manuals. They rated 29.8% of the activities as Confirmation, 62.2% Structured, 6.7% Guided, 1.3% Open, and 0% Authentic. Their analysis included 63 geoscience (46 geology and 17 meteorology) activities, all of which were interpreted as Confirmation, the lowest level of inquiry.

In addition to enjoyment of the tasks themselves, the positive influence of instructors in introductory science classes has been cited as a key factor associated with student persistence in science and engineering (Brainard & Carlin, 1998). Generating and sustaining student interest can be critical in improving recruitment and retention rates in geoscience programs (Moskal et al., 2004). When labs are paired with large lecture courses, GTAs

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Level 0: Confirmation</th>
<th>Level 1/2: Structured inquiry</th>
<th>Level 1: Guided inquiry</th>
<th>Level 2: Open inquiry</th>
<th>Level 3: Authentic inquiry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem/question</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Theory/background</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Procedures/design</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Not provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Results analysis</td>
<td>Provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Results communication</td>
<td>Provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Conclusions</td>
<td>Provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
</tr>
</tbody>
</table>

Note: Adapted from Buck, Bretz, and Towns (2008), Table 2.
often have more contact with undergraduate students than do the lecture professors (Gardner & Jones, 2011). Given the role of GTAs in teaching content and their potential impact on recruitment, it is important that we encourage the use of best teaching practices if we are to meet the growing needs of the U.S. geoscience workforce (Geissman, 2012). Even when labs are redesigned around best teaching and learning practices, there is no guarantee that GTAs will effectively implement these practices.

A constructivist or “reformed” pedagogy (MacIsaac & Falconer, 2002) incorporates activities that encourage students to work collaboratively, analyze questions that emphasize concepts over facts, and provide opportunities for students to assess their learning and for the instructor to provide feedback (Heath, Lakshmanan, Perlmutter, & Davis, 2010; National Research Council, 2012). Reformed instruction builds on research findings about student learning and has been shown to improve conceptual knowledge and attitudes in a variety of disciplines (e.g., Crouch & Mazur, 2001; Knight & Wood, 2005; Kortz, Smay, & Murray, 2008; Sesen & Tarhan, 2011). Inquiry, as defined previously, describes the nature of lab activities, and the degree of class reform reflects how the student interacts with the material, their peers, and their instructor. Just as we can use a rubric to define the level of inquiry in lab activities, we can use the Reformed Teaching Observation Protocol (RTOP; Sawada et al., 2002) to describe the degree of reformed instruction in a lab class on the basis of five subscales:

- **Lesson Design and Implementation** measures to what extent the design and application of the lesson draws on student input, exploration, and negotiation of meaning.
- **Propositional Knowledge** describes whether the lesson is more fact or concept oriented and the teacher’s command of the material.
- **Procedural Knowledge** assesses what students were asked to do during the lesson, including making predictions, forming hypotheses, and engaging in self-reflection of what they know.
- **Student–Student Interactions** are assessed on the basis of their quantity and quality, and the variety of scales at which they occur (e.g., pairs, small groups, whole class).
- **Student–Teacher Relationships** gauge how the teacher promoted active student participation, and acted as a resource person for students.

---

**TABLE 2**

<table>
<thead>
<tr>
<th>Semester</th>
<th>Total observations</th>
<th>Number of lab topics observed</th>
<th>Observations of new GTAs (1st semester)</th>
<th>Observations of experienced GTAs (more than 2 semesters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2011</td>
<td>20</td>
<td>4</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Fall 2011</td>
<td>28</td>
<td>7</td>
<td>15</td>
<td>13</td>
</tr>
</tbody>
</table>

*Note: GTAs = graduate teaching assistants.*

---

**FIGURE 1**

*Level of inquiry.*
Each subscale is comprised of five statements that are ranked using a Likert scale from 0 (never occurred) to 4 (very descriptive of the class), for a total score of 0–100. As with MacIsaac and Falconer (2002), we use the term reformed teaching to mean classroom practices that result in an RTOP score of greater than 50. These are student-centered classes that feature activities that discipline-based educational research has shown to increase student learning (National Research Council, 2012).

Methods

This research was conducted at a large, public research university in the southeast. The university serves more than 34,000 undergraduate and graduate students. Participating GTAs were selected on the basis of their current involvement in teaching an introductory geology lab, willingness to participate, and the compatibility of the GTAs’ and researchers’ schedules for the purposes of observations. An effort was made to observe both new (first semester) and experienced (at least third semester) GTAs (Table 2).

Training for GTAs includes a university wide, half-day orientation to teaching, plus a 3-hour departmental seminar at the beginning of the fall semester led by the lab supervisor. GTAs meet weekly with the lab coordinator, an experienced GTA, to review labs, discuss teaching strategies, and address any classroom management issues. Experienced GTAs are encouraged to share their teaching experiences with new GTAs, and everyone can suggest improvements to the labs.
**Characterizing the nature of the labs**

We used the rubric of Buck et al. (2008) to characterize the level of inquiry in 11 Physical Geology labs. The point value for each activity was printed in the lab, visible to both GTAs and students alike. Using these point values, we calculated the percentage of a student’s grade earned at each level of inquiry for each lab (Figure 1). The authors established excellent interrater reliability ($K = 0.8496$; Cicchetti, 1994) with the rubric before characterizing all of the labs. The percentage of a student’s grade attributable to an inquiry level was multiplied by the “value” of that level to calculate an inquiry score. The numeric levels provided by Buck et al. (2008) from Confirmation to Authentic are 0, ½, 1, 2, and 3. For example, if we were to score an “average” lab analyzed by Buck et al. (2008), 30% was composed of Confirmation activities ($30 \times 0 = 0$ inquiry score), 62% was Structured ($62 \times 0.5 = 31$), 7% was Guided ($7 \times 1 = 7$), and 1% was Open ($1 \times 2 = 2$), the lab would be awarded an inquiry score of 40 points.

To measure the degree of reformed instruction in the lab, we used the detailed RTOP revised rubric and protocol as devised by Budd, van der Hoeven Kraft, McConnell, and Vislova (2013). Two observers (including the first author) established excellent interrater reliability ($K = 0.8535$; Cicchetti, 1994). This was calculated by comparing observations made using two video lectures and two live classroom observations. GTAs were alerted prior to the observation of each lab, and observers spent a minimum of one hour in the classroom before scoring.

**Results**

*Levels of inquiry in introductory geology labs*

The Physical Geology labs were characterized by a range of levels of inquiry (Figure 1). On the basis of the classification system of Buck et al. (2008), the Physical Geology labs were found to contain 15.3% Confirmation, 43.1% Structured, 35.1% Guided, 6.5% Open, and 0% Authentic activities. All of the labs contained some Confirmation or Structured activities, which were often used to familiarize students with new material. However, the Physical Geology labs featured a higher proportion of Guided and Open activities than what had been identified in lab manuals by Buck et al. (2008), where a majority of activities featured low levels of inquiry. Physical Geology labs averaged an inquiry score of 70.5, ranging from 25.0 (Minerals and Igneous Rocks) to 111.11 (Groundwater; Figure 2a).

There is a moderate correlation between the inquiry score and average RTOP score earned by each GTA teaching the observed labs, $r(7) = 0.61, p = .07$ (Figure 2b).

**Teaching styles of GTAs**

Eleven Physical Geology labs are taught each semester. We did not observe the first lab or the three involving field trips. At least four classes taught by different GTAs were observed for each of the remaining seven labs. RTOP scores ranged from a low of 49 for a GTA teaching the Minerals and Igneous Rock lab to a high of 84 for a GTA teaching the Geologic Time lab. With one exception, all labs were credited with high RTOP scores (MacIsaac & Falconer, 2002; Figure 2a). This was true regardless of whether the GTAs were new or experienced.

**Teaching practices of experienced versus new GTAs**

Experienced GTAs outscore novice instructors on all five RTOP subscales, but there was a statistically significant difference on three of them (Table 3; Figure 3). Experienced GTAs taught in a more reformed manner on subscales measuring Propositional Knowledge, Procedural Knowledge, and Stu-
Graduate Teaching Assistants in Inquiry-Based Labs

Discussion

We identified a higher proportion of Guided and Open inquiry activities in the Physical Geology labs than that identified by Buck et al. (2008) in undergraduate science lab manuals. This means a shift away from the lower levels of inquiry (Confirmation, Structured). These lower levels of inquiry emphasize the nature of science as a collection of facts, rather than as a process, so this change may lead to a deeper student understanding of the nature of science. Despite the overall increase in inquiry, two of the Physical Geology labs (Minerals and Igneous Rocks, Sedimentary and Metamorphic Rocks) contained more than 90% Confirmation and Structured inquiry activities (Figure 1). These labs will be targeted for future changes to bring the degree of inquiry in line with the remainder of the labs. Further work is needed to determine whether students learn more in higher inquiry Physical Geology labs.

When provided with an inquiry lab format, GTAs exhibit a range of reformed teaching practices (as evidenced from scores ranging from 49 to 84 across multiple labs). There is a moderate relationship between the average RTOP score and the degree to which student’s grades are accounted for at higher or lower levels of inquiry (Figure 2b). Therefore, most of this variation is interpreted to be a consequence of the nature of the lab activities, rather than the GTA. This correlation between reformed teaching and inquiry suggests that although the two are linked, the degree of reform is also dependent on other features, potentially including instructor, class size, and student engagement. Providing higher inquiry labs is one way to promote reformed

Table 3: Average score earned by Physical Geology GTAs on each RTOP item and subscale.

<table>
<thead>
<tr>
<th>RTOP Subscale item</th>
<th>Experienced physical geology GTAs</th>
<th>New physical geology GTAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.3</td>
<td>2.0</td>
</tr>
<tr>
<td>2</td>
<td>3.5</td>
<td>3.3</td>
</tr>
<tr>
<td>3</td>
<td>3.2</td>
<td>3.4</td>
</tr>
<tr>
<td>4</td>
<td>3.1</td>
<td>2.9</td>
</tr>
<tr>
<td>5</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Total: Lesson Design and Implementation</td>
<td>14.9</td>
<td>14.1</td>
</tr>
<tr>
<td>6</td>
<td>3.2</td>
<td>2.9</td>
</tr>
<tr>
<td>7</td>
<td>3.2</td>
<td>2.9</td>
</tr>
<tr>
<td>8</td>
<td>3.9</td>
<td>3.8</td>
</tr>
<tr>
<td>9</td>
<td>2.8</td>
<td>2.7</td>
</tr>
<tr>
<td>10</td>
<td>2.8</td>
<td>2.4</td>
</tr>
<tr>
<td>Total: Propositional Knowledge</td>
<td>16.1</td>
<td>14.6</td>
</tr>
<tr>
<td>11</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>12</td>
<td>3.1</td>
<td>3.1</td>
</tr>
<tr>
<td>13</td>
<td>3.0</td>
<td>2.3</td>
</tr>
<tr>
<td>14</td>
<td>1.8</td>
<td>1.1</td>
</tr>
<tr>
<td>15</td>
<td>2.3</td>
<td>2.1</td>
</tr>
<tr>
<td>Total: Procedural Knowledge</td>
<td>13.8</td>
<td>12.3</td>
</tr>
<tr>
<td>16</td>
<td>2.3</td>
<td>1.9</td>
</tr>
<tr>
<td>17</td>
<td>2.6</td>
<td>1.9</td>
</tr>
<tr>
<td>18</td>
<td>3.8</td>
<td>3.5</td>
</tr>
<tr>
<td>19</td>
<td>2.8</td>
<td>2.3</td>
</tr>
<tr>
<td>20</td>
<td>3.2</td>
<td>3.1</td>
</tr>
<tr>
<td>Total: Student–Student Interaction</td>
<td>14.7</td>
<td>12.9</td>
</tr>
<tr>
<td>21</td>
<td>2.9</td>
<td>2.3</td>
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<tr>
<td>22</td>
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<td>2.1</td>
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<tr>
<td>23</td>
<td>3.1</td>
<td>1.9</td>
</tr>
<tr>
<td>24</td>
<td>3.0</td>
<td>2.6</td>
</tr>
<tr>
<td>25</td>
<td>3.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Total: Student–Teacher Interaction</td>
<td>15.0</td>
<td>11.7</td>
</tr>
<tr>
<td>RTOP Total</td>
<td>74.4</td>
<td>65.5</td>
</tr>
</tbody>
</table>

Note: GTAs = graduate teaching assistants; RTOP = Reformed Teaching Observation Protocol.
teaching in introductory courses.

