Innovations in College Science Teaching, 2015
Preface

In the year 1988, two men, John Dunkhouse and John Penick, edited a Society for College Science Teachers’ Monograph. It was entitled, Innovations in College Science Teaching. Twenty seven years later, the Society is revisiting Innovations to reflect on this period in Academia. The goals for this monograph are:

- to design environments that inspire students to take ownership of their learning.
- to provide students with voice and with choice.
- to remind students that learning is a social endeavor.
- to reinforce the fact that learner questions and the act of questioning are the very nature of learning.
- to encourage real world problem solving, enabling students to be motivated to reach higher in their pursuit of knowledge.

Mintz (2013) in his paper on The Future is Now segment “Innovation2: Evidence-based pedagogy” indicated that instructional design will have more emphasis on learning objectives, mastery of key concepts and assessments that are very closely associated with the goals of learning. He further suggest that today’s courses will include more social learning, more active learning and assessments that are ‘real-word.’


Cover photo courtesy of Nancy Elwess.

This monograph contains evidence-based pedagogy and lots of it! We hope you will enjoy the compilation.

# Contents

**Preface** ................................................................................................................................. ii

**Contents** ................................................................................................................................. iii

**Chapter 1  Walls are not needed to learn!** .................................................................................. 1

_The sciences are of sociable disposition, and flourish best in the neighborhood of each other; nor is there any branch of learning but may be helped and improved by assistance drawn from other arts._ – Blackstone

**Do People Really Get Paid For Doing This? Teaching and Learning Biology in an Informal Setting** by Antonios Pappantoniou ........................................................................................................ 2

**Harnessing the Power of Immersive Innovative Environmental Experiences**
_by Ryan Walker, Renee M. Clary, Kimberly Carroll, and Kenneth Anthony_ ......................... 5

**Chapter 2  The Benefits of Undergraduate Research!** ............................................................... 21

_It is a profound mistake to think that everything has been discovered; as well to think the horizon is the boundary of the world._ – Lemierre

**Course-based Undergraduate Research Experiences (CUREs)** by Lee E. Hughes .................. 22

**Understanding Inquiry in Science Education** by Wendy Martin ............................................. 30

**Undergraduate Research as an Innovative Learning Experience: Student Perspectives on Professional Impacts** by Grant E. Gardner, Miriam Ferzli, Penny Shumaker Jeffrey, and Damian Shea .......................................................... 35

**Two Sides of the Coin: How a Departmental Culture of Inquiry Teaching and Undergraduate Research go Hand in Hand** by Kerry L. Cheesman .................................................. 49

**Chapter 3  Methodologies that Support Innovation!** ................................................................. 64

_In science, as in common life, we frequently see that a novelty in system or in practice cannot be duly appreciated till time has sobered the enthusiasm of its advocates._ – Maud

**Distilling Best Practices for Teaching and Learning in Anatomy and Physiology**
_by Murray Jensen_ ....................................................................................................................... 65
Successfully Flipping the Classroom for Organic Chemistry by Ronaldo J. Cavazos, Jr., Amy K. Petros, and Robby A. Petros ..........................................................79

Checking for Understanding in the College Classroom: Using Formative Assessment to Inform Instruction and Enhance Learning by Maureen E. Squires .........................92

Professional Development with Innovative Co-Teaching by Renee Clary, Anastasia Elder, James Dunne, Deborah Tucker, Debbie beard, Svein Saebo, Charles Wax, and Joshua Winter ..........................................................................................................................103

Using Controversy and Argumentation to Develop Students’ Critical Thinking Skills By Renee M. Clary and James Wandersee ...........................................................................115

Using an Interdisciplinary Critical Friends Group to Manage the Risks with Innovative Teaching by Darlene Panvini, Sally Barton-Harwood, Lauren Lunsford, Kim Daus, Kate McGowan, Bobbie Smith-Whitehouse, and Ryan Fox .................................................................131

Chapter 4 Building an Innovation Tool Kit ..................................................................................140

If you get stuck, draw with a different pen. Change your tools; it may free your thinking -Paul Arden

Students Learn, You Save Time: The Exam Rewrite Option by Kathleen H. Lavoie ..........141

Let Them See Light by Nancy L. Elwess .....................................................................................145

Using a Trade Book to Show How Change Influences Society by Sandra M. Latourelle, Karen E. Case .............................................................................................................152
CHAPTER 1
Abstract

Informal education occurs outside the confines of the classroom. Frequently it involves collaboration between formal institutions of learning and organizations such as museum, zoos and nature centers. This paper describes a collaborative effort between Housatonic Community College, in Bridgeport Connecticut and the Connecticut Audubon Society. The focus of this collaboration is a biological study of streams and ponds at the Roy and Margot Larsen Wildlife Sanctuary. A primary objective of this experience is to have students design and execute an aquatic field study. Students learn techniques of sampling and identifying aquatic organisms, and collecting the data a biologist would require assessing these organisms.

Introduction

Informal education is defined as education that occurs outside the confines of the classroom. A variety of organizations including museums, nature centers, zoos, botanical gardens etc. can offer science students and faculty, informal education experiences. Such experiences frequently involve collaboration with formal institutions of learning. The National Science Teachers Association recently revised its position paper on the role and importance of informal science learning (NSTA, 2012). According to Yager and Falk (2008) 75% of Nobel Prize winners reported that their interest in science was first ignited in informal environments. Informal educational experiences allow students to explore science and nature in a way they could never do in a lecture hall or a teaching laboratory. These experiences are often associated with hands-on learning, particularly in the sciences. Informal learning experiences are typically voluntary, learner motivated and at least in part guided by learner interest (Dierking et al, 2003).

College science students spend relatively short periods of time in a classroom either in formal lecture or lab activities. Often this is not enough time to really learn science skills and adapt those skills to real life situations. Students frequently get the false impression that scientific research can occur in the short intervals of time that it takes to complete an in-class lab activity. We can give students a sense that science is a time consuming pursuit and scientific research occurs over long time periods by having them do semester long science investigations. Even this does not convey the impression that much of scientific research is long-term and often longitudinal in nature. In order to offer students an informal science education experience combined with a research project, a collaborative effort between the Connecticut Audubon Society and Housatonic Community College in Bridgeport, Connecticut was developed.
The Project

Working with student volunteers for four summers, we have developed a picture of the aquatic life in the streams and ponds of a local Audubon Society sanctuary. Although many of our students express an interest in pursuing advanced level studies in biology and environmental science, most of them have never experienced doing biological fieldwork. Under guidance and direction students undertake a field project, the focus of which is a biological survey of streams located at the Roy and Margot Larsen Sanctuary of the Connecticut Audubon Society and an assessment of Painted Turtle, *Chrysemys picta*, populations in the sanctuary’s Farm Pond. The summer field experience has scientific, educational and even some intangible objectives:

- Learn to identify local aquatic fauna;
- Collect and interpret data a biologist would require to assess an animal population;
- Learn techniques to safely and humanely collecting and identifying organisms;
- Become proficient in the use of measuring devices and collecting equipment;
- Foster a sense of responsibility and teamwork among the students;
- Develop facility in explaining their work to the public.

Students working on this project are a self-identified group chosen from general biology classes. Prior to taking students into the field, a formal classroom session is required of all volunteers. During this session the scope of the project is discussed and safety in the field is stressed.

First Day in the Field

It is important that the students guide the project. This gives students an immediate sense of ownership in the project and motivates them to come to the field on a consistent and timely basis. We walk through the field site, along streams and around the pond. This leads to a discussion of what type of data we should gather, and where it should be collected. Collection sites are chosen to give the broadest possible array of habitats within the streams and ponds i.e. mud bottoms, gravel and rock bottoms, slow moving water, fast moving water, stream segments with lots of riparian growth and areas with little or no cover.

The Farm Pond is sampled for turtles. The Painted Turtle, *C. picta*, is part of a long-term life history project. This requires a discussion of what constitutes a life history study. Once the students understand this, they can decide on what data to collect and how to go about doing it. Students are asked to develop data sheets so that data can be collected and recorded in the field.

Second Day in the Field and Beyond

With the second fieldtrip, collecting and identifying organisms and collecting of data begin in earnest. The use of keys and field guides (Whitworth, 1996) is introduced to the students. So that students are not hurt and animals are treated humanely, the students are shown how to handle animals, determine their gender, weigh and measure them. After being photographed, all specimens are returned unharmed to the collection site. The process is repeated on a weekly basis for the duration of the summer. Students have access to data collected in previous summers. Discussions of how to handle and manipulate the data are always part of the conversation. The data that students collect are used in courses as an introduction to data handling, graphing etc.
Conclusions

Students commit to working in the field two days per week, throughout the summer months and adhere to this schedule despite the fact that no one is paid or even given class credit for their efforts. They experience real world applications of biology and put to practice what they learn in a classroom. Some of the skills and behaviors that are an outcome of this experience include:

- An ability to identify a broad variety of local aquatic organisms;
- An appreciation of animal life history as reflected in the data they collect;
- Handling animals in a manner that is humane for the animal and safe for both the animal and the student;
- Cooperative skills by working together as a team. Students cooperate with each other collecting and identifying organisms and recording data. No individual serves as a permanent “secretary” simply recording names and numbers. All students are actively engaged in all aspects of the project;
- A sense of responsibility by arriving at the project site in a consistent and timely manner;
- The field site is a public access area. Members of the public frequently hike through the area and ask about our work. Students develop skills explaining their work to the public;

At the end of one such fieldtrip a student asked if people actually got paid for doing this type of work. Perhaps this is a future biologist in the making.

References


National Science Teachers Association. 2012. An NSTA Position Statement Learning Science in Informal Environments. science.nsta.org/nstaexpress/PositionStatement_InformalScience_draft...


Harnessing the Power of Immersive Innovative Environmental Experiences

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Undoubtedly, future citizens will face difficult decisions with regards to environmental policies and sustainability issues. In order to make informed choices within their communities, our students must understand their local environments, and become stakeholders. Where does environmental education begin? Before students can be successfully taught, teachers must also be environmentally literate, with effectual pedagogical skills for disseminating content. In the US system, fewer than 15% of science teachers had taken a formal course in environmental education (Stern, Powell, and Ardoin, 2008). Professional development programs can be effective for increasing content knowledge (Banilower, Boyd, Pasley, and Weiss, 2006), but effectiveness of the professional development—including inquiry teaching and investigative classroom culture—is linked to the amount of professional development (Supovitz and Turner, 2000).

Traditional summer development programs are presented within 2-4 weeks, and many confine teachers to school libraries, lecture halls, or university labs. Some teachers view stipends within these professional development programs as supplemental income, and not an opportunity to grow as a professional; these teachers count the days until the summer program is over so that they may finally enjoy their summer vacation. Program retention beyond the summer can also be difficult (Clary, Elder, Dunne, Tucker, Beard, Saebo, Wax, and Winter, this volume).

The Great Smoky Mountain Institute at Tremont (GSMIT) offers professional development for college students and in-service teachers. The GSMIT innovative approach for outreach provides science content knowledge and models effective pedagogical techniques, but within immersive programs over a relatively short time period of 2-5 days. GSMIT programs reduce classroom time, but increase participant participation through immersive experiences. Our analyses reveal that GSMIT’s shorter sessions can meet program objectives, and maintain quality participant experiences. Data from three immersive environmental programs show the GSMIT innovative approach transforms professional development into a positive experience, empowering participants to implement change and seek out additional learning opportunities.

Environmental Education: Research Results

Environmental Professional Development
The first challenge for environmental education is identified as the continuation and expansion of the range of professional development (PD) opportunities within the field (Marcinkowski, 2010). Nature-based excursions have long had a significant role in teaching strategies; collaboration, advance planning, and visits with students heighten the place-responsive sensitization (Mannion,
Fenwick, and Lynch, 2013). The local community has the potential to develop students’ community identity and enhance environmental literacy (Zachariou and Symeou, 2008). Incorporation of environmental education in after-school programs in urban environments also achieved positive results for engaging students with science and linking content to family heritage in the Dominican Republic (Bruyere, Wesson, and Teel, 2012). However, an immersive 6-day program in a watershed resulted in significant changes in environmental attitudes of teacher participants, but no significance in science enthusiasm for their students (Meichtry and Smith, 2007).

Analyses of environmental professional development programs typically involve PD sessions greater than a week in duration. A professional development program in Hawaii that involved middle and high school in-service teachers resulted in greater participant confidence to teach environmental science; professional relationships with program instructors were also maintained beyond the program (Rivera, Manning, and Krupp 2013). However, the program was 4 weeks in duration. Similarly, a two-week intensive curriculum with the GLOBE (Global Learning and Observations to Benefit the Environment) curriculum resulted in significant gains in teachers’ efficacy (Moseley, Huss, and Utley, 2010).

**Teacher Barriers within Informal Learning Environments**

In order for environmental professional development to be effective, it must target barriers that teachers face in engaging their students within informal learning environments that involve content experts. Research identified two key areas of weakness: 1) lack of experience teaching in the outdoors, and 2) lack of both content and pedagogical knowledge (Walker, 2012).

The classroom teacher’s lack of experience teaching in natural environments resulted in teachers’ anxiety and an inflated sense of perceived difficulty for their students. As a result, teachers simplified or “watered down” questions asked by teacher naturalists, providing hints, or even answering for their students. Walker (2012) suggested these responses may be an attempt for teachers to protect themselves from embarrassment resulting from their students’ inability to answer the naturalist’s question. This teacher interference prevents students from thinking about the information being presented. As a result, students wait until the teacher simplifies the material, instead of struggling with the new information.

The classroom teachers’ lack of both content and pedagogical knowledge for teaching in informal settings results in teachers’ perceived need to be the “expert” (Walker, 2012). Classroom teachers often try to disguise that they are not content experts. They may use vague language, which results in ineffective communication. Some observed strategies that attempt to mask insufficient content knowledge are 1) proceeding through a lesson at a fast pace, which results in students struggling to keep up; and 2) reducing the number of questions the students can ask (Walker, 2012). As a result, students will direct their questions to the teacher naturalist in informal learning environments. During cooperative instruction events, when naturalists are not present, students’ questions are not immediately addressed and often go unanswered. Alternatively, when teachers approach their roles as learners, along with the students, a more stable learning environment is created in which both teachers and students learn from the naturalist (Jenkins, Walker, Tenenbaum, Sadler and Wissehr, 2015).

Both weak areas can be addressed by modeling effective instruction techniques, and working with teachers to deconstruct their experience (Walker, 2012). Having the teachers participate as
students during lessons allows them to experience inquiry in the outdoors from the learner’s perspective. Facilitators then deconstruct the experience to allow participants to explore aspects of instruction that may be overlooked by the teachers. Modeling is widely accepted as an instructional technique in professional development and preservice science teacher education because it provides teachers an example they can emulate (Supovitz and Turner, 2000). Additionally, modeling allows teachers an opportunity to reflect specifically about the nature of the lesson and conceptually link it to their K-12 classroom (Windschitl, 2003). After deconstructing the lesson, teachers then apply these instructional techniques through peer teaching with structured feedback.

**Great Smoky Mountains Institute at Tremont (GSMIT)**

Established in 1969, Great Smoky Mountains Institute at Tremont (GSMIT), considered to be a leader in residential environmental learning centers, is one of the longest running programs in the United States. GSMIT’s active research agenda seeks to improve instruction and evaluate impact on student learning.