Given a course designed around reformed, student-centered principles, Physical Geology GTAs were able to teach in a reformed fashion, despite having relatively minimal instructional training. That new and experienced GTAs had similar scores on the Lesson Design subscale suggests that the labs are set up to ensure some consistency in the application of reformed pedagogy. We anticipated little variation in Lesson Design as the labs were designed by the lab supervisor, rather than the GTAs themselves, and GTAs are instructed how to teach the labs during weekly meetings. Experienced GTAs displayed significantly higher Propositional Knowledge and earned higher scores in the Procedural Knowledge and Student–Teacher Relationships subscales. Propositional Knowledge describes what the teacher knows and how well they are able to organize and present the material conceptually, rather than as a series of facts. The significant difference in this subscale is not a reflection of the knowledge of the GTAs. Instead, it stems from the number and quality of connections made between labs and the real world, or the current lab with prior labs (Item 10 in Table 3). Experienced GTAs did a better job of either making those connections themselves or asking students to provide them. Higher scores were often earned through detailed discussions between students and teachers.

The Procedural Knowledge subscale is linked through a construct of inquiry with a number of items from the Lesson Design and Implementation subscale (Piburn & Sawada, 2000). Experienced GTAs were more likely to ask divergent questions (more than one “right” response) and allow questions and comments from students to determine the focus and direction of classroom discourse. They were also more likely to ask students to develop alternative solutions, question their assumptions, and consider why they were using a procedure. This resulted in higher scores on the Student–Teacher Relationships subscale for experienced GTAs. Higher scores in this subscale were primarily a result of the teacher engaging students in meaningful conversations that could change the direction of the lesson. Some of these differences may be a result of increased experience with the way the labs run. New GTAs are less comfortable diverging from the lab as written and so stifle some of the natural discussion if they feel it is off track. For new GTAs, questions and comments rarely changed the focus and direction of classroom discourse, but instead were addressed individually. New GTAs tended to end discussions as soon as a single correct answer was reached; experienced GTAs were more likely to push for alternative answers. Experienced GTAs were more patient and encouraging with students as they experienced the challenges of the scientific method. They allowed students to spend time identifying and discussing additional problem-solving strategies. The familiarity with the lab reduced the cognitive load for experienced GTAs, allowing them to incorporate additional references that went beyond basic instruction as defined by the lab activities. It may also create an increased level of comfort in predicting and addressing common student challenges.

We interpreted the lack of contrast in the Student–Student Interactions scores of novice and experienced GTAs to mean that they are more dependent on how the lab is structured than the GTA’s familiarity with the lab materials. For example, an activity that instructs groups to draw geologic cross-sections, trade them between groups, and discuss differences in interpretations does not require much input from the GTA. Instructions included in the lab can provide guidance that ensures more interactions between students.

We have shown that we can readily apply tools to measure the level of inquiry and the degree of reformed teaching exhibited by GTAs in geology labs. If the labs are designed with the goal of supporting both the GTAs and undergraduate students, the GTAs need relatively minimal instruction to teach in a reformed manner and will improve their instruction with time. Some guidance can be provided in the lab itself to ensure labs are taught consistently. These results hold promise for science departments hoping to effectively incorporate inquiry-based labs in their curriculum, while encouraging effective teaching practices among their GTAs.

Acknowledgments
We thank Alison Moyer for her assistance conducting observations and April Grissom and Doug Czajka for their help co-coding with the inquiry rubric. We would also like to thank each of the GTAs for their openness and willingness to participate in this study.

References
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Aeronautical Engineering and Aerospace Engineering: A Learner-Centered Teaching Perspective in Higher Education

By Omid Gohardani, Amir S. Gohardani, Erin Dokter, and Kyla Macario

Teaching in the 21st century requires a modern teaching practice coherent with the evolutions of the Information Age. Interestingly, teaching practices have stretched beyond an art form and into the realm of science. Following these scientific trails, one can argue that one of the greatest challenges educators currently face is to maintain student interest in demanding subjects. From an educator's point of view, however, all subjects are equally demanding, as the adopted teaching practice for a particular subject matter equally needs to ensure that a student-learning experience is generated. Furthermore, an efficient teaching method for a particular subject is not necessarily equally efficient for another subject. Hence, the road map to professional teaching could essentially start from an empty page and develop into a detailed map that could prove to be valid for a specific teaching environment. In this article, particular facets of learner-centered education in higher education are highlighted with an emphasis on teaching subjects in aeronautical/aerospace engineering. Implementation of novel techniques in communicating ideas through illustrations, posters, and animations represents one of the interactive educational approaches of this specific era.

The Information Age constantly presents significant challenges to educators worldwide. Given the large portfolio of interactive means for communication—partially generated by advancements in technology—a classical teaching style of lecturing without any interactive elements could commonly be perceived as dreary within the contemporary learning and teaching environments. Adoption of a modern teaching style should therefore incorporate the gems of technology in favor of providing students with memorable learning experiences.

In this article, selected aspects of learner-centered education (LCE) teaching are reviewed with the purpose of highlighting a number of key features that portray a diverse set of methods used in learner-centered teaching (LCT). Following a short journey through selected glimpses of LCE and aerospace teaching education, a number of practical teaching methodologies are presented. These endeavors build on the advantages of the Information Age and introduce a novelty in capturing students’ attention spans throughout the teaching practice phase and during the students’ learning process.

Learner-centered education

In contrast to the traditional learning perception in a classroom setting, which primarily features a teacher or an educator as the main axis of information delivery, LCE focuses on the information flows brought to learners and serves as an application in further learning (Gunderman, Williamson, Frank, Heitkamp, & Kipfer, 2003). One of the main benefits of LCE is its emphasis on various teaching methods, which entails a transition of the role of the teacher from information provider to facilitator of the learning process (Blumberg, 2008).

Weimer (2002) identified five essential training areas to achieve LCT, including the function of content, the role of the instructor, the responsibility for learning, the processes and purposes of assessment, and the balance of power. In essence, the foundation of LCT rests on a solid basis consisting of knowledge and development of skills in conjunction with self-awareness of the learner. In this context, the role of the instructor is concentrated on student learning, allowing for the responsibility of learning to be placed on students. This shift of responsibility is essentially achieved by motivation of students and learning assessment as a part of the learning cycle (Blumberg, 2008). The applications of LCE have been realized in many scientific fields such as medical sciences (Chiang, Chapman, & Elder, 2010; Gunderman et al., 2003), computer science (Quintana, Krajcik, & Soloway, 2003), and psychology (McCormbs, 1993). The topic of learner-centered education has been the focal point
of many different investigations. This topic has been examined on the basis of its challenges (Cornelius & Gordon, 2008; Curry, Hershman, & Saizow, 1996; Meece, Herman, & McCombs, 2003; Sadler, 2012), implementation (Boyd, 2012; Gerstein et al., 2010; Schuhm, 2004; Schweisfurther, 2011; Thompson, 2013; Tudor, 1992; Wood, 2008), attitude change in students (Spencer, Phipps, & Alowayesh, 2012), effectiveness (Wang, Lee, Chen, & Wei, 2012), and the shift from teacher-centered education (Wolbrink & Burns, 2012). In this article, the practical approach for implementing LCE and LCT in aeronautical and aerospace engineering disciplines is underlined. Hence, an excursion through particular phases of the aerospace education domain is of further interest, followed by a few related case studies.

**Selected glimpses of aerospace education**

An increasing level of aeronautical and aerospace activities mirrors an unprecedented incentive to pursue new areas within these disciplines. In view of all the significant achievements within the aeronautical and aerospace engineering sectors, respectively, one of the challenges of educating new students for the future is to partially modernize the education programs so they reflect the needs of the future (Fletcher, 1997). Further, Fletcher and Page (1993) also recognized that the increasing focus on space exploration and use requires highly educated individuals with space engineering capabilities. For this purpose, a substantial technology transfer needs to take place from government and industry to academic institutions.

Exchange of ideas among different aerospace engineering institutions can be perceived as at least a limited knowledge transfer. Over the years, a considerable number of such collaborations have taken place (Dannenhoffer & Cottrell, 2005; Evans, Robinson, & Tate-Brown, 2009; Flammia et al., 1993; Koster et al., 2012; Olague, Leslie, Burton, & Knight, 2012; Raghunathan et al., 2005; Robinson, Evans, Tate, & Uri, 2008; Rosendhal, Sakimoto, Pertzborn, & Cooper, 2004; Schilling, 2012; Smith, Seigler, Smith, & Jacob, 2008; Tal, 2004; Thompson, 2003). In 1989 several MIT faculty members visited the Moscow Aviation Institute in an effort to promote student and faculty exchange and information (DeMeis, 1990). This effort marked one of the important steps for institutional collaborations between two of the leading countries in aerospace engineering. Collaborations of this kind have evolved to include an increasing number of countries making contributions to space technologies (Degtyarev et al., 2011). Emerging new topics in aerospace engineering are analyzed with new learning tools ranging from intelligent adaptive cyber-physical ecosystem for aerospace engineering education (Noor, 2011) to classical hands-on projects (Swartwout, 2011).

The role of LCT has become increasingly important with respect to the introduction of distance learning in aerospace engineering. Most aerospace professionals cannot afford to leave their current positions in order to meet the residency requirements for graduate studies in aerospace engineering. Salary loss due to an absence from the aerospace engineering field has to be balanced with the prospective future earnings as a result of achievements in higher education. Furthermore, it is well established that key personnel cannot afford to be absent from their positions for prolonged periods of time. In order to meet the demands for higher education in aerospace sciences and for the purpose of fulfilling their respective residency requirements, recognized institutions such as Columbia University and Michigan Technological University now offer doctoral degrees by distance learning (Jones & Klose, 2012). From this perspective, the prospects of pursuing higher education within aerospace sciences by means of distance-learning programs, and the subsequent shift from teacher-centered learning toward LCT is hence becoming more frequent with programs such as the one offered for master of science degrees within Aerospace Engineering at the University of Alabama (Jones & Klose, 2012).

**Methodology and methods of the study**

A specific method that can be highly efficient in learner-centered approaches is the activation of the general senses. When such an approach is adopted, the focus should primarily be set on these three senses: sight, hearing, and touch. In essence, this methodology seeks to include at least one of the senses during each learning phase. The idea is to incorporate a mixture of these senses for different learning tasks, hence expanding the learning process to incorporate visual, auditory, and kinesthetic learners. Implementation of the aforementioned theory can be traced in an example that relates to a Future of Flight learning session. In this lecture series, the future of flight is examined by several means of educational tools that are representative of different layers for different learners, in accordance with the information in Figure 1.

Each of the components described in Figure 1 activate the interest of a distinct sense or a collective of senses. Exposure of learners to the broad spectra of learning consequently enables a more successful teaching process. The implemented methodology in this study makes use of various means in order to promote an LCE approach. Thus, the focus of this methodology is to consistently use different technological channels.
in the teaching of subjects within the fields of aeronautical and aerospace engineering.

**Case I: The Theory of Flight**

Case I represents one case of capturing the interest of the learners in general aviation. This teaching approach was particularly aimed at the introduction and identification of four basic forces acting on an aircraft during flight with a partial goal of defining an airfoil. Given that the learners in the class only had general knowledge about aviation, the teaching level was tailored for a 100-level course.

During this teaching session, the outlined topics consisted of establishing a force balance on an aircraft during flight and defining an airfoil, followed up by an interactive quiz. The session targeted auditory learners, kinesthetic learners, and visual learners. Microsoft PowerPoint and ELMO Visual Presenter as technological instruments for presentation purposes were used, and the principal teaching efforts were primarily directed toward generating student interaction and brainstorming activities.

The analogy to fully comprehend a flight scenario was instigated by showcasing a video clip in which birds from a level flight position went in for landing. Through capitalizing on the learners’ previous understanding of a simple scenario that revealed how a bird or an aircraft could maintain level flight, the force balance between the aircraft weight, lift, thrust, and drag was established. Another analogy was also given with regards to drag generation. The empirical experience of placing the palm slightly outside the window of a moving vehicle and feeling the force of the wind is a clear indication of the exerted drag force on the palm.