From the beginning, GSMIT recognized the importance of including teachers in instruction as a central component of connecting people to nature. GSMIT’s philosophy is to provide teachers the support they need to successfully teach in an outdoor setting; then that experience will act as positive reinforcement and, teachers will apply what they have learned—not only at GSMIT, but also at their schools when they return. Teachers often lack professional development opportunities in environmental education. Few teacher preparation programs and in-service professional development programs include environmental education (Ramsey and Hungerford, 2002). GSMIT attempts to rectify this situation by providing teachers with immersive environmental education opportunities. GSMIT’s teacher retreats target their professional development to help teachers overcome barriers for effective teaching in natural environments.

**GSMIT’s Immersive Environmental Experiences**

GSMIT offers different immersive experiences, all of which are designed to target the same objectives: 1) build an appreciation for nature, 2) deliver science content, and 3) develop participants’ understanding and ability to implement effective teaching practices. This research focuses upon three immersive programs involving GSMIT. While the data collection strategies can be easily adapted to any program, the evaluation methods for program impact were specifically designed to address each program’s unique challenges.

**The Teacher Escape Weekend**

Teacher participants arrive at the dorms or tents early Friday morning, and leave Sunday morning. The teachers’ role is that of learner, and they participate as students in lessons presented by GSMIT faculty. Professional development options offer teachers lesson choices to meet their individual interests and needs. Content lessons include geology, stream physics, stream life, history, and citizen science. Pedagogical training includes inquiry instruction, writing in content areas, and professional mentoring for experiential learning. Day 1 focuses on pedagogy while Day 2 focuses on content. However, on Day 1, teacher participants are directed to closely observe the GSMIT faculty in the subsequent lessons to see their application of effective teaching strategies. The Teacher Escape Weekend includes teacher socials and
campfires at night, and teambuilding activities led by GSMIT staff. Teacher participants also receive a targeted professional development seminar presented by education researchers.

To assess the effectiveness of the Teacher Escape Weekend, pre- and post-surveys were administered to in-service teacher participants (N = 43). The pre-survey asked participants to share what they hoped to gain from the professional development experiences, while post-surveys asked 1) the most meaningful aspect of the experiences; 2) which part of the experiences teachers planned to implement in their classrooms; 3) what Tremont experience did teachers want to do more, or learn more about; 4) recommendations for future GSMIT professional development programs; and 5) the list of the lessons that they had attended. Responses were subjected to content analysis (Neuendorf, 2002).

**The Teacher Science Institute**

Whereas Teacher Escape Weekends focus on general environmental professional development within the natural setting of the Great Smoky Mountains National Park, the Teacher Science Institute professional development workshops delve into a specific area of science content. Participants focus upon a topic for a week (e.g., current trends in air quality, climate change, research-based citizen science projects that are easy to replicate at participants’ schools). These programs are slightly longer (5 days for the Teacher Science Institute, when compared to 2 full days for the Teacher Escape Weekends). During the Teacher Science Institute, GSMIT exposes teacher participants to new approaches and tools for improving science teaching and learning that will transform their classrooms (Figure 1). The overarching objective for these professional development sessions is to provide in-service teachers opportunities to participate in hands-on science learning, so that they can develop science content knowledge while gaining an appreciation for teaching hands-on science in outdoor settings.

![Figure 1: GSMIT faculty demonstrating bird banding to teacher participants during a summer Teacher Science Institute. (Photograph courtesy of Ryan Walker)](image)

Within the Teacher Science Institute, regardless of content topic, three short sessions focusing on the nature of science, inquiry, and pedagogical practices are dispersed throughout the week-long professional development program. The optimal schedule is to have sessions at the beginning,
midway, and the end of the program, since systematic placement helps researchers understand how the workshop sessions influence teachers’ perceptions of science learning, outdoor education, and hands-on instruction. The surveys implemented within each session comprise a professional development workshop reflection through 7 total questions.

**Session 1: Setting the Stage.** The first session (approximately 15 minutes in duration) begins with an opening question, “What is scientific knowledge and how it is different from other ways of knowing?” The GSMIT experts guide the discussion to elucidate differences in scientific knowledge, and how science is unique by the process by which it occurs. This segues into an investigation of the typical manner in which science is taught in formal classrooms, and how much classroom time is devoted to process, versus dissemination of scientific facts. In-service teacher participants question whether a focus upon facts limits students’ ability to think critically and solve problems. The group discussion moves toward the identification of what teaching science through inquiry “looks like” within the classroom, with respect to both students’ and teachers’ roles. Data are collected with a written survey instrument that probes teachers’ perceptions of the 1) difficulties associated with teaching hands-on science, and 2) difficulties associated with teaching science in outdoor environments. Teachers are instructed to continue to think about these questions throughout the professional development week.

**Session 2: Modeling Science Instruction.** The second session (approximately 15 minutes) occurs in the middle of the professional development session. The GSMIT experts lead the discussion, returning to the original Session 1 theme of difficulties for teaching hands-on science, and specifically hands-on science in outdoor environments. Teacher participants next complete the second written survey, responding to questions 3) whether the GSMIT experience thus far influenced their perceptions of these difficulties, and 4) the extent each teacher participant feels that he/she could include this type of instruction in his/her classroom. Following the survey, the teacher participants are asked to observe the methods used by the naturalist instructors, and how the naturalists approach instruction. While many of them have no formal education, they have extensive experience working with children in the GSMIT natural environment. The naturalists are thoughtful about how they complete tasks, how they ask questions, and even how they answer questions.

**Session 3: Deconstructing Effective Instruction.** The final session (approximately 45 minutes in length), is held toward the end of Teacher Science Institutes. Teacher participants discuss various aspects of the naturalists’ instruction that they feel contributes to successful hands-on science teaching in outdoor environments. From this discussion, teachers’ observations are deconstructed, and inferences are made on how these variables influence instruction. In some workshops, teachers act or recreate naturalists’ actions, in a charades-based activity in which the group tries to determine which behavior the teacher is depicting, and how this behavior influences instruction. Session 3 is also accompanied by a survey, in which teachers answer the final 3 questions, 5) the most useful thing they learned from their observations, and how this could be incorporated in teaching; 6) the extent the professional development experience influenced their perception of teaching hands-on science; and 7) the most meaningful aspect of the experience. The session concludes with a discussion about modeling as an instructional tool, and examples of modeling use in classrooms.

The survey responses, activity notes, and facilitator’s impressions were all coded to determine change in participating teachers’ attitudes throughout the 5-day Teacher Science Institute.
Preservice Teachers: The Maymester Informal Science Education Course
Mississippi State University offers a 3-week “Maymester” course in informal science education, which is held during the intersession between Spring and Summer semesters. Enrolled preservice teachers experience teaching and learning science in the outdoors, via field experiences in the Great Smoky Mountains National Park. The course utilizes research-based effective instructional methods, assessment strategies, inquiry to teach science process skills, civic responsibility, and citizen science.

As a 3-credit course, the informal science education class consists of three weeks of intensive instruction: Week 1 is held on the university campus, and incorporates instruction on the history of ecology education, effective informal methodologies, and the interdisciplinary nature of science education; Week 2 is held in the Great Smoky Mountains National Park, at a residential center where preservice teachers gain their first teaching experience from outdoor science education field experts (Figure 2); and Week 3 returns to the university campus to deconstruct the experience, reflect, and establish connections to classroom instruction. Although the Maymester course is 3 weeks in duration, the actual field experience at GSMIT is a 5-day immersive experience, similar in length to the Teacher Science Institute. However, the Maymester course at Mississippi State University targets preservice teachers, as opposed to the in-service teacher GSMIT programs (Teacher Escape Weekend, Teacher Science Institute).

Activities and lessons are specifically designed to challenge preservice teachers’ views of effective teaching. Activities are then used to reconstruct views of effective instruction that include inquiry and place-based methods. During the week-long immersion experience through GSMIT, students participate as both learner, and teacher to their peers. Similar to the Teacher Escape Weekend and the Teacher Science Institute, students are asked to closely watch the GSMIT faculty deliver content-focused lessons. After each lesson, students reflect as a group, and discuss elements of the GSMIT faculty instruction that can inform their own teaching. Each student is required to teach a peer lesson to the group, delivering content from his or her field of expertise and receiving peer feedback. All lessons included inquiry instruction from research-supported best practices in outdoor settings.
Figure 2: Preservice teachers participate in environmental inquiry activities in the Great Smoky Mountains as part of a Maymester course. (Photograph courtesy of Ryan Walker)

Data were collected using strategically embedded assessments within regular coursework. This allowed researchers to not only evaluate formative assessments for program improvements, but also summative assessments for overall impact on student growth. We will focus upon the “Reflection on Practice” assignment within this analysis. Students constructed a detailed but concise reflection (no more than 350 words) that personally justified the inclusion of informal learning experiences within regular classroom instruction, and the impact these experiences have on student learning. This reflection assignment was coded using a reductionist coding approach in grounded theory (Strauss and Corbin, 1998). Due to the intensive requirements of the course, a smaller number of students participated in the data collection, with 7 preservice teachers’ reflection assignments coded. Because of the nature of the research, a small sample is sufficient to develop middle range theory not yet fully developed but consistent with other findings (Strauss and Corbin, 1998).

Results

The Teacher Escape Weekend

Analysis of pre- and post-surveys for Teacher Escape Weekend participants (N = 43) are represented under 2 categories: the type of lessons selected by participants (Table 1) and outcomes interpreted from participant responses (Table 2).
Data collection from post surveys revealed a relatively even distribution of participant selection for pedagogical training during the Saturday morning session, which is consistent with content area courses presented Saturday afternoon and Sunday morning. Interestingly, teachers in participant teams from the same school intentionally selected different activities to gain a wider range of experiences. These teachers then shared their experiences with their peers. The citizen science session drew the highest attendance for a science content focused session. Social science or history focused sessions, such as Walker Valley history and the Greenbriar school experience, were popular choices of participants (n = 25).

Data analyses revealed participants’ self-identified 1) most meaningful aspect of the experience; 2) components that can easily be implemented within their classrooms; 3) aspects of the experience teachers would like more of; and 4) recommendations for program improvement (Table 2). Almost half of the teachers identified collaboration as the most meaningful aspect of the experience (n =19). Teacher 17 noted, “The most meaningful aspect of the Tremont teacher escape weekend is having good experiences outdoors with quality people.” Acquiring content knowledge and having an opportunity to connect with nature were both identified by 25% of participant teachers as the most meaningful component (n =11), while learning about other GSMIT school programs and having an opportunity to experience and learn about effective instruction techniques were identified as most meaningful by 18% of the teachers (n = 8). For the most meaningful component, Teacher 44 wrote, “The naturalists’ enthusiasm and knowledge of the area they were presenting. Their passion continues to be an inspiration for me.” Finally, 7% of the teachers identified the educational resources that could be used in their schools as the most meaningful aspect of the Teacher Escape Weekend.

With regards to GSMIT workshop elements that could be easily implemented into classrooms, one third of in-service teachers identified citizen science (n =14) and inquiry-based instruction (n = 13). Teacher 18 identified both components in the response: “Citizen science as an inquiry experience. I want to combine them.” GSMIT classroom resources and the interdisciplinary instructional techniques were identified by 16% of teachers (n = 7) as easily transferrable into their classroom instruction. Three teachers provided responses that did not fit into the established categories. This included a response from Teacher 35 that stressed the importance of bringing students outside, and a comment from Teacher 19, which explained that every aspect of the experience was transferrable.

| Table 1: Lessons Selected by Participants in the Teacher Escape Weekend |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Saturday AM     | Saturday PM     | Sunday AM       | n               |
| Creative expressions | 11 Stream Physics | 8 Geo Hike     | 12              |
| Mentoring       | Stream Life     | Walker Valley  | 15 15 8         |
| Easy inquiry    | Citizen Science | Half day hike  | 20 4 17         |
|                 |                 | Greenbrier school |               |
|                 |                 | Mentoring       | 2               |
|                 |                 |                 | 43 43 43        |
| 43              | 43              | 43              |

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Table 2: Teacher Escape Weekend Participant Outcome Responses

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of responses</th>
<th>Percent of teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most meaningful aspect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collaboration</td>
<td>19</td>
<td>44.19%</td>
</tr>
<tr>
<td>Connection to nature</td>
<td>11</td>
<td>25.58%</td>
</tr>
<tr>
<td>Content knowledge</td>
<td>11</td>
<td>25.58%</td>
</tr>
<tr>
<td>Program</td>
<td>8</td>
<td>18.60%</td>
</tr>
<tr>
<td>Effective instruction</td>
<td>8</td>
<td>18.60%</td>
</tr>
<tr>
<td>Resources</td>
<td>3</td>
<td>6.98%</td>
</tr>
<tr>
<td>Implementation into classroom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citizen science</td>
<td>14</td>
<td>32.56%</td>
</tr>
<tr>
<td>Inquiry</td>
<td>13</td>
<td>30.23%</td>
</tr>
<tr>
<td>Interdisciplinary</td>
<td>7</td>
<td>16.28%</td>
</tr>
<tr>
<td>Resources</td>
<td>7</td>
<td>16.28%</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>6.98%</td>
</tr>
<tr>
<td>More</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science content knowledge</td>
<td>6</td>
<td>13.95%</td>
</tr>
<tr>
<td>History</td>
<td>6</td>
<td>13.95%</td>
</tr>
<tr>
<td>Hiking</td>
<td>5</td>
<td>11.63%</td>
</tr>
<tr>
<td>Resources</td>
<td>3</td>
<td>6.98%</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>6.98%</td>
</tr>
<tr>
<td>Collaboration</td>
<td>2</td>
<td>4.65%</td>
</tr>
<tr>
<td>Recommendations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nothing</td>
<td>7</td>
<td>16.28%</td>
</tr>
<tr>
<td>More resources</td>
<td>3</td>
<td>6.98%</td>
</tr>
<tr>
<td>Split</td>
<td>3</td>
<td>6.98%</td>
</tr>
<tr>
<td>Timing</td>
<td>3</td>
<td>6.98%</td>
</tr>
<tr>
<td>Suggested topic</td>
<td>2</td>
<td>4.65%</td>
</tr>
<tr>
<td>Different social</td>
<td>1</td>
<td>2.33%</td>
</tr>
</tbody>
</table>

Teacher response rates dropped slightly for the program elements they would like more of, but 14% of teacher participants \((n = 6)\) expressed interest in learning more science content. The same number of participants requested more local history into the program \((n = 6)\), while other teacher participants requested additional hikes \((n = 5)\), and more resources to take back to the classroom \((n = 3)\). Although collaboration was identified as the most meaningful aspect of the experience by 44% of participants, few \((n = 2)\) requested more time for mentoring and collaboration with peers.

The final item on the post survey asked participants to make recommendations to improve the Teacher Escape Weekend. Responses dropped off significantly, but seven teachers \((n = 7)\) specifically stated that would change nothing. The remaining responses were loosely grouped into five categories: 1) a request for more resources \((n = 3)\); 2) splitting the veteran and rookie teachers for specialized programming \((n = 3)\); 3) the timing of the professional development \((n = 3)\); 4) splitting the veteran and rookie teachers for specialized programming \((n = 3)\); 5) the timing of the professional development \((n = 3)\).
These final categories provide little insight into program improvement, but will be considered by GSMIT faculty and staff in a general context.

The Teacher Science Institute
For a total of 23 participants (N = 23), the data from the 7 survey questions (Session 1, 2, 3), discussion notes from the three sessions, impressions of the naturalist, and activity notes were analyzed to determine a robust understanding of how the Teacher Science Institute experience influenced teachers’ perceptions of science and their understanding of hands-on science instruction.