In these sessions, the enabling link resulting in an interaction between the educator and the students was partially denoted through the minute reflection. This concept permitted learner reflections about a series of questions that did not require any previous aeronautical knowledge and were aimed to revisit the inherent subconscious stored knowledge.

Interaction with students would often lead to a brainstorming session about the topic in question. This session was further followed by the instructor highlighting the correct assumptions made by the learners. In addition, there would also be a discussion about the reasoning behind the inaccuracy of certain assumptions. The emphasis in this framework was nonetheless always placed on learner engagement and in favor of stimulating unique experiences for the learners. Engagement of both visual and auditory learners was simply achieved through the introduction of interactive quizzes. In the aforementioned quizzes, musical compositions and audio clips in conjunction with animated graphics would expose the learners to a session in which the crucial topics of the subject matter would be highlighted. In these quiz sessions, the learners rapidly established a feel for what they would expect, and hence their engagement level in the topic was enhanced considerably. To incorporate the kinesthetic learners in this teaching series, the definition of an airfoil was easily explained by folding of a blank paper sheet with the two ends of the paper placed on top of another and the flat hollow region in between them representing the airfoil. The sheet of paper further facilitated the explanation of why an extrusion of an airfoil could represent a wing section. Different aircraft rotations were further explained through animations, the making of paper airplanes, and analogies with bird flight. In conclusion, on the basis of the postassessment reviews of these activities, learners that participated in these series of lectures felt that they were encouraged in critical thinking and exposed to a learner-centered approach in the basics of flight.

**Case II: The Future of Flight**

In contrast to Case I, which was aimed more at a classroom session, the Future of Flight lecture series...
was essentially aimed at a larger audience beyond a classroom setting. Hence, the different building blocks in these series consisted of teaching measures that would result in an overview of the topic without the presence of a lecturer or a narrator.

A learning session was implemented with the purpose of exploring the future of flight. In particular, the implemented methods in this study consisted of the following:

- an interactive presentation, using both audio and video;
- a static presentation, implementing simplified graphics; and
- an animated presentation, using motion picture design in education.

In the interactive session, the class became a center stage for the educator who interacted with the learners on a frequent basis. The challenges associated with such an approach included instigating the interaction with the learners. A simple measure for this initial interaction was to include a quiz-type session in PowerPoint, where each question was based on the initial student knowledge about the subject. Thus, the session first and foremost enabled the educator to assess the knowledge level of the learners. Following this trail of thought, dual benefits were gained for both the educator and the learners. From the learners’ perspective, the self-confidence level is built simply as they systematically recognized their undiscovered strengths and the wells of their previous knowledge. From the vantage point of the educator, the interactive quiz is a natural opening remark and yields to an instant involvement of the learners. The role of audio clips in this context cannot be overemphasized. In essence, learners are not expecting any audio output during a PowerPoint presentation. Hence, coordinated audio clips that, for instance, will last during the allocated time slot for answering each question can contribute to several positive factors. Initially, these audio clips instantly promote a level of suspense. In this setting, the learner will be given the opportunity to provide the educator with his or her answer during the duration of the audio clip. In addition, usage of audio clips adds another level of interaction with the learner where the audio length, its character, and frequency of usage can be adapted to a particular task of interest in the presentation.

Second, for static presentation purposes, a poster that features simplified graphics is considered. We believe that using a colorful poster such as the one shown in Figure 2 is more likely to capture the attention of the learners in comparison to a conventional scientific poster with plain graphics. The challenge herein is placed in having a clear and distinct means of communication with the learner. This objective can for instance become actualized by a timeline, as shown in Figure 3, which further reveals the development of different aerospace design concepts. The timeline serves a twofold purpose. First, it depicts a distinct categorization between different conceptual designs. This in itself provides the learner with an overview of diverse categories. Second, the piece of information within each time period is conveyed by means of text and illustrations, respectively.

A motion picture or animation activates different senses of the learners simultaneously and could spark their curiosity according to the interactive means of the Information Age. A snapshot of an animation sequence is shown in Figure 4, and the animation clip is also included as an attachment to this article.

The notion of viewing a set of images in motion can sometimes lead to an unaware learning process. This method—if tailored to specific teaching subjects—can represent one of the most interesting aspects of a teaching process and typically draws the attention of the majority of the learners because of its unusual feed of information. The medium for teaching...
with a motion picture can consist of both audio and video. Such a teaching method, however, could prove to be time demanding and requires that the educator makes long-term plans before introducing a specific lecture series.

Data collection and learning assessment
The first case study was aimed at identification of the basic forces acting on an aircraft during flight. The learning assessment method at the end of each classroom session was actualized by open discussions with the students and through a quiz.

Results
Two different case studies were carried out for topics related to aeronautical and aerospace engineering. The first topic was titled The Theory of Flight and the second topic was titled The Future of Flight, respectively. The learners in the class were a diverse group of individuals with a general knowledge about aviation. These lecture series were further tailored for a 100-level class. Hence, the educators made use of the existing knowledge of the learners and implemented different interactive methods to activate a mixture of senses. Through up-to-date and interactive presentation approaches, the learning process was expanded to incorporate visual, auditory, and kinesthetic learners, as highlighted in LCT and LCE. The learning objective results based on interactive quizzes are shown in Figure 5.

Conclusions
The LCE approaches undertaken in this study have exhibited that it is possible to effectively implement LCT in teaching endeavors within aeronautical and aerospace engineering. It is interesting that the results from this study also indicate that despite the intricate nature of the aforementioned disciplines, explanation of ideas could potentially become easier through interactive media. The findings of this study further point to the fact that different teaching practices can increase the diversity in the learning process and include learners from different learning styles. In essence, adaptation of information sharing via different forums on the internet can further remove any restrictions imposed by spatial con-
A conceptual airport suggestion for the future. The vertical compartment airport enables simultaneous landings and takeoffs of at least eight aerospace vehicles, hence, minimizing airport congestion to a level where it is virtually nonexistent. Source: Conceptual design by Dr. Omid Gohardani and Dr. Amir S. Gohardani, ©2011. All rights reserved.

FIGURE 5
The class structure, allocations of lecture tasks, and percentage of students who learned the class objectives related to introduction to flight.

Acknowledgment
The authors dedicate this journal article to the late memory of Dr. Kristopher Allen Weatherly, who served as an active contributor to this specific study and provided fruitful suggestions to the Learner-Centered Education program at the University of Arizona. Dr. Weatherly will always be remembered as an outstanding educator and as a true source of inspiration to the entire teaching community and all those who had the pleasure of knowing him. Any opinions, findings, and conclusions expressed herein are those of the authors only and do not necessarily reflect the corporate views of any organization(s) affiliated with the authors.

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Our lives are filled with polls and surveys. We are asked to participate in dozens every year. We all face the same onslaught. There are pollsters everywhere. It is part of modern life and the ubiquitous presence of phones and the crushing onslaught of the electronic juggernaut, leading us to be wary of anyone approaching with a clipboard in a neighborhood mall or a stranger at a table hailing with a hearty greeting in an airport—especially at election time, when everyone has their own polling agency and spins the results in their own inimitable style.

And we can’t just be part of a poll; we have to be enlightened with the results. We are then bombarded with statistics on our computer, on our iPad, and from nattering nabobs on television. Nowhere are we safe from intrusion, be it in our bedroom or bath. And you are not safe in this essay either. For we are here to tell you the results of a survey that we posted for folks who regularly peruse the website of the National Center for Case Study Teaching in Science (NCCSTS). We asked faculty about their use of case studies and videos in their General Biology classrooms. We think the results are enlightening because General Biology is arguably the course most commonly taught to students in high schools and college. And the flipped classroom is the hottest ticket in town.

What prompted our interest in all of this is that we submitted a successful grant proposal to the National Science Foundation making the argument that case study teaching is now one of the favorite methods of science, technology, engineering, and mathematics (STEM) teachers because it engages students with real-world problems. It promises to help overcome the disenchantment found in 60% of the STEM students who choose to leave the disciplines. According to an editorial in Science by Gates and Mirkin (2012), three factors are responsible for the attrition: uninspiring introductory courses (86% of science faculty use lecture as their primary mode of teaching), difficulty with the required math, and an unwelcoming academic culture in STEM. One of the major innovations in the college STEM classroom developed to help correct this situation is case-based learning (Herreid, 1994), which teaches scientific content, concepts, and skills in a real-world, problem-solving context that provides the kind of active, student-centered learning called for in Vision and Change (American Association for the Advancement of Science, 2011). In fact, Gates and Mirkin recommended that the “federal government catalyze widespread adoption of active learning approaches using case studies, problem-based learning, peer instruction, and computer simulations” (p. 1545).

As much as we favor case study teaching (Herreid, 2007), there are some critics who have argued that it uses too much class time. Faculty who are concerned with the coverage issue say they can’t afford to turn over a class to a case study because they won’t be able to get through the material that they believe is essential or is mandated. Faculty making this assertion often ignore two important facts, of course: (a) many students who have suffered through the lecture method still receive Ds and Fs or withdraw—the method clearly doesn’t work for them, and (b) you can still get coverage without the teacher having to say it all out loud; there are other ways to get coverage.

That’s where the flipped classroom comes in. The classical flipped approach advocates that teachers give the students homework that covers the essential material habitually presented in lecture, then when class time rolls around, the teacher has time for practical exercises such as case studies, games, contests, problem solving, etc., which reinforce the key points of the material. Thus, the approach flips the normal classroom pedagogy on its head, reversing the usual procedure of lecture first, homework after.

Now let’s be clear about this: There is little new about this approach. Ever since the invention of the printing press, countless teachers have implored their charges to read
the chapter in the book ahead of time, often to no avail. Additionally, this approach is the centerpiece of team learning, developed by Larry Michaelsen, where students are given reading assignments before class, and then in class they encounter individual quizzes, group quizzes, and finally case studies (Michaelsen, 1992, 2002). Herreid (2002, 2004) has described the successful use of Michaelsen’s method in STEM courses. Just-in-time teaching (JiTT) requires significant student preparation too. Students are required to accomplish web-based assignments that are due shortly before class. The instructor reads the student submissions and adjusts the classroom lesson to suit the students’ needs. Class time is spent dealing with questions and introducing material on a need-to-know basis (Novak, Patterson, Gavrin, & Christian, 1999; Simkins, Maier, & Rhem, 2009). “Hybrid courses” and “blended courses” (Buzzetto-More & Sweat-Guy, 2006; Wu, 2010) have students learning their subject matter via a combination of traditional classroom interactions and some form of internet-based learning. These and related methodologies, cooperative learning (Slavin, 1990), collaborative learning (Dillenbourg, 1999), and process-oriented guided inquiry learning (Farrell, Moog, & Spencer, 1999; Hanson & Wolfskill, 2000) share some of the same advantages and challenges. Like the flipped classroom, all of these methods allow instructors to cover principles, facts, and terms as part of out-of-class student preparation and use classroom time to engage in active learning exercises in which they apply what they have learned.

But what’s new about the flipped method is this: We now have the internet, YouTube, and a host of other websites like the Kahn Academy and Bozeman Science that provide high-quality short videos that cover key concepts in STEM education. In less than 10 minutes one can see an animation video of the differences in mitosis or meiosis, an explanation of DNA replication, or how the planets move. A student can look at these repeatedly. When made well, these videos appeal to a crop of students who are immersed daily in a visual culture with high entertainment value. There are two clear problems however. The first is how to get the students to watch and learn from these sources. This problem is often solved by giving short exams either online or in the classroom before the classroom exercises begin. The second problem is that not enough
high quality video material or case studies exist. This challenge is now partially being met with videos that are produced by groups such as the Khan Academy (www.khanacademy.org) and Bozemanscience (bozemanscience.com/science-videos/) or by faculty who are creating their own using software programs like Camtasia, PaperShow, and ShowMe or apps on the iPad like Educreations and Explain Everything, which they then post to YouTube, iTunes U, and Podcasts (Vodcasting) or on course management systems such as Blackboard or Moodle. Still, we are a far cry from having high-quality free videos that cover the fundamental topics in general biology. It is the latter problem that our current National Science Foundation grant is trying to address over the next 3 years. As a preliminary step to that work, we invited members of the NCCSTS’s listserv to take a survey designed to find out how many of them are currently using cases and the flipped classroom approach.

This survey was only intended for faculty teaching General Biology at the college level. Over 1,300 people answered the Survey Monkey’s call, 46% of them high school teachers of Advanced Placement (AP) biology courses. Virtually all respondents were teaching face-to-face classes, although a handful was also teaching via distance learning. The typical class size was 11–25 students (47%) or 26–50 students (34%). These sizes are quite favorable to various forms of case study and flipped classroom exercises. Not all of us have such luxury. Some of the key findings are not too surprising to those of us immersed in the day-to-day operations of General Biology, but they are nonetheless relevant to those of us interested in seeing that the flipped classroom gets a fair shake. First, let’s look at the topics covered by the teachers who responded to our survey. A typical General Biology textbook gives us a sense of the material, but what is the emphasis we find among case study teachers? Figure 1 provides the answer.

What is striking from Figure 1 is that the topics that many of us took as young biology students are still being taught today, but the emphasis is quite different. The course called “biology” didn’t exist at all until the 1960s. Students took separate courses in zoology and botany, a year of each. And those courses were totally focused on taxonomy, diversity, life cycles, anatomy, and physiology, with a bit of Mendel, ecology, and evolution thrown into the mix. One
lecture (repeat: one lecture) in each of zoology and botany on the cell was standard; we didn’t know much about it in the old days. Today, the curriculum is turned on its head. Our standard course in biology focuses heavily on the cell and molecular biology, with genetics and heredity leading the way. Biodiversity, if it is taught at all, is relegated to a few survey classes. And life cycles? Forget it. Anatomy and physiology topics don’t fare much better, especially if we are talking about plants. Evolution actually is much better represented today than in the previous generation, unless you are in a creationist stronghold.

Figure 2 shows how teachers use case studies to teach these subjects. You might expect it to be pretty much the same as in Figure 1, but there are differences because the pattern also reflects the availability of cases. For example, there are very few cases available in plant structure and function. The same is true in biodiversity, so these topics receive even less emphasis than we might expect. Contrariwise, there are a large number of cases in genetics and heredity, evolution, and ecology, as these fields are easier to find suitable topics for cases. They receive more attention than expected.

When we asked teachers where they got their cases, overwhelmingly, it was from the NCCSTS website. This is to be expected, given that the survey emanated from this site, but further, the site is arguably the largest and best known peer-reviewed case repository of STEM cases, with over 500 cases published. Other sources are less well used. A handful of instructors (6%) said that they used their own cases or had picked them up from the news media; (3%) said they got them from textbooks or journals (Waterman & Stanley; Campbell & Reese; McGraw Hill texts; The American Biology Teacher; Sadava et al.; Journal of Heredity; The American Biology Teacher); and 1% came from other case study websites (Environmental Protection Agency; Howard Hughes Medical Institute; Evergreen State College’s Native American Case Collection; TED talks).

What kinds of cases studies do the General Biology faculty actually find most useful in their classrooms? Surprisingly to us, there was abundant diversity: 275 different cases were chosen out of a total of 500 cases available (55%), but 80 of these cases were only chosen one time (i.e., these cases were specific to the tastes and needs of only one teacher). On the other hand, 195 cases were identified by more than one person. The Mystery of the Seven Deaths (the top choice), which teaches students about cellular respiration and the electron transport chain though a story based loosely on the real-life 1982 Chicago Tylenol murders, was chosen by 75 different faculty (17.6% of total taking the survey),
but because 46 faculty said they used cases but didn’t identify the particular cases used, the percentage is probably higher. This is especially likely since most of these folks said they used cases exclusively from the NCCSTS website.

Figure 3 shows the distribution of the choices and the overwhelming number of faculty who favor cell and molecular biology. With this as background, let’s turn to how these case study teachers are responding to the flipped classroom movement. Our survey shows that only 20% have seriously integrated the method into their classrooms, with over 40% rarely or never using it, and 35% using it occasionally. So far it seems that the method hasn’t been widely adopted.

Figure 4 shows the subject areas where videos are used; recognize that this reflects on both the teachers’ choices and the limited availability of videos in certain subject areas.

Most faculty who use videos don’t make them themselves. Only 20% of the faculty who responded to our survey do so. And the ones that have been submitted to the NCCSTS as examples are mostly slide show presentations with the teacher’s disembodied voiceover explaining all. A few showed an inset with a headshot of the instructor as well. Interestingly, in a survey of 200 faculty who said they were crafting instructional videos, 47 different software programs were identified. The most common ones were Camtasia (44%), iMovie (24%), Windows Movie Maker (9%), and Tegrity (8%). In spite of the different programs used, creative videos were rare (e.g., there were none like the animations showcased by The Virtual Cell Animation Collection at the Molecular and Cellular Biology Learning Center (http://vcell.ndsu.edu/animations/). But because no one seems to have studied the impact of these different styles of presentation, it is hard to be critical except on aesthetic grounds; indeed, the videos showing a student teacher giving a minilecure might be the most compelling and enlightening after all.
on open-access sites. And in spite of its great publicity, few biology teachers use those of the Khan Academy; the latter are basically chalkboard descriptions with a voiceover. Students are not enchanted with such presentations in our experience. In contrast, the Bozeman science series has a wide audience (see http://www.bozemanscience.com/about/). This site is maintained by Paul Andersen, a high school science teacher in Bozeman, Montana, who has produced hundreds of videos published on YouTube in all fields of science. His videos are brief, with large numbers of pictures and always with a headshot of him talking. He is young, energetic, and articulate. Take a look at him giving a TED talk and you will get the idea (http://www.bozemanscience.com/speaking-workshops/).

Returning to the theme of this essay, case studies in science have a great potential; thousands of instructors are using them. But their use would be much more common if we solved the major problem of coverage. It is a given that teachers need to feel that they are treating their subject matter in sufficient depth in their classes. The flipped classroom approach—with its reliance on excellent videos—is one solution to this dilemma. But the bottom line is that we need more excellent cases supported by videos that are targeted, readily obtained/accessible (e.g., via YouTube), and need we say it again . . . free.

Acknowledgments
This material is based on work supported by the National Science Foundation (NSF) under Grant Nos. DUE-0341279, DUE-0618570, DUE-0920264, and DUE-1323355. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

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Emotion, Engagement, and Case Studies

By Clyde Freeman Herreid, David R. Terry, Paula Lemons, Norris Armstrong, Peggy Brickman, and Eric Ribbens

Three college faculty taught large general biology classes using case studies and personal response systems (clickers). Each instructor taught the same eight cases in two different sections, except the questions within the cases differed. In one section the questions were lower order (LO) factual inquiries, and in the other they were largely higher order (HO) application, analysis, or evaluation queries. Students indicated after each case how much they were engaged or emotionally involved in the cases. Cases ranged significantly in both attributes, but for all cases students indicated that they had a higher engagement level than an emotional involvement. There were minor but statistically significant correlations among engagement, emotion, and learning gains. Generally, cases with LO questions evoked greater engagement and emotion than cases with HO questions.

The importance of emotion and its impact on learning has attracted serious attention in recent years. Investigations connecting the two range across the spectrum, and they emphasize different aspects of the emotional range (e.g., joy/sadness, acceptance/disgust, anger/fear, surprise/anticipation) as they relate to questions about the role of stress (Joels, Pu, Wiegert, Oitzl, & Krugers, 2006); the amygdala (Dolan, 2002; Richter-Levin & Akirav, 2003); norepinephrine and its central role in the emotional regulation of memory (Hu et al., 2007); emotions evoked by text material (Ainley, Corrigan, & Richardson, 2005); effects of emotion and emotional strategies in e-learning environments (Lee, 2011, 2012); the importance of gender differences (Ingleton, 1995); reality TV in the classroom and emotional intelligence (Luke, 2006); personality and success in analyzing case studies (Parkinson & Taggar, 2006); measuring emotions in an academic setting (Pekrun, Goetz, Franzel, Barchfeld, & Perry, 2011); and the effect of using “clickers” on learning and emotion (Stowell & Nelson, 2007). As instructors who are interested in the use of case studies in science, technology, engineering, and mathematics (STEM) education (Herreid, 2007), we have wondered if cases that probe emotional issues can affect the learning of particular subject matter. If emotion is a serious factor in determining learning outcomes, how might we design case studies to take advantage of that fact?

Case studies have been used for 100 years in law and business schools in the instruction of students. The design of these cases has naturally attracted attention from case writers and teachers, but the issue of the emotional content of the case has seldom been raised. For example, Robyn (1986) summarized some key qualities of good cases in the field of public policy, mentioning that they should be brief, of general applicability, conflict provoking, and decision forcing. If cases are designed with the latter two criteria mind, these elements could potentially evoke strong emotional reactions, which may in fact affect learning.

Erskine, Leenders, and Mauffette-Leenders (1981), in their seminal book on case studies in the field of business, produced a model called the case difficulty cube, showing how cases can be created that fall along three dimensions of increasing difficulty: analytical, conceptual, and presentational. Once again, the issue of emotion was not directly discussed here or in Herreid’s (1997/1998) list of criteria for a good case, although its importance may be inferred from the fact that he argued that cases should focus on an interest-arousing issue, create empathy for the central characters, and involve conflict. In an analysis of 100 studies in a wide variety of professions, Kim et al. (2006) identified five core attributes of cases: relevant, realistic, engaging, challenging, and instructional. But nowhere does the word emotion appear in their...
The students multiple-choice questions where the teacher periodically inserting a PowerPoint projection system. In the case study, the instructor presents the case study using a PowerPoint projection system. The teacher periodically inserted the PowerPoint projection system into the presentation. In the study, the instructor presented the case study using a PowerPoint projection system. The teacher periodically inserted the PowerPoint projection system into the presentation. In the study, the instructor presented the case study using a PowerPoint projection system. The teacher periodically inserted the PowerPoint projection system into the presentation.

The report of Young and Anderson (2010) is particularly interesting because it compares learning with two types of cases in which emotional factors could come into play; two different case study formats (clinchently oriented cases versus personally oriented cases) were compared in a microbiology course. Clinical cases were impersonal, terse recitations of pertinent technical facts that a person might require to make a diagnosis of a patient. Personally oriented cases presented material as a “story about the patient with information regarding their family circumstances, personal characteristics, ethnic information and individual motivations” (p. 108). The authors found that using personalized cases significantly improved long-term retention of course content and also that these cases were more effective in developing patient empathy and aiding students in understanding issues patients have with complying with treatment recommendations.

The issue of emotion is directly addressed in the research by Lundeberg and colleagues (2011) on “clicker cases.” Clicker cases are especially appropriate for large classes. An instructor presents the case study using a PowerPoint projection system where the teacher periodically interrupts the flow of the storyline and asks the students multiple-choice questions (Herreid, 2006). The questions are projected on a screen, and students answer by using personal response system remote control devices (clickers); their answers are sent via radio frequency and received by a classroom computer. Data from individual students can be collected, but typically class averages are displayed to the class in the form of a histogram, and a discussion follows. In a comparison of eight clicker-case studies, a dozen faculty from different institutions concluded that strong clicker cases were those that caused “emotional dissonance,” captured attention, and involved students in interpreting data or making decisions (Lundeberg et al., 2011). Emotional involvement was a key difference that characterized the case that faculty rated as best (Cell Division) and worst (Characteristics of Life). As part of that study, Kang, Lundeberg, Wolter, delMas, and Herreid (2012) noted that clicker cases created learning environments that are particularly conducive to female students’ engagement and learning. They theorized that this is because the cases often contained an emotional “hook” into the material, often through a personal story in which a protagonist faced a dilemma or a crisis, and created a particular interest or empathy in female learners that motivated their learning. In none of these studies did the authors attempt to define in any rigorous or testable way just what the terms engaging or emotion meant, nor does there appear to be a common operational definition for these terms.

To further our understanding of the role that emotion and engagement play in student learning, we undertook this study comparing student responses to eight different clicker cases. Our interest in student engagement as part of this equation stems from the obvious point that students must be paying at least minimal attention to a case to be able to interact with the material and to respond to the clicker questions. Like the term emotion, student engagement and how it should be measured is filled with debate as Taylor and Parsons (2011) noted, and they indicated that researchers have recently been turning to students asking how they would measure engagement. Traditionally, engagement has been measured using self-reporting surveys, questionnaires, checklists, and rating scales. We retain that approach here in the current study. The National Survey of Student Engagement (NSSE) is the most notable (Kuh, 2001). Largely, researchers have focused their attention on long-term interactions of students with teachers, schools, or curriculum rather than on a single classroom exercise. But the overwhelming conclusion is that active learning strategies such as using case studies are a pivotal motivator for student engagement. When students are engaged, “they show generally positive emotions during ongoing action including enthusiasm, optimism, curiosity and interest” (Skinner & Belmont, 1993, p. 572).