Session 1: Initial perceptions of teacher science workshop. These data were collected from teachers’ written responses to the initial survey in Session 1, items 1 and 2. Data were coded using a reductionist approach to reveal major themes (Strauss and Corbin, 1998). Table 3 presents the perceptions of teachers associated with teaching hands-on science. Table 4 presents initial teachers’ perceptions of the difficulties in teaching science outdoors. Lack of resources and lack of time were the primary identified barriers to teaching hands-on science, while outdoor science teaching barriers included lack of appropriate locations, time, and necessary resources for outdoor lessons.

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of responses</th>
<th>Percent of teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teachers do not have resources or materials</td>
<td>18</td>
<td>78.26%</td>
</tr>
<tr>
<td>Teacher lack of class time</td>
<td>11</td>
<td>47.83%</td>
</tr>
<tr>
<td>Teachers are unable to maintain classroom management</td>
<td>7</td>
<td>30.43%</td>
</tr>
<tr>
<td>Teachers lack of funding</td>
<td>5</td>
<td>21.74%</td>
</tr>
<tr>
<td>Teachers are limited by state standards (hands on not tested)</td>
<td>5</td>
<td>21.74%</td>
</tr>
<tr>
<td>Teachers lack required background knowledge</td>
<td>3</td>
<td>13.04%</td>
</tr>
<tr>
<td>Class sizes are too large to accommodate hands-on activities</td>
<td>3</td>
<td>13.04%</td>
</tr>
<tr>
<td>Schools lack an appropriate outdoor space for investigations</td>
<td>3</td>
<td>13.04%</td>
</tr>
<tr>
<td>Student lack focus and motivation for hands-on activities to be effective</td>
<td>2</td>
<td>8.70%</td>
</tr>
<tr>
<td>Hands-on activities require lots of additional work for teacher</td>
<td>2</td>
<td>8.70%</td>
</tr>
</tbody>
</table>

Session 2: Influence of the experience. Data from teachers’ written responses from Session 2 were collected and analyzed. Data were interpreted with a directed but open-ended analysis to reflect the development of each teacher’s perception within the experience; teachers’ responses were reviewed independently to reflect the influence on each individual’s perception (Strauss and Corbin, 1998). A positive change in perception is defined as a participant’s initial skepticism of these methods (from items 1, 2), evolving to less resistant, and finally more accepting over the course of the week-long professional development program (items 3, 4). A negative change in perception is defined as a participant’s initial positive attitude becoming more negative as the week progressed. The final category, or no change, is defined as a teacher’s static view throughout the week. In addition to these data, the teachers’ major concerns or areas of growth were identified and collated. Table 5 presents these results on the evolution of teacher’s attitudes toward teaching hands-on science in outdoor environments.
Table 4. Initial teacher perceptions of difficulties associated with teaching science in the outdoors.

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of responses</th>
<th>Percent of teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location, No appropriate places, quiet and natural.</td>
<td>11</td>
<td>47.78%</td>
</tr>
<tr>
<td>Lack of time because of short periods, standardized testing.</td>
<td>9</td>
<td>39.13%</td>
</tr>
<tr>
<td>Lack of travel funds, resources and equipment for investigations</td>
<td>8</td>
<td>34.78%</td>
</tr>
<tr>
<td>Teacher related issues</td>
<td>7</td>
<td>30.43%</td>
</tr>
<tr>
<td>Weather</td>
<td>6</td>
<td>26.09%</td>
</tr>
<tr>
<td>Safety, liability, allergies and kids getting injured</td>
<td>6</td>
<td>26.09%</td>
</tr>
<tr>
<td>Student related issues</td>
<td>5</td>
<td>21.74%</td>
</tr>
<tr>
<td>Requires approval from administration, administration perception of play</td>
<td>3</td>
<td>13.04%</td>
</tr>
</tbody>
</table>

- Teacher-related issues include the lack of teachers’ skills in managing a class in the outdoors, and worries of student behavior; Teachers lacked experience teaching outside, content knowledge.
- Student-related issues include lack of experience, poor preparation, and lack of focus and motivation.

Table 5. Teachers’ change in attitudes over the duration of the week.

<table>
<thead>
<tr>
<th>Teacher perception</th>
<th>Concerns addressed</th>
<th>Number of teachers</th>
<th>Percent of teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive shift in attitude (N=19)</td>
<td>Inquiry</td>
<td>9</td>
<td>39.13%</td>
</tr>
<tr>
<td></td>
<td>Locations necessary for effective outdoor ed.</td>
<td>5</td>
<td>21.74%</td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>3</td>
<td>13.04%</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>7</td>
<td>30.43%</td>
</tr>
<tr>
<td>Negative shift in attitude (0)</td>
<td>N/A</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No change (N=4)</td>
<td>Positive</td>
<td>4</td>
<td>17.39%</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Nineteen teachers (n = 19; N = 23) experienced a positive shift in attitude toward hands-on science investigations in the outdoors during the Teacher Science Institute professional development workshop. This total includes changed teachers’ perceptions about the use of inquiry (n = 9). One teacher (Participant 7) explained what she/he had learned from the experience: “As a teacher you can’t be afraid to get your hands and feet dirty. Go into the river; lead a group of students into the water. Students need to learn by doing things hands on, it captures the moment and retains the experience in their minds and memory as something I did.” Having a proper location for effective outdoor education was another area for growth (n = 5). Many teachers realized that they didn’t need a lot of space. Time was another area that facilitated a positive view in teachers’ attitudes, with one participant noting, "short demos or long term investigations a little each day” could be used to implement hands-on inquiry in the outdoors. The last category (“other”) affecting positive attitude shift includes resources, connection to nature, teacher confidence, student motivation, and deeper student learning. Participant 23 explained that this experience “reinforced what I am all ready [sic] doing.” No one reported that the immersive experience had a negative impact on their perceptions about teaching hands-on science in the outdoors. Four individuals maintained a positive perception of these methodologies throughout the GSMIT experience.
Session 3. Most meaningful aspect of the experience. These data were collected from teachers’ written responses to the last survey question, item 7. Data were coded using a reductionist approach to reveal major themes (Strauss and Corbin, 1998). Table 6 presents the categories, and the numbers/percentages of teachers who expressed these perceptions. Teachers reported that increased content knowledge, appreciation of nature, awareness of effective instructional methods, and collaborative opportunities were all meaningful aspects of the Science Teacher Institute.

Table 6. Most meaningful aspect of the experience.

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of teachers</th>
<th>Percent of teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaining content knowledge</td>
<td>7</td>
<td>30.43%</td>
</tr>
<tr>
<td>Having the opportunity to connect with inner child and gain an</td>
<td>6</td>
<td>26.09%</td>
</tr>
<tr>
<td>appreciation for nature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased awareness for effective methods of instruction.</td>
<td>5</td>
<td>21.74%</td>
</tr>
<tr>
<td>Having an opportunity to share ideas and establish relationships</td>
<td>4</td>
<td>17.39%</td>
</tr>
</tbody>
</table>

Summary. These results demonstrate that the Science Teacher Institute was a success. Two of the major points of significant impact were teachers’ perceptions for 1) the use of hands-on science teaching methods, and 2) resources necessary for effective outdoor instruction.

Initial teachers’ perceptions of the use of hands-on science teaching methods were skeptical, with a total of 78.26% perceiving that they did not have resources or materials necessary for teaching hands-on science (n = 18). Another 47.83% felt they lacked sufficient class time to incorporate hands-on science (n = 11). Finally, 30.43% of teachers felt that they would be unable to maintain classroom management while teaching hands-on science (n = 7). As a result of participation in the GSMIT immersive program, 39.13% of the teachers specifically mentioned that they had a new positive outlook on teaching hands-on science (n = 9). Participant 9 remarked that “Teaching hands-on science was very intimidating to me before this experience but now I feel like I have learned some practical methods to do this type of teaching with my students and I have also gained confidence in my ability.”

Initial teachers’ perceptions of availability of resources necessary for effective outdoor instruction were also skeptical. These teachers did not recognize an appropriate area for teaching within natural environments in their local areas (47.78%, n = 11). One teacher explained, “Our school lacks a quality green space or even quiet areas outside” (Participant 19). After participation in the GSMIT immersive program, several teachers acknowledged that “I don’t need a lot of space.” Participant 18 reflected, “I feel more confident in moving from inside, to the outside. I feel I have more techniques to try at home.”

Preservice Teachers: The GSMIT Maymester Informal Science Education Course
Preservice teachers’ (subset, N = 7) reflection assignment was coded through a reductionist approach in grounded theory (Strauss and Corbin, 1998). Five stable themes emerged from the analysis, including 1) place-based instruction provides sensory experiences that connect the environment to participants’ lives; 2) inquiry-based instruction motivates students and develops critical thinking; 3) self-reflection facilitates metacognition of the learning process; 4) inquiry-
based instruction in natural environments has lasting impact, and 5) informal learning environments and inquiry provide interdisciplinary instruction opportunities.

**Place-based instruction.** Participation in the GMSIT experience led preservice teachers to feel intrigued by their surroundings. The abstract version of environmental education that is presented in most textbooks was replaced with increased understanding of interlocking “big picture” ideas. Instead of simply learning science, the preservice teachers were able to do science. Learning involved all senses, and through hands-on inquiry learning, the preservice teachers answered their own questions, which led to ownership of the material. Preservice Teacher 8 exhibited growth in understanding of place-based instruction; he/she stated, “At Tremont I learned, I will try to use the local environment wherever I am to teach my students similar to the instructional methods that were used in the mountains.” This preservice teacher understands that place-based methods are not limited to a particular setting, but can be incorporated into any classroom, with many different natural settings.

Participant preservice teachers also valued the opportunity to connect environmental education content to real life experiences. The GMSIT opportunity built upon content that had been acquired by participants in a regular classroom; however, content was presented in a manner that made it relevant and meaningful to the student. Preservice Teacher 5 remarked, “This is an experience that I could not have gotten in the regular classroom…I would not have been able to feel the atmosphere of which areas were most suitable.”

**Inquiry-based instruction.** Preservice teachers’ reflections indicated that they had not only developed a deep understanding of what inquiry is, but also learned effective strategies for implementing inquiry within the classroom. Participants were able to break down specific components of inquiry-based instruction in order to facilitate inquiry among their students. Participants acknowledged that inquiry stimulates students’ natural curiosity and provides ownership in the learning process, making students stakeholders in their education. One participant, Preservice Teacher 6, linked inquiry learning with student motivation: “Before this trip I only knew inquiry as a vocabulary word and I never thought about it as much more than that, but after this experience I realize that this is a wonderful tool that can get kids motivated and eager to learn.”

Preservice teachers recognized different levels of inquiry exist, and can be implemented to transition students to student-centered learning. Teachers should guide the process from teacher-centered instruction to open inquiry. Students must first understand inquiry as a process, with inquiry incorporated through hands-on activities that promote questioning and deep thinking. Preservice Teacher 8 expressed that inquiry was not a replacement for traditional instructional methods, but rather a tool that can be implemented to increase students’ learning. This teacher remarked, “After the week spent at Tremont it is has become clear that there must be a balance between formal and informal instruction in the classroom.”

**Self-reflection:** An overwhelming majority (n = 6) of participants identified self-reflection as meaningful aspect of the GMSIT experience. Preservice Teacher 1 noted growth as both a teacher and learner: “My time at Tremont taught me a lot about myself as a learner and a teacher…It made me a better learner. It made me a more mindful teacher.” Preservice Teacher 6 noted a change of views on classroom teaching: “I viewed education as a teacher centered classroom based practice but this experience changed my perspective.”
**Lasting learning:** Over half \((n = 4)\) of the preservice teachers acknowledged the powerful and lasting aspect of inquiry and place-based instruction in natural learning environments; participants reflected on how much more they have learned in this education course than in earlier courses presented via more traditional methods. “I know I’ll retain more knowledge from just a week at Tremont than most of the content I learned over the spring semester. That is how impactful informal education is, and that is the experience that I will someday give to my own students,” wrote Preservice Teacher 3. Participants noted that the Maymester course provided the foundation for new learning opportunities, and will serve as a cornerstone of their educational training for the rest of their careers.

**Interdisciplinary instruction:** Preservice teachers identified how inquiry and place-based instruction support multiple content areas. The interdisciplinary approach to instruction allows students to ask the big questions that cannot be confined to a single subject area. This includes topics such as sustainability, conservation, scientific processes and social action with natural places, all of which represent cornerstones of environmental education. Preservice teachers acknowledged that a cooperative teaching approach, or team teaching, may be an effective teaching strategy for implementing interdisciplinary instruction within a classroom. Preservice Teacher 1 stated, “The idea of inquiry as a tool to facilitate learning can be used as an extension to between concentrations of any lesson.” Through participation, preservice teachers gained an understanding of the value of teaching interdisciplinary topics and connecting subjects for their students.

**Summary.** Since the objective of the Maymester course was to challenge preservice teachers’ views of effective teaching, and reconstruct their views to include inquiry and place-based methods of instruction, analysis of the reflection assignment confirmed that the course objective was met.

**Discussion**

By reducing the amount of seat time and increasing the amount of participation through immersion experiences, GSMIT programs have streamlined the delivery of professional development while still maintaining a quality professional development experience. These research results challenge the traditional method of professional development, and propose an alternative model. Data show this innovative approach can not only meet program objectives, but can transform professional development into a positive experience, empowering teacher participants to implement change and seek out additional learning opportunities.

In this research, we focused upon in-service and preservice teachers’ perceptions of science as a process, inquiry learning, and teaching science in outdoor environments. While general environmental science content is delivered within professional development programs (e.g., Teacher Escape Weekends, Maymester course), or specialized content knowledge that focuses upon a specific environmental issue is disseminated (e.g., Science Teacher Institute), we did not focus upon the content knowledge gains in our assessments. Therefore, future research is needed to determine participants’ content gains—and retention of content gains—beyond the GSMIT immersive professional development programs.

All GSMIT immersive experiences resulted in positive gains in teachers’ perceptions for teaching science as inquiry, and incorporating natural outdoor environments within their instruction. Participants acknowledged that inquiry engages and motivates students, and natural
environments facilitate interdisciplinary instruction, for “big picture” understanding. In-service teachers’ initial perceived barriers—such as time requirements, specialized equipment, and appropriate environments within their local areas—were overturned through the GSMIT immersive experiences. By the end of the professional development program, participating teachers perceived that scientific inquiry within outdoor environments was possible, and desirable, in their science courses. The motivation recorded by participating teachers suggests that the enthusiasm will affect K-12 classrooms: “I learned how easy it is to get things done, once you venture out and do them. I feel in the classroom I don't take the initiative to do things because I feel it would be too difficult. Now I know it is worth it” (Participant 14, Teacher Science Institute). Future longitudinal studies are needed to determine the impact of teachers’ modified attitudes in the use of inquiry methods and outdoor environments within their classrooms.

However, this research underscores the impact and innovation of short, immersive environmental experiences. We propose that university faculty and staff should consider restructuring professional development and outreach programs to include short immersive experiences. This research also suggests modifications in science teaching: By engaging college students, in-service teachers, and K-12 students via inquiry learning within natural environments, instructors may significantly impact course outcomes. Furthermore, creatively considering how we assess these outcomes can help us capture that impact in a meaningful way.

Acknowledgement

The authors acknowledge the contributions of Sarah Radencic, Department of Geosciences at Mississippi State University, for her assistance in developing the preservice teacher surveys for the Maymester Informal Science Education course.