On the basis of the literature cited previously, we anticipated that cases that involved characters who were real people, were contemporary, and displayed Plutchik’s (1980) fundamental eight basic emotions (anger, fear, sadness, disgust, surprise, anticipation, trust, joy) might have the greatest effect on the student learning. Similarly, we hypothesized that cases that engaged students would be those that piqued their curiosity and interest with realistic and relevant stories. We did not expect that cases that were a simple recitation of facts would have that impact.

This was part of a larger study, addressed in another paper, which considered the question of how the...
type of questions asked in a clicker case can affect critical thinking. Next we describe the methodology for the larger study as background to our present focus in this paper on emotion and case studies.

**Methods**

Bloom (1956) catalogued knowledge into different categories ranging from low order to higher order (critical thinking) stages. We used this model to design two versions of a set of eight clicker cases, one version of a case with lower order (LO) questions focused on factual knowledge and comprehension and the other version with higher order (HO) questions that required application, analysis, and evaluation. Synthesis was excluded because of the use of multiple-choice questions (Crowe, Dirks, & Wenderoth, 2008). The clicker case studies were designed for use in six general biology courses, each with 100–330 students. Three different faculty were involved in the study. Each taught two classes. In one class they taught the case with LO questions and in the other the case with HO questions. Thus we could compare the effectiveness of the two different types of case questions in terms of their impact on students’ critical thinking.

The number of questions that were posed in each case varied between 7 and 12. The cases were taught in one or two consecutive class periods, depending on their subject material. Points toward the final grade were granted for attempting to answer the questions.

We used three different methods of assessment of critical thinking and learning: the Watson-Glaser Critical Thinking Appraisal (WGCTA; Watson & Glaser, 1994), a multiple-choice test, and two essay questions. These evaluation instruments were administered to students at the beginning and at the end of the semester and are explained in more detail next. Relevant to the present paper, at the end of each clicker case the last two slides asked the students to rank their emotional involvement and their engagement with the case using Likert scales as seen in Figure 1.

Note that we did not attempt to define either of the terms for the students as there is not an accepted operational definition of these terms in the literature. Rather, the literature is encumbered by an enormous range of definitions, so the results should be considered exploratory. With this minimalist approach, we hoped to find out at least if different cases evoked different responses and if this had any perceived impact on their learning. A further limitation of the research is that we have only group averages for most of the students and therefore cannot provide a detailed analysis of the impact of the cases on individual students.

**Participants**

The three instructors in the study were veterans in the use of case studies and clickers and were case study authors themselves. Further, they had previously participated in the research of Lundeberg et al. (2011), and during that study they taught six out of the eight cases used in the current study. Also, they were deeply involved in the design of all of the final versions of the cases, and they tested these eight cases during a year of pilot work before the data in the present paper were collected.

Two of the instructors were situated at a large, doctoral-granting, public institution in the southeastern United States. Their four courses each had about 330 students. The third instructor was at a large, masters-granting, public institution in the Midwestern United States. His two courses each had about 100 students. Although there were some differences in the general biology syllabi and clientele between instructors, the two courses taught by each instructor were closely matched in terms of the demographic analysis. No significant differences were found between the classes as evidenced by a one-way multivariate analysis of variance (MANOVA) examining gender, ethnicity, GPA, major, year of study, and prior case or clicker experience (Wilks’s Λ = .993; F(7, 1286) = 1.22, p = .29). Instructors ran their general biology courses as usual except for the inclusion of eight case studies covering cells, metabolism, DNA replication, genetic code, Mendelian genetics, the genetics of sex linkage and crossing over, evolutionary mechanisms, and human evolution. The cases were incorporated into lecture-based courses that included varying use of active learning.
techniques. All instructors used clickers throughout the semester to assess student understanding of the questions.

**HO question and LO question clicker cases**

HO clicker cases were defined as those cases with at least 50% HO questions (application, analysis, evaluation), whereas lower order clicker cases were defined as clicker cases with all LO questions (knowledge, comprehension). Eight clicker cases were prepared in two versions, differing primarily in the nature of their questions. Six of the eight cases (with a mixture of LO and HO questions) had been used in our previous study (Lundeberg et al., 2011), although some modifications were made. Two were created new for this work.

The writing of HO clicker questions was guided by a tool derived

<table>
<thead>
<tr>
<th>Short Title</th>
<th>Full title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santhi</td>
<td>Cross-Dressing or Crossing Over?</td>
<td>Students learn about sex determination, meiosis, and chromosomal “crossing over” through the story of Santhi Soundararajan, an athlete from Kathakkurichi, India, who was stripped of a medal at the 2006 Asian Games after failing to pass a sex test.</td>
</tr>
<tr>
<td>Patrick</td>
<td>Why Is Patrick Paralyzed?</td>
<td>Students learn of a rare genetic disease in which an enzyme is deficient in a critical metabolic pathway—the first step in aerobic respiration. Based on a real-life situation, the case challenges students to make connections between energy production, enzymes, and metabolic diseases.</td>
</tr>
<tr>
<td>Druid</td>
<td>The Case of the Druid Dracula</td>
<td>This case is based on a crime featured on the BBC program Crimewatch in December 2001 that was solved because of forensic DNA analysis. Students learn how the structure of DNA and the mechanism used by cells to duplicate DNA were critical to the forensic analysis. They then determine the statistical validity of the forensic data in the same way a prosecutor would prepare the case for a courtroom.</td>
</tr>
<tr>
<td>Human Evo</td>
<td>The Discovery of Ardi</td>
<td>This case details the painstaking work of the discovery and reconstruction of fossils of a new genus of “humans.” Taking over 20 years of work, dozens of researchers piece together the diet, anatomy, and behavior of Ardipthecus ramidus. Students make predictions based on the data and compare their conclusions with those of the experts.</td>
</tr>
<tr>
<td>Canid</td>
<td>Not Necessarily on Purpose</td>
<td>The case, which deals with evolution, speciation, and natural selection and interprets phylogenies as they apply to the Canidae family, is based on the idea that the domestication of the dog was not likely an intentional event in human history, but rather the result of natural selection events.</td>
</tr>
<tr>
<td>Take 2</td>
<td>Take Two and Call Me in the Morning</td>
<td>Students read about a college student, Ellie, who becomes sick. As they set out to identify the cause of the illness, students learn about the differences between viruses, prokaryotes, and eukaryotes to decide which organism is causing the infection.</td>
</tr>
<tr>
<td>Mendel</td>
<td>Mendel Dreams</td>
<td>Students are introduced to the life and work of Gregor Mendel, who as the story opens is terminally ill and reminiscing about his pea plant experiments. Students analyze data the way that Mendel presumably had to do himself. The case covers early genetics including monohybrid and dihybrid crosses and discusses the downfall of the blending hypothesis.</td>
</tr>
<tr>
<td>Decoding</td>
<td>Decoding the Flu</td>
<td>This case was designed to develop students’ ability to read and interpret information stored in DNA. Students follow the story of “Jason,” a student intern at the Centers for Disease Control (CDC). While working with a CDC team in Mexico, Jason is the only person who does not get sick from a new strain of flu. It is up to him to use molecular data collected from different local strains of flu to identify which one may be causing the illness.</td>
</tr>
</tbody>
</table>
from Bloom’s Taxonomy (Anderson & Krathwohl, 2001; Bloom, 1956), the Blooming Biology Tool (Crowe et al., 2008), and related work (Bissell & Lemons, 2006). Specifically, this tool aligns action verbs with LO and HO questions (Lemons & Lemons, 2013). To improve the validity and quality of HO questions, seven biologists who were not involved with question writing rated every question. Questions that were not rated HO by a majority of raters were revised and rated again until they earned a HO rating (Lemons & Lemons, 2013).

Assessment of student learning
We assessed student learning at the beginning of the semester (pretest) and at the end of the semester (posttest) using three measures: (a) the WGCTA (Watson & Glaser, 1994), (b) a content-oriented multiple-choice test consisting of 40 AP-type exam questions, and (c) two short-answer questions requiring content and HO cognitive skills. The results of this work will be reported in a separate paper, but a brief description of the approach follows: The WGCTA (Watson & Glaser, 1994) was administered in one class session, and the multiple-choice test and short-answer questions were administered together in a separate class session. All pretests were administered during a regular class session. Students did not receive credit for pretest completion, but they were verbally encouraged to do their best (e.g., so that instructors could learn what students know and don’t know). The WGCTA posttest was administered in one of the last class sessions of the semester. The multiple-choice test and short-answer

<table>
<thead>
<tr>
<th>TABLE 2</th>
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</thead>
<tbody>
<tr>
<td>Students rate low-order cases as more engaging than high-order cases.</td>
</tr>
<tr>
<td>Treatment</td>
</tr>
<tr>
<td>Lower order</td>
</tr>
<tr>
<td>18.8%</td>
</tr>
<tr>
<td>Higher order</td>
</tr>
<tr>
<td>15.5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student ratings of individual cases for their level of engagement.</td>
</tr>
<tr>
<td>Case</td>
</tr>
<tr>
<td>Santhi</td>
</tr>
<tr>
<td>M = 2.48 ± 1.17</td>
</tr>
<tr>
<td>Human Evo</td>
</tr>
<tr>
<td>M = 2.63 ± 1.27</td>
</tr>
<tr>
<td>*Patrick</td>
</tr>
<tr>
<td>M = 2.65 ± 1.16</td>
</tr>
<tr>
<td>Druid</td>
</tr>
<tr>
<td>M = 2.69 ± 1.24</td>
</tr>
<tr>
<td>Canid</td>
</tr>
<tr>
<td>M = 2.73 ± 1.24</td>
</tr>
<tr>
<td>Take 2</td>
</tr>
<tr>
<td>M = 2.78 ± 1.17</td>
</tr>
<tr>
<td>*Mendel</td>
</tr>
<tr>
<td>M = 2.92 ± 1.26</td>
</tr>
<tr>
<td>*Decoding</td>
</tr>
<tr>
<td>M = 3.22 ± 1.21</td>
</tr>
</tbody>
</table>

*Significantly different from case above, using the Holm’s sequential Bonferroni method at the .05 level.
questions were administered as part of the final exam.

**The case studies**

The eight case studies used in this study were all designed to deal with fundamental topics typically taught in a general biology class. Table 1 shows a summary of each case with their abbreviated titles, followed by the full formal title and a short description; a version of each can be accessed on the website of the National Center for Case Study Teaching in Science (sciencecases.lib.buffalo.edu).

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**Results**

**Engagement**

A two-way contingency table analysis determined that students in the LO case study classes rated the cases as more engaging than those in the HO case study classes. Treatment and Engagement were found to be significantly related, Pearson $\chi^2(4, N = 8,968) = 43.90, p < .001$. See Table 2 for values.

A two-way contingency table analysis determined that students rated some cases as more engaging than others. Cases and Engagement were found to be significantly related, Pearson $\chi^2(28, N = 8,968) = 326.97, p < .001$. See Table 3 for values. Note that the cases are arranged in the table with the most engaging cases at the top. (The lower the mean, the more engaging was the case ranked.) The asterisks on the left side of the table indicate that the answer distribution for a case is significantly different from the case just above it. This was established using post hoc chi-squares tests. However, it is important to emphasize that the mean values give an inadequate representation of the

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**TABLE 4**

Students rate low-order cases as more emotional than high-order cases.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Most (1)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Least (5)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower order</td>
<td>544</td>
<td>12.5%</td>
<td>632</td>
<td>14.5%</td>
<td>1,306</td>
<td>30.1%</td>
</tr>
<tr>
<td>Higher order</td>
<td>441</td>
<td>10.3%</td>
<td>500</td>
<td>11.7%</td>
<td>1,238</td>
<td>28.9%</td>
</tr>
</tbody>
</table>

**TABLE 5**

Student ratings of individual cases for their emotional content.