References


CHAPTER 2
Course-based Undergraduate Research Experiences (CUREs)

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Introduction

The report Vision and Change in Undergraduate Biology Education: A Call to Action (AAAS, 2011) recommends that instructors who teach undergraduates consider integrating research into their classrooms and student laboratories. This report cites the growing body of literature that indicates that involvement of undergraduates in research experiences increases learning in the sciences (NRC, 2000, 2003; Lopatto, 2003, 2007, 2009; Laursen et al., 2010). As well, it is noted that undergraduate research experiences can have an especially strong effect on underrepresented minority students (Jones et al., 2010) and that early experiences were particularly influential.

While traditional apprentice-based research experiences can be highly effective for undergraduates, the number of students that can be served is limited. Individual research experiences require a great deal of investment in both faculty time and resources that necessarily limit the total number of students than any faculty member can successfully mentor at a given time. Yet, embedding research experiences within courses and teaching laboratories can leverage both time and resources to provide the advantages of participation in research to a larger number of students. These experiences, known as course-based undergraduate research experiences (CUREs), represent a growing teaching innovation in the sciences and are beginning to impact thousands of students annually.

What are CUREs?

CUREs are described as an experience in which students address a research question or problem that is of interest to the broader community with an outcome that is unknown both to the students and to the instructor (Domin 1999; Bruck et al., 2008; Weaver et al., 2008). Corwin Auchincloss et al. (2014) note that CUREs involve many undergraduate students in science research at one time and all students who enroll in a course are able to participate. Corwin Auchincloss and colleagues additionally described five dimensions that could be used to describe different learning contexts in laboratory settings and identified the combination that is found in CUREs. The five dimensions are “use of science practices”, “discovery”, “broader relevance or importance”, “collaboration”, and “iteration”. They note that in CUREs, students engage in multiple scientific practices. Study design and the purpose of the investigation may be either student or instructor driven. As well, the outcome is unknown, the findings are novel, and the relevance of the students’ work extends beyond the course. Students also have many opportunities for action throughout the work. Collaboration is important in CUREs and includes interactions among students, teaching assistants, and instructors in the course. The instructor’s role is to provide both guidance and mentorship to students in the course. Finally, the risks of
generating “messy” data are inherent in CUREs, and iteration is very often built into the process. The authors note that the frequency and intensity of each activity will vary in different CUREs, but this combination is common to CUREs and distinguishes them from traditional laboratory courses, inquiry laboratory courses, and research internships.

**Participating in CURE Programs**

Faculty members interested in participating in CUREs at their institution have the option of creating their own CURE course or adopting an existing CURE curriculum. For someone new to CUREs, the easiest path to implementing these experiences would be to connect with an existing CURE program. These programs typically provide a proven curriculum, laboratory protocols, training, and some research or data infrastructure. A research community with other participating faculty also provides support and advice. In the biological sciences, a number of national programs or networks have developed CUREs that are used by participating institutions. Some examples include the Science Education Alliance – Phage Hunters Advancing Genomics and Evolutionary Sciences (SEA-PHAGES), Genomics Education Partnership (GEP), and Small World Initiative (SWI).

**SEA-PHAGES**

The SEA-PHAGES program began in 2008 with support from the Howard Hughes Medical Institute (HHMI) and was adapted for college-level courses from the Phage Hunters Integrating Research and Education (PHIRE) program developed at the University of Pittsburgh (Hanauer et al., 2006). Over the program’s first five years, it grew to include more than 4,800 student participants at 73 schools (Jordan et al., 2014).

In SEA-PHAGES, students participate in a two-semester long research experience early in their college education, typically during the freshman year. The program has primarily focused on the isolation and characterization of viruses, known as bacteriophages or phages, that infect a single bacterial host, *Mycobacterium smegmatis* mc²155. During the fall semester, students in the course working either independently or in pairs collect soil samples and attempt to obtain bacteriophage isolates on a lawn of the mycobacterial host on an agar surface. Once a viral plaque is confirmed, the students then complete several iterations of infection and picking of isolated plaques to purify the isolate. When the student is confident that they have a purified bacteriophage, a high titer lysate (HTL) of the phage is obtained which can be used to isolate phage DNA and to visualize the phage using electron microscopy. The HTL of all phage isolates are archived at the University of Pittsburgh, and the details of their isolation and characteristics are made available to the SEA-PHAGES and scientific communities through a website, http://www.phagesdb.org.

One or more of the bacteriophages from each school is selected by the students for genome sequencing at the end of the first semester. The phage DNA is sequenced over the winter break, and genome sequences are returned to the classes early in the spring. Students in the course spend the spring semester annotating and analyzing the genome sequence of their institution’s phage. Students determine both the position and function of putative genes in the genome using bioinformatics software tools. By the end of the course, the completed genome annotations are sent to the SEA-PHAGES program for final quality review, following which the annotations are submitted to the Genbank sequence database for publication. Students at SEA-PHAGES institutions currently isolate over 1,000 new bacteriophages each year, as recorded at the PhagesDB website. These isolates continue to expand knowledge on the
genetic diversity of bacteriophages that infect the selected mycobacterial host. The program also shows the ability of CUREs to involve large numbers of students in meaningful scientific discovery. A recent paper produced by SEA-PHAGES best illustrates this point. Pope et al. (2015) compares the genomes of 627 phages that infect *Mycobacterium smegmatis*. This paper has 199 faculty and 2,664 student co-authors (HHMI, 2015). The SEA-PHAGES program continues to expand each year, adding new institutions through an application process. Faculty members from participating institutions receive training in the wet lab protocols and bioinformatics tools used in the program, as well as access to community resources. The scientific scope of the project has also expanded to include a number of hosts in the bacterial order of Actinobacteria, including not just *Mycobacterium*, but also *Arthrobacter, Rhodococcus, Streptomyces*, and other genera.

Assessment of the program has found that SEA-PHAGES students scored as well in 20 learning gains measured by the SURE and CURE surveys (Lopatto, 2004) as did students who completed a summer undergraduate research experience (Jordan et al., 2014). This study also found that SEA-PHAGES participants matriculated into the second year at significantly higher rates than did benchmark groups of either all students or STEM majors with the same number of years of college experience who were enrolled at the same school. Jordan et al. (2014) conclude that early engagement in a research experience improves student retention into the second year.

Genomics Education Partnership
The Genomics Education Partnership (GEP) began in 2006 and consists of a consortium of primarily undergraduate institutions and the Biology Department and Genome Center of Washington University in St. Louis. More than 100 colleges and universities participate in the GEP with the goal of providing undergraduate students with a research experience in genomics (Lopatto et al., 2014) and more than 1,000 students participate annually (Shaffer et al., 2014). According to the GEP website (http://gep.wustl.edu/), participating undergraduates learn to take raw sequence data to high quality finished sequence, and to annotate genes and other features, leading to analysis of a question in genomics and research publication. GEP organizes research projects and provides training/collaboration workshops for PUI faculty and teaching assistants. The GEP investigates the evolution of the Muller F element, a region of the *Drosophila* genome that exhibits both heterochromatic and euchromatic properties, and the evolution of the F element genes. Undergraduates are involved in both finishing, improving the quality of draft sequence, and annotating designated regions of the *Drosophila* genome. Students work on 40-kb “projects,” which are reassembled to generate large domains for analysis following quality control checks (Lopatto et al., 2014).