<table>
<thead>
<tr>
<th>Case</th>
<th>Most (1)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Least (5)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santhi $M = 2.72 \pm 1.23$</td>
<td>211</td>
<td>19.0%</td>
<td>269</td>
<td>24.3%</td>
<td>382</td>
<td>34.5%</td>
</tr>
<tr>
<td>*Patrick $M = 2.90 \pm 1.23$</td>
<td>194</td>
<td>15.2%</td>
<td>288</td>
<td>22.5%</td>
<td>421</td>
<td>32.9%</td>
</tr>
<tr>
<td>*Druid $M = 3.22 \pm 1.24$</td>
<td>124</td>
<td>10.6%</td>
<td>192</td>
<td>16.5%</td>
<td>402</td>
<td>34.4%</td>
</tr>
<tr>
<td>*Human Evo $M = 3.40 \pm 1.33$</td>
<td>95</td>
<td>12.1%</td>
<td>86</td>
<td>11.0%</td>
<td>247</td>
<td>31.5%</td>
</tr>
<tr>
<td>Canid $M = 3.42 \pm 1.27$</td>
<td>90</td>
<td>10.5%</td>
<td>87</td>
<td>10.2%</td>
<td>286</td>
<td>33.4%</td>
</tr>
<tr>
<td>*Mendel $M = 3.69 \pm 1.30$</td>
<td>98</td>
<td>8.9%</td>
<td>92</td>
<td>8.3%</td>
<td>306</td>
<td>27.7%</td>
</tr>
<tr>
<td>Decoding $M = 3.77 \pm 1.25$</td>
<td>78</td>
<td>7.0%</td>
<td>85</td>
<td>7.7%</td>
<td>299</td>
<td>27.0%</td>
</tr>
<tr>
<td>*Take 2 $M = 4.08 \pm 1.22$</td>
<td>95</td>
<td>7.8%</td>
<td>33</td>
<td>2.7%</td>
<td>201</td>
<td>16.5%</td>
</tr>
</tbody>
</table>

*Significantly different from case above, using the Holm’s sequential Bonferroni method at the .05 level.
statistical point that we make; it is the overall distribution of the student votes across the Likert scale that we note that are different among cases, not the mean values per se, which are sometimes nearly identical.

**Emotion**

A two-way contingency table analysis determined that students in the LO case study classes rated the cases as more emotional than those in the HO case study classes. Treatment and Emotion were found to be significantly related, Pearson $\chi^2(4, N = 8,625) = 41.78, p < .001$. See Table 4 for values.

A two-way contingency table analysis determined that students rated some cases as more emotional than others. Cases and Emotion were rated some cases as more emotional than others. Cases and Emotion were found to be significantly related, Pearson $\chi^2(28, N = 8,625) = 1193.29, p < .001$. See Table 5 for values. Note that the cases are arranged in the table with the most emotion evoking cases at the top. (The lower the mean, the more emotional was the case ranked.) Again, the asterisks on the left side of the table indicate that the Likert distributions displayed for a case is significantly different from the case just above it. This was determined using pairwise post hoc chi-squares tests. A statistically significant ($p < .01$) but weak positive correlation was found between the case-specific engagement level and the case-specific emotion level, $r(656) = .26$.

**Learning gains**

Although we will present a more complete analysis of the learning gains in a forthcoming paper, here it is useful to outline our method of assessment. A one-way analysis of covariance (ANCOVA) was conducted to determine if there were differences in learning gains between the cases with LO questions versus those with HO questions. The independent variable consisted of the eight cases. The dependent variable was the change score (post–pre) on the multiple-choice questions specific to each case, and the covariate was the pre-MC score on those same questions. The ANCOVA was significant, $F(7, 9972) = 102.52, MSE = 2.22, p < .001$. Decoding showed the greatest learning gain ($M = 1.98 \pm 1.58$; pre-MC = 2.07 ± 1.34), followed by Santhi ($M = 1.77 \pm 1.55$; pre-MC = 1.40 ± 1.05), Mendel ($M = 1.57 \pm 1.48$; pre-MC = 2.07 ± 1.25), Druid ($M = 1.57 \pm 1.48$; pre-MC = 2.34 ± 1.24), Canid ($M = 1.49 \pm 1.43$; pre-MC = 1.53 ± .99), Patrick ($M = 1.18 \pm 1.55$; pre-MC = 1.31 ± 1.02), Human Evo ($M = 1.14 \pm 1.32$; pre-MC = 1.25 ± .99), and Take 2 ($M = 0.62 \pm 1.49$; pre-MC = 1.67 ± 1.11).

Follow-up tests were conducted to evaluate pairwise differences among these adjusted means. Post hoc comparisons were made using Dunnett’s C test, a test that does not assume equal variances among the groups. The order (and significance) of learning gains is as follows:

Decoding > Santhi, > Mendel, Druid, & Canid > Patrick & Human Evo > Take 2

A statistically significant ($p < .01$) but extremely weak positive correlation was found between the case-specific multiple-choice test change score (mean learning gain) and the case-specific emotion level, $r(9,978) = .08$.

**Discussion**

What do the results suggest about how we might design cases to engage the most interest and learning? As expected, the results indicate that cases differ in their emotional tone and their engagement potential. Further, there is a low but significant correlation between the two. This is evident in the rankings.

Here are the engagement rankings:

Santhi & Human Evo > Patrick, Druid, Canid & Take 2 > Mendel > Decoding

Here are the emotion rankings:

Santhi > Patrick > Druid > Human Evo & Canid > Mendel & Decoding > Take 2

Interestingly, students were much more likely to give all cases strong engagement scores than give them strong emotion scores. In fact, the average emotion score was 3.4 (recall that the strongest possible emotion score was 1 and the weakest was 5 on the Likert scale), whereas the average engagement score was 2.8. There was not a single instance in which a case had a stronger emotional response than an engagement response. This may reflect students’ reluctance to expose themselves to public scrutiny of their emotions, whereas engagement is a much less threatening and neutral word. But possibly it is because the whole exercise of using clickers involves active participation; this is engagement, and they recognize it.

What are the characteristics that make some cases more engaging and emotional than the others? Pekrun (2010) arranged academic emotions...
into four categories: achievement emotions, topic emotions, social emotions, and epistemic emotions. According to D’Mello and Graesser (2012, pp. 145–146), “Achievement emotions (e.g., contentment, anxiety, and frustration) are linked to learning activities (e.g., homework, taking a test) and outcomes (e.g., success, failure). Topic emotions are aligned with the learning topic” (e.g., empathy for a protagonist such as Santhi or Patrick). “Social emotions such as pride, shame, and jealousy are not directly related to the topic but reflect the fact that educational activities are socially situated. Epistemic emotions arise from cognitive information processing, such as surprise when novelty is encountered or confusion when the student experiences an impasse.” It would appear that in our present study we tapped into all aspects of academic emotions; however, we did not collect any data that would allow us to quantify differences among the cases that might exist in these qualities.

Plutchik (1980) identified eight basic emotions (anger, fear, sadness, disgust, surprise, anticipation, trust, and joy), and Skinner and Belmont’s (1993) research pointed out that engagement is expressed via enthusiasm, optimism, curiosity, and interest. Even a superficial reading of the cases suggests that they would be quite variable in these qualities, and we have not made any attempt to quantify these differences. But we note that on the high end of the scales, Santhi, Patrick, and Druid cases evoked strong scores: They involved real people under serious distress; moreover, they also induced curiosity and interest as to the eventual outcome of their stories. On the lower end of the emotion and engagement continuum, we see Decoding the Flu, which largely lacked these qualities as it was an obviously fabricated story line. The Human Evolution case is interesting because it ranked high in engagement but was middle of the road in generating emotion. This is rather predictable because there were no obvious emotional tags, but we humans are inherently fascinated with our origins, hence we can expect high engagement scores. Because of space limitations, we cannot provide a detailed examination of each case. However, we can point out that the type of learning required of the student may influence or overwhelm the impact of emotion. For example, a major part of the learning goals for Decoding and Druid are for students to understand and be able to apply a process (transcribing, translating, and replicating nucleotide sequences). Human Evolution and Take 2 require more data interpretation, analysis, and categorization.

The results unexpectedly showed that LO question cases produced higher emotional and engagement levels than HO question cases. One of the faculty instructors remarked that this might be due to the students in the HO question class being more frustrated with the difficulty of the questions than in the LO question class and thus enjoying it less. This comports well with D’Mello and Graesser’s (2012) conclusions that learners can experience cognitive disequilibrium and confusion when they face contradictions, incongruities, anomalies, obstacles to goals, and other impasses. Failure to resolve these issues will eventually lead to boredom. Nonetheless, there was no statistical difference in learning gains shown in the multiple-choice exams between the HO and LO groups (Terry et al., n.d.). So whatever the reason for the LO cases’ appeal, this difference did not play out in terms of the learning gains.

As far as the learning gains are concerned, there was a statistically positive correlation between the emotion that students experienced and the learning gains. Below is the order of the learning gains:

Decoding > Santhi, > Mendel, Druid, & Canid > Patrick & Human Evo.> Take 2

Here are the emotion rankings:

Santhi > Patrick >Druid > Human Evo & Canid > Mendel & Decoding > Take 2

The relation between this sequence and emotion and engagement is very weak. Additionally, Decoding appears at the top of the list—in spite of the fact that it was positioned at the bottom of the engagement and emotional scales. Clearly, learning is not strongly dependent on these qualities. But what should be remembered is this: The potential for learning gains was undoubtedly different for different cases. Students come into class with varying backgrounds in subject matter; the cases themselves vary in the amount of information and challenges that they pose. Further, their precase scores vary among the cases; potentially, topics with higher precase scores have less room for improvement than those topics with low pretest scores. However, an analysis does not bear this prediction out, as the correlation between pretest scores and learning gains across the eight cases was not statistically significant, r(6) = .40, p = .32. This lack of statistical significance could very likely be due to small sample size (only eight cases), but pretest scores clearly don’t seem to make much of a difference in
terms of average learning gains in this study.

So, what does this all mean to the design of case studies? This exploratory study suggests that cases vary in how engaging and emotional they are for students. Further, the literature quoted in the introduction suggests that if we want emotional and engaging cases, they should involve protagonists that are contemporary, real, threatened, or under duress and that evoke our sympathies. Indeed, these are the same qualities that make novels, films, and TV shows intriguing. Certainly, our data on cases such as Santhi are consistent with this notion. But what exactly are we measuring when we ask students about their emotion and engagement? Further, will the same cases (e.g., Santhi and Decoding) produce similar learning gains in other student populations? The complexities of this issue have suddenly become even deeper with the report of Plass, Heidig, Hayward, Homer, and Um (2013), who have recently shown that the color and shape of objects in a multimedia presentation can influence emotion and learning. Clearly, if we are to improve our understanding of these properties, we must establish operational definitions where we can establish what the differences among cases might be.

Complicating the issue further, our data also suggest that learning can take place even with lower levels of emotion and engagement such as we note with the Decoding case, where large amounts of information was effectively delivered about the structure of DNA and its transcription into RNA. This begs the question: Why should we make an effort to design cases with the engaging or emotional components when the best case in terms of learning outcome doesn’t have these qualities at all? The answer might be that there are other outcomes, such as enthusiasm for science, that teachers are trying to engender in students that are not measured by exam questions. But if learning outcomes are what we are interested in, we need to make every effort to dissect what it is about cases such as Decoding that made it so successful. And because previous research has indicated that emotional impact can influence learning, under what circumstances does this happen and when does it not? Such questions go to the heart of case study design, which we take up in a forthcoming paper on learning gains (Terry et al., n.d.).

Acknowledgment
This material is based on work supported by the National Science Foundation (NSF) under Grant DUE-0920264. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

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Current Issues in Education, 14, 1–32.


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NSTA National Science Teachers Association
Training the Foot Soldiers of Inquiry: Development and Evaluation of a Graduate Teaching Assistant Learning Community

By Kimberly Linenberger, Michael C. Slade, Elizabeth A. Addis, Emily R. Elliott, Glené Mynhardt, and Jeffrey R. Raker

As part of a Howard Hughes Program for Innovation in Science Education grant at Iowa State University, a series of interdisciplinary graduate teaching assistant learning communities (TALC) were developed. The purpose of these communities was to create an environment to facilitate teaching assistants’ pedagogical development and training to enhance the implementation of inquiry experiences in the undergraduate laboratories. The TALC evaluated in this study were held for two consecutive semesters and included teaching assistants who facilitated multiweek course-based research experiences in their respective STEM courses. Topics discussed during the TALC were based on the teaching assistants’ concerns related to teaching this type of course. Evaluation consisted of weekly reflection responses, a pre- and post-survey of instructional methods they consider to facilitate inquiry, pre–post definitions of inquiry-based instruction, and end-of-semester evaluations of the learning community experiences. This article outlines the development of the TALC and findings from the various forms of evaluation.

More and more research focused on the implementation and effectiveness of inquiry-based instruction that incorporates research experiences is making its way into the educational and scientific literature (Lindsay & McIntosh, 2000; Newton, Tracy, & Prudente, 2006; Russell & Weaver, 2011; Samarapungaven, Westby, & Bodner, 2006; Weaver, Russell, & Wink, 2008). These studies often describe the specific research project conducted, acceptance of the project by students as a viable learning experience, and a lengthy list of project pitfalls and recommendations for improvement. Course-based research experiences (CBREs) in the instructional laboratory (i.e., pseudo-research experiences) as teaching tools are still in their infancy as viable and easily implementable instructional practices. One area that has had little study is the pedagogical development of graduate student teaching assistants (TAs) tasked with implementing these CBREs. Because graduate student TAs are commonly the primary resource for undergraduates in laboratory courses at large universities, their ability to implement the CBRE is paramount to the labs’ success. Although several studies have discussed general training for TAs (Addy & Blanchard, 2010; Baumgartner, 2007; Marbach-Ad et al., 2012; Petrinjak, 2010), there is little research to describe how to prepare TAs for the unique environment inherent to courses with embedded CBREs. This manuscript addresses the formation, implementation, and evaluation of a two-semester learning community designed to give TAs the opportunity to develop the necessary skills to teach in CBRE learning environments. It also addresses the concerns of those TAs currently attempting to implement CBREs.

Formation and implementation

In the context of a university-wide initiative at Iowa State University aimed at implementing inquiry-based laboratory experiences into the undergraduate curriculum, TAs and postdoctoral research associates from a broad array of science, technology, engineering, and mathematics (STEM) disciplines (i.e., biology, chemistry, geosciences, and psychology) were brought together into a learning community. Support for this initiative was provided through a Howard Hughes Medical Institute (HHMI) grant. The focus of the learning community was to address the concerns of TAs tasked with implementing CBREs in their
respective laboratory courses. The degree to which CBREs were implemented in the courses ranged. Many courses in chemistry consisted of traditional “cookbook” experiments for the first 8 weeks and then began the CBRE module. Biology courses had traditional experiments but required students to think of a researchable question based on the topic of the traditional lab, and at the end of the semester the students had 2–3 weeks to answer one of the questions. The geoscience courses used inquiry-based experiments throughout with a CBRE at the end of the semester. Therefore, the amount of inquiry training and experience the TAs came to the learning community with and used throughout the semester varied greatly. The biology TAs had much more latitude in regard to how they went about teaching the material in the laboratory, whereas the geoscience and chemistry TAs had a much more scripted role in their teaching.

The purpose of the interdisciplinary participant mix was to leverage the idea that despite content differences, the experiences of TAs in these instructional settings are similar. TAs from courses implementing CBREs in the instructional laboratory self-selected to participate in the learning community. TAs received a stipend for participating in the amount of their semester student fees and were encouraged to list their participation in the learning community on their curriculum vitae; stipends were distributed at the conclusion of each semester. Participation in the learning community was limited to two semesters.

### TABLE 1

Weekly discussion topics and relevant articles read by participants in the learning community.

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic of discussion</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>First semester</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Introduction to the Learning Community</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Understanding Inquiry-Based Instruction</td>
<td>Weaver, Russell, &amp; Wink 2008; Spencer, 1999; Eberlein et al., 2008</td>
</tr>
<tr>
<td>3</td>
<td>Asking Good Questions</td>
<td>Lord &amp; Baviskar, 2007; DeHaan, 2011; Heer, 2009; Overbaugh &amp; Shultz, 2008; Crowe, Dirks, &amp; Wenderoth, 2008; Chin, 2007; Blosser, 1991&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>Promoting Student Interest / Motivation</td>
<td>Callahan, 2010; Svinicki, 2005; Davis, 1993&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>Working with Faculty and Course Instructors</td>
<td>Internal documents provided by faculty (if any), listing expectations of TAs; survey results of faculty and TAs for comparison and discussion</td>
</tr>
<tr>
<td>7</td>
<td>Wrap Up</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td><strong>Second semester</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Transitioning Experiments to an Inquiry Format</td>
<td>Bruck, Bretz, &amp; Towns, 2008; Allen, Barker, &amp; Ramsden, 1986; Volkman &amp; Abell, 2003</td>
</tr>
<tr>
<td>2</td>
<td>Developing Rubrics</td>
<td>Biggs, 2003; Andrade, 2005; Allen &amp; Tanner, 2006&lt;sup&gt;b&lt;/sup&gt;; Crow, Dirks, &amp; Wenderoth, 2008&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>Giving Feedback to Students</td>
<td>Brookhart, 2008; Weaver, 2006</td>
</tr>
<tr>
<td>4</td>
<td>Fostering Student Interest and Motivation</td>
<td>Ryan &amp; Deci, 2000; Vanderbilt University, Center for Teaching, 2013; Kirk, 2013; Callahan, 2010&lt;sup&gt;ab&lt;/sup&gt;; Svinicki, 2005&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>Transitioning Students to an Inquiry Format</td>
<td>Bruck &amp; Towns, 2009; Duran, McArthur, &amp; Van Hook, 2004</td>
</tr>
<tr>
<td>6</td>
<td>How Students Learn</td>
<td>Riefer &amp; Willingham 2010; Pashler et al., 2007</td>
</tr>
<tr>
<td>7</td>
<td>Wrap Up</td>
<td>None</td>
</tr>
</tbody>
</table>

*Note: TA = teaching assistant.*  
<sup>a</sup>Optional reading; <sup>b</sup>New teaching assistant learning communities (TALC) members were directed to these as optional.
Sixteen TAs participated in the first semester; four of the authors of this manuscript facilitated the learning community. Due to various conflicts (such as graduation, time commitments, and scheduling), five TAs were unable to participate for a second semester. However, three new TAs were able to join, so 14 TAs participated in the second semester. Five of the authors of this manuscript facilitated the second-semester community. For consistency in comparison, only the 11 TAs participating throughout both semesters will be considered in the analysis. Six TAs were female; 10 were doctoral students, and one was a master’s degree student. There was an even distribution of disciplines: two TAs were from psychology, and three each were from biology, chemistry, and geosciences, respectively. Six TAs were set on future careers in academia, one wanted to continue research in bioinformatics and work closely with the education community, and the remaining TAs were unsure as to the degree teaching would be incorporated into their future career plans.

The TALC met biweekly in 1-hour sessions for the first semester. Because of a majority request to increase the amount of discussion time, the second semester community met for 1.5-hour sessions. Meetings included a mix of individual reflections, small group activities and discussions, and whole community discussions. Between sessions, TAs responded to reflection questions; the facilitators used these reflections in evaluating and planning future sessions. TAs read two to three journal articles and web pages in preparation for each session, which are included in Table 1.

<table>
<thead>
<tr>
<th>Number</th>
<th>Instructional method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Completing worksheets</td>
</tr>
<tr>
<td>2</td>
<td>Listening to the instructor lecture</td>
</tr>
<tr>
<td>3</td>
<td>Taking multiple choice/true or false/fill-in-the-blank tests</td>
</tr>
<tr>
<td>4</td>
<td>Reading assignments in a textbook</td>
</tr>
<tr>
<td>5</td>
<td>Engaging in experiments with predetermined outcomes</td>
</tr>
<tr>
<td>6</td>
<td>Engaging in experiments with predetermined, written procedures</td>
</tr>
<tr>
<td>7</td>
<td>Memorizing concepts</td>
</tr>
<tr>
<td>8</td>
<td>Writing lab reports for experiments with preset procedures and results</td>
</tr>
<tr>
<td>9</td>
<td>Receiving factual information from the teacher</td>
</tr>
<tr>
<td>10</td>
<td>Passively watch a demonstration of a principle or process</td>
</tr>
<tr>
<td>11</td>
<td>Identifying variables and designing appropriate controls for experiments</td>
</tr>
<tr>
<td>12</td>
<td>Answering questions about prior knowledge</td>
</tr>
<tr>
<td>13</td>
<td>Asking clarification questions during or after class</td>
</tr>
<tr>
<td>14</td>
<td>Participating in an in-class simulation or group exercise</td>
</tr>
<tr>
<td>15</td>
<td>Participating in a class discussion</td>
</tr>
<tr>
<td>16</td>
<td>Developing new examples of a specific concept or process in action</td>
</tr>
<tr>
<td>17</td>
<td>Making predictions based on prior knowledge</td>
</tr>
<tr>
<td>18</td>
<td>Giving individual presentations, or participating in group presentation in class</td>
</tr>
<tr>
<td>19</td>
<td>Writing formal lab reports on novel results</td>
</tr>
<tr>
<td>20</td>
<td>Students reviewing or critiquing another students’ work</td>
</tr>
<tr>
<td>21</td>
<td>Searching outside primary literature sources to learn what is already known</td>
</tr>
<tr>
<td>22</td>
<td>Designing and implementing new procedures or models</td>
</tr>
<tr>
<td>23</td>
<td>Exploring alternative methods for solving problems</td>
</tr>
<tr>
<td>24</td>
<td>Identify questions/concepts that guide scientific investigations</td>
</tr>
<tr>
<td>25</td>
<td>Comparing data or otherwise collaborating with other groups</td>
</tr>
<tr>
<td>26</td>
<td>Communicating findings to the rest of the class</td>
</tr>
<tr>
<td>27</td>
<td>Using graphs, basic statistics (mean, st. dev., t-test, etc.) to summarize and analyze results</td>
</tr>
<tr>
<td>28</td>
<td>Explaining unexpected results, and considering potential sources of error</td>
</tr>
<tr>
<td>29</td>
<td>Asking new questions based on data analysis from a previous experiment</td>
</tr>
<tr>
<td>30</td>
<td>Reflecting on one’s own work or learning</td>
</tr>
<tr>
<td>31</td>
<td>Explaining data from experiments without a predicted outcome, or using other evidence to make and defend conclusions</td>
</tr>
</tbody>
</table>

Note: Adapted from Bohrer, Ferrier, Johnson, & Miller, 2007, p. 95.
Biweekly discussion topics
A key feature of the learning community was that biweekly discussion topics emerged from self-reported concerns of the participating TAs (Darling-Hammond & McLaughlin, 1995). These concerns were gathered via a survey conducted during the first session of the learning community and from the first semester evaluation. The topics listed in Table 1 were the concerns the TAs mentioned most often when asked about their teaching in an inquiry-based course. A more detailed explanation of each session can be found in the supplementary material.

An additional key feature of the community was how the community was facilitated. To promote open discussion and build the community environment, course instructors were not directly involved with the learning community. Postdoctoral research associates either involved with the inquiry laboratory development or with extensive training in inquiry instruction selected the readings, developed the activities, and led the discussions. We believe that this is a key component—and what set this group apart from other more traditional groups for formal TA training. This independence from faculty was commonly listed as a strength of the group in evaluations.

Because the focus of the community was to develop TAs’ inquiry-based teaching abilities, the second-semester TAs were encouraged to cofacilitate a session under the guidance of the postdoctoral research associates. Groups of two to three TAs chose reflection questions, selected readings, developed activities, and led discussions during each session; the planning and leading of these TA-led sessions were done in consultation with a postdoctoral research associate.

Evaluation of the learning community
During the first session of the first semester, the TAs completed a survey including which concerns they had in teaching inquiry-based labs, how they defined “inquiry-based instruction,” and their experience with the 31 teaching methods shown in Table 2. They were asked about their experience with these methods both as an undergraduate student and as a TA, as well as what they perceived the importance of these techniques was in relation to inquiry-based teaching. Data from this survey was used as a baseline for assessing the TAs’ familiarity with inquiry-based teaching.

Subsequent surveys were administered at the end of each semester to evaluate the TAs’ perception of the effectiveness of the different instructional methods used in the community, the strengths of the community, any improvements that could be made, the TAs’ familiarity with inquiry-based instruction, and how this experience had impacted their teaching. All data collected for assessment purposes was obtained with consent from the TAs and approval from Iowa State University Institutional Review Board.

Only the data from the Instructional Methods Survey and end-of-semester surveys will be discussed herein. Nonparametric statistics were used to determine significant differences in how the TAs responded to the Methods Survey. The short-answer responses from the end-of-semester surveys were coded using the constant comparative method (Lincoln & Guba, 1985), which determined common themes in the data. Responses were then tabulated to provide a graphical depiction of the number and range of responses. For brevity, only responses mentioned by more than two TAs are presented.

Results and discussion
Familiarity with classroom instructional methods
The first administration of the Instructional Methods Survey provided insight into the TAs’ prior experiences and prior knowledge of inquiry instruction. For this survey, the TAs ranked how often these methods were used during their undergraduate instruction and during their current teaching practices. Responses were given on a scale from 1 to 5, with 1 being never to 5 being used ~75–100% of the time. The instructional methods were also ranked 1 to 5 in terms of their importance to inquiry, with 1 being not important and 5 being essential.

On first inspection of Figure 1, it can be seen that the TAs’ own undergraduate learning experiences (blue) were not consistent with what they deemed most important to inquiry instruction (green). For instance, the TAs more often experienced “2: Listening to the instructor lecture,” “6: Engaging in experiments with predetermined, written procedures,” and “8: Writing lab reports for extension” during their undergraduate instruction, while only rating these methods as moderately important to inquiry instruction. The converse is also seen in Figure 1. TAs infrequently experienced “21: Searching outside
primary literature sources to learn what is already known,” “22: Designing and implementing new procedures or models,” and “23: Exploring alternative methods for solving problems” even though they rated these methods as being essential for inquiry instruction.

This inverse trend is also seen in comparing the TAs’ current use of instructional methods (red) to those they deem most important for inquiry instruction, although to a lesser extent. The TAs are still using methods including “2: Listening to the instructor lecture,” “6: Engaging in experiments with predetermined, written procedures,” and “8: Writing lab reports for experiments with preset procedures and results” ~50%–75% of the time even though they are teaching a laboratory with research-like experiences. However, they are also to the same degree using methods they initially deemed essential to inquiry instruction such as: “14: Participating in an in-class simulation or group exercise,” “15: Participating in a class discussion,” “17: Making predictions based on prior knowledge,” and “31: Explaining data from experiments without a predicted outcome, or using other evidence to make and defend conclusions.”

A Spearman’s Rho (Ψ) ranked correlation was conducted for each teaching method among all three variables. Because of the small sample size and the Likert-scale rakings for each variable, Spearman’s Rho ranked correlation was chosen over a Pearson correlation. A significant correlation ($p < .05$) was seen between the TAs’ prior experience with the method and their current use of it for methods 7 ($\Psi = 0.704$), 10 ($\Psi = 0.763$), 14 ($\Psi = 0.900$), 20 ($\Psi = 0.742$), 23 ($\Psi = 0.722$), 28 ($\Psi = 0.640$), and 31 ($\Psi = 0.683$). This strong significant correlations between the methods

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**FIGURE 1**

Teaching assistants’ experience with 31 instructional methods. Blue lines represent experience with the instructional method during their undergraduate experience. Red lines represent the extent to which they use the methods during current laboratory instruction. Green lines represent the importance of the instructional method for inquiry-based instruction.

**FIGURE 2**

Teaching assistants’ views of the importance of 31 instructional methods to inquiry instruction across the teaching assistant learning communities (TALC). Blue lines represent views prior to the TALC. Red lines indicate views after one semester of the TALC. Green lines indicate views after two semesters of the TALC.
used to teach the TAs and the degree to which they use those methods now is consistent with prior research that concludes that we teach how we were taught. This is also consistent with the fact that this was a survey measuring the TAs’ experience with these methods prior to implementing the CBREs for the first time.

Instructional methods 7 (P = 0.688) and 10 (P = 0.860) were the only two instructional methods that were significantly correlated between the TAs’ undergraduate experience and the importance of the method for inquiry-based instruction. In correlating the instructional methods the TAs currently use with what the importance of the methods for inquiry methods 2 (P = 0.748), 4 (P = 0.699), 7 (P = 0.699), 10 (P = 0.889), 12 (P = 0.671), and 27 (P = 0.704) show significant correlations (p < .05). Although methods 2, 4, 7, and 10 would not traditionally be considered important for inquiry by experts, in discussion with the TAs, they thought that these methods were needed to ensure proper safety procedures in lab.

In order to determine how their views of inquiry instruction changed over the duration of the TALC, the “importance to inquiry” portion of the Instructional Methods Survey was also administered at the end of both semesters of the TALC as part of its evaluation (Figure 2). The methods that were deemed essential across all 3 administrations were “13: Asking clarification questions during or after class,” “23: Exploring alternative methods for solving problems,” “29: Asking new questions based on data analysis from a previous experiment,” and “30: Reflecting on one’s own work or learning.” In discussions with the TAs, it was revealed that the consistency in “2: Listening to the instructor lecture” and “9: Receiving factual information from the teacher” resulted from the need for dissemination of prelaboratory safety information, even in more open-ended inquiry teaching settings.

To determine if any of the changes in importance was significant across time, a Friedman’s test was conducted for each method. The Friedman’s test is the nonparametric equivalent to a one-way repeated measures analysis of variance and was chosen because of the small sample size and ordinal data. For this sample, Friedman’s chi-square values ranged from 0.15 to 3.65 with p-values all above 0.5. Hence, although there is some movement in scores noted previously, the movement across participation in the TALC is not statistically significant as a whole for each method. This is most likely because of the lack of differentiation in the 5-point Likert scale and a ceiling effect, resulting in there being little room to improve from the beginning.

**Evaluation of the TALC**

As part of the end-of-semester evaluation, the TAs ranked their level of understanding of the various topics discussed during the TALC sessions prior to and after the completion of the TALC on a scale from 1 to 5 with 1 being never heard of before and 5 very familiar and have experience (Figure 3). The greatest increase in level of knowledge from prior to post-TALC occurred in the areas of understanding “inquiry-based instruction” and “Bloom’s taxonomy.” The improved understanding of these two areas are not surprising, as the focus of the TALC was to develop methods of implementing inquiry-based instruction. Likewise, the discussions of assessment and asking and fostering better questions revolved around the introduction and understanding of Bloom’s taxonomy. It should be noted that there was an overall self-reported increase in understanding across all of the topics covered during the TALC; however, Friedman’s test indicated significant differences in understanding over time participating in the learning community for only five of the eight topics: inquiry-based instruction (15.59, p < .001), effective questioning (9.95, p < .01), Bloom’s taxonomy (7.09, p < .05), rubric development (7.09, p < .05), and rubric use (9.86, p < .01).

The TAs were also asked to list three strengths of the TALC (Figure 4) and three improvements that could be made to the TALC (Figure 5) on both of the end-of-sememster evaluations. For both semesters, the greatest strengths mentioned were the discussions and the interdisciplinary nature of the TALC. For instance, one student mentioned that the combination of these two aspects “allowed for learning of new techniques.” Other aspects that were mentioned by several TAs were the sense of community and the ability to speak freely in a safe environment. An example of this would be “I felt supported in the group to talk about ideas and concepts that may get you reprimanded if you talked about [them] with your advisor or instructor (boss).” This is why emphasis has been placed on the facilitators being postdoctoral researchers not assigned to being “in-charge” of any of the teaching labs. It allowed for open discussion among the group without there being a right or wrong answer.

The decrease in facilitator strength and appearance of activities as a strength during the second semester can be explained by the difference in facilitation format between the two academic terms. The facilitators (i.e.,
the postdoctoral researchers) were mentioned as strengths often after the first semester because they were the ones leading the discussions. This changed during the second semester as the TAs increased their roles in the learning community, both in leading discussions and incorporating more activities, which is noted in Figure 4.

Compared with the perceived strengths of the TALC, the improvements that the TAs mentioned varied between the first and second semester (Figure 5). For the first semester, the TAs wanted a longer meeting that was not held Friday mornings at 8 a.m. Following both semesters, TAs thought more TAs could benefit from the TALC and wanted more diversity by “incorporating more ‘soft’ science disciplines,” TAs from other courses, and TAs not facilitating a CBRE laboratory. It was also suggested during both semesters that there should be more interaction with faculty by having “guest speakers that teach classes [that are] inquiry based” or getting “feedback from faculty about TAs in TALC” regarding their teaching. In addition, the TAs wanted more practice applying inquiry either by “making a cookbook lab into an inquiry lab” or “practicing in a real environment what we learn.”

There were some aspects of the TALC that the TAs saw as strengths but still needed some improvement (Figures 4 and 5). The majority of TAs felt the group discussions were beneficial. To account for this, the length of the TALC meetings were lengthened second semester to 1.5 hours with the goal of allowing more time for discussion of the readings. However, this goal was not necessarily achieved. According to the TAs, the discussions needed to be more focused and structured, because they
still felt that there was not enough time to discuss the readings. This issue is potentially a result of having the TAs lead the discussions, and their relative lack of experience leading a more discussion-oriented “class” of this kind, which is far different from a typical laboratory session. The TAs also felt that developing their pedagogical knowledge was a strength of the TALC but at the same time they wanted more emphasis placed in this area by “providing a list of strategies for presenting information,” or “including not only the labs but also teaching in general.” Because the focus of the TALC was on facilitating inquiry labs, efforts were made to provide additional information about the “Preparing Future Faculty” program on campus for more comprehensive pedagogical development.

Finally, one of the most important questions we asked the TAs at the end of each semester was how the learning community had influenced them as an educator. Perhaps most interesting in Figure 6 is the number of TAs who mentioned that the TALC helped them become more reflective in their teaching. This sentiment is exemplified by these two quotes: “[teaching] can always be improved, and that constant self-evaluation is necessary to continue getting better at it,” and “It has encouraged me to take chances, get messy and make mistakes! I can go for it!” The TAs have gained confidence in their ability to teach using this style of instruction, especially in the areas of how to ask effective questions and keeping students motivated throughout a research project. After the first semester, all of the TAs said their experience had been so fulfilling and they learned so much that they would continue for a
second semester of the TALC. In fact, the TALC was so influential for one of the TAs that she stated the following, “Before I started TALC, I was pretty sure I wanted to get into industry after getting my PhD. I am [now] actually seriously considering teaching at a 4 yr college too! That is how much it helped.”

Conclusion
For institutions implementing CBREs in their instructional laboratories, we recommend training graduate student TAs in pedagogy associated with facilitating inquiry-based learning. Although the findings discussed are based on TAs’ self-reported data, many important recommendations can still be made on the basis of the development and assessment of the interdisciplinary graduate TALC at Iowa State University. First, there must be a great emphasis placed on training TAs in an environment where they feel safe to voice their concerns about the class and give advice to other TAs. This could be accomplished by having a senior TA, postdoctoral assistant, or a faculty not associated with the laboratory facilitating the teaching so the TAs do not fear repercussions of speaking openly. Second, there are TAs that seek greater pedagogical content knowledge, and this is the perfect opportunity to develop effective educators and improve undergraduate instruction simultaneously. Third, there is strength in the interdisciplinary nature of the TALC—the “me too” effect. The TAs took solace in the fact that other TAs were having the same issues in other disciplines, and they were able to get ideas for different strategies to help overcome some of the common issues they faced. The interdisciplinary nature was so important to them that the TAs wanted more diversity within the group by adding additional “soft” science assistants because of the perspective they brought to the group.

The results of the first year of the TALC were so overwhelmingly positive, based on the feedback from the TAs, that a second cohort of TAs of a pseudo-research experience has begun and the TALC model has expanded to include cohorts for TAs of large introductory physics courses (which were recently made more open-ended), as well as chemistry courses using the Science Writing Heuristic (Burke & Greenbowe, 2006), TAs of a large introductory biology laboratory implementing inquiry techniques, and TAs for a large introductory biology lecture implementing active learning strategies. Additional studies are currently underway to determine to what degree the instructional strategies used in the laboratories influence students’ understandings of the nature of science and their retention in STEM disciplines.

Acknowledgments
We would like to thank the 19 TAs who graciously participated in the learning community. These graduate students taught us just as much, if not more, about educating others in novel learning environments than we taught them. We would also like to thank the Howard Hughes Medical Institute for funding the grant at Iowa State University that made this learning community possible. Likewise, we would like to thank Dr. Craig Ogilvie for tasking us, the authors, with the responsibility of designing and facilitating this great learning community and learning experience.

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