Pre- and post-assessments have been collected for the GEP and found that participating students show gains in their knowledge of genes and genomes (Shaffer et al., 2010, 2014). Postcourse surveys also show an overall pattern and numerical scores very similar to those of students in dedicated summer research programs (Lopatto, 2007; Shaffer et al., 2014)

Small World Initiative
The Small World Initiative (SWI) is a relatively new CURE program and was initiated at Yale University in 2012. The SWI has grown to include more than 50 partner institutions around the globe (http://www.smallworldinitiative.org/about).
The SWI seeks to engage students in a research experience that connects to real-world problems, in this case the rise antibiotic resistance and lack of effective new drugs. Participants in SWI conduct research to discover new antibiotic-producing microorganisms and to potentially screen new antibiotics. The project seeks to harness the power of large numbers of students to address this problem and contribute to the development of a database of antibiotic-producing organisms, their habitats, and trends in their discovery. Students in SWI courses isolate bacteria from soil samples and screen the isolates for antibiotic activity against ESKAPE organisms, a group of non-pathogenic bacteria that are relatives of known disease-causing organisms. Like other CURE projects, SWI provides training and curricular materials as well as a community of faculty partners. The SWI curriculum is flexible and can be incorporated into lower-level biology laboratory courses or with microbiology laboratory courses. While this project has not yet published student assessment data, the SWI shows the potential for CUREs to engage students in relevant research topics that could have an impact on society.

Creating your own CURE
With the right project idea, any faculty member could create a CURE for use at their institution. Because CUREs seek to answer research questions that are unknown, faculty members can develop projects from aspects of their own scientific research. As an example, the University of North Texas (UNT) has created a CURE course for upper-level undergraduates called Advanced Research in Life Sciences. Different research topics which rotate each semester were developed by several faculty members in the Biological Sciences. The course is taught in a classroom/laboratory, called the Classroom-based Research Laboratory (CRL), which was equipped for basic biology research through an HHMI-funded Science Education Grant. The CRL is designed to accommodate 16 students in a research class section. Currently, one CRL course section is offered per semester with topics rotate among participating faculty. The research topics vary widely with faculty expertise. The author of this work (Hughes) teaches a research course on Advanced Bacteriophage Genetics. This course builds on the SEA-PHAGES program that is also offered UNT and gives students the opportunity to conduct in depth genome analysis and comparison beyond what is performed in the freshman-level program. The CRL course research directly advances the bacteriophage research of the author. Likewise, other CRL topics have been developed to complement and assist in the research of the supervising faculty member. Dr. Ed Dzialowski teaches a CRL course on Developmental Physiology, Dr. Kent Chapman teaches a section on Cell Biology, Biochemistry, and Molecular Biology topics related to his plant research, and Dr. Aaron Roberts teaches a course on Environmental Toxicology. Each of these faculty members has found the CRL course they have developed to be a very satisfying teaching experience, and several students in the course sections have been recruited into graduate positions in these labs following graduation.

Practical Considerations
Having conducted CUREs of local design and having participated in both the SEA-PHAGES and SWI programs, I would like to share some practical considerations that may be useful for anyone considering implementing a CURE at their institution.
1. Be prepared. Beginning a CURE for the first time can involve a significant investment of time and energy for any faculty member, whether developing your own or joining an existing program. Do your research and be sure that the project is a good fit for you and your institution. Know what resources are available to you and ask in advance for anything you may need from the department or institution, such as equipment, supplies, or release time for course development.
2. Start slowly. After investing time and preparation into implementing a CURE at your campus, take the time to evaluate your progress before over-committing. Once you have successfully piloted one or a few course sections, you can better identify the unique challenges that you will face at your institution and determine how to address those issues. This will allow you to handle the inevitable bumps in the road in a positive way and move forward in an informed manner. Once you feel confident in this new way of teaching, you can look at expanding your student enrollment or types of CUREs offered as appropriate to your situation.

3. Make the most of the process. Faculty members can find a CURE to be extremely rewarding if they can connect the research to their own professional interests. This can be easily accomplished when developing a CURE around your own research topic, but can also occur when joining an existing CURE program. Because many different types of projects and networks exist, it can be possible to find a project that relates to current research interests. In most programs, faculty members can work together to network and move the research agenda forward in ways that benefit the group’s membership. To find a program that relates to your areas of interest, see the website of the Course-Based Undergraduate Research Experiences Network (CUREnet; http://curenet.cns.utexas.edu/).

4. Make it work. CUREs have been successfully implemented at a number of institutional types. Every institution is different and has its own unique characteristics. As a faculty member at your institution, you know what those factors are and how they can be best utilized to support a CURE. There will also be factors that will need to be overcome. Utilize the experiences of other faculty from similar institutions to help you come up with strategies that can help you be successful.

5. Institutionalize. Projects can come and go quickly at a university, especially if only one person is spearheading the effort. Long-term stability of the CURE can be assisted by institutionalizing the project. When possible, try to integrate the CURE into the regular curriculum by giving the course a regular course number and identifying specific degree requirements that can be fulfilled by the course. Also attempt to involve more faculty members so that the sustainability of the project does not rely on a single person’s availability.

6. Manage costs. CUREs can be expensive, but they are not necessarily so. Before starting your CURE, determine what equipment and supplies will be needed. Then, identify existing resources that can be leveraged to make the course fit within your budget. Can the course be taught in a laboratory room that already has the needed equipment? Can the experiments replace a portion of existing laboratory exercises in a laboratory course? Maybe the expense will be offset by switching in the CURE experiments for regular exercises that have similar supply costs.

Conclusion
Undergraduate research experiences have been shown to be an effective method for increasing student persistence in the sciences, and ongoing research is providing evidence that CUREs can deliver similar benefits as apprentice-based research experiences. Importantly, CUREs can provide these experiences to many more students than can individual mentoring. Numerous opportunities exist for faculty members in the sciences who are interested in implementing a CURE at their institution. Several examples of nation-wide projects are
highlighted in this work, and the CUREnet website contains a searchable list of many other opportunities and examples at institutions across the country. Faculty may choose to engage with one of these existing programs or can use these examples to develop their own CURE based on their individual research interests. Whichever path is chosen, CUREs are a growing type of learning experience that can be fulfilling for both students and faculty. These research experiences give large numbers of students over time an opportunity to participate in authentic research experiences and to conduct science investigations that can be meaningful to both themselves and society.

**Literature Cited**


Abstract

Inquiry-based instruction has been shown to be beneficial to science instruction from K-16, yet few classrooms are implementing it. Research in science education shows that inquiry-based instruction promotes critical thinking and reasoning skills necessary for science literacy in the 21st-century. There are many reasons teachers are not implementing inquiry into their classrooms such as time constraints and classroom management. This article addresses these issues and offers suggestions to teachers that may help them implement inquiry into their classrooms.

Introduction

Experiences such as formulating questions, probing for answers, and finding relationships are the goals of inquiry-based learning. Being actively engaged in learning through this student-centered, educational method can be traced back to the educational philosopher John Dewey. Dewey (1933) advocated for student-centered learning based on real-world experiences, which is deeply intertwined with the history of constructivism. Piaget’s (1972) cognitive constructivism theory and Vygotsky’s (1978) social constructivism theory also have significant relevance to modern-day use of inquiry-based teaching methods. But what does ‘inquiry’ mean anyway?

The usage and implementation of ‘inquiry’ in the literature is immense. If you look up the meaning of inquiry, you will find a multitude of definitions. In 1960, Webster’s Collegiate Dictionary defines inquiry as: (1) search for truth, information, or knowledge; research; investigation; (2) a seeking for information by asking questions; interrogation; a question or questioning (Webster’s, 1960). Currently online, Merriam-Webster defines inquiry as: (1) a request for information; (2) an official effort to collect and examine information about something; and (3) the act of asking questions in order to gather or collect information (Inquiry, 2014). If you Google the word ‘inquiry’ you will find page after page of choices describing its meaning, however, it is usually associated with a teaching or learning method and it usually follows a similar theme, which is to seek information.

The National Science Education Standards distinguishes ‘inquiry’ used in a science laboratory and in a classroom this way, “Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (National Research Council [NRC], 1996, p. 23). In both the scientific laboratory and in an inquiry-based science classroom, inquiry drives investigation of
the natural world by forming questions based on observations, develop hypotheses about phenomena, and devise experiments to test their hypotheses.

**School Standards and Reform**

In 1961, the National Education Association’s Educational Policies Commission (EPC) published a document titled The Central Purpose of American Education, which defines the central and fundamental purpose of schools in America. The central purpose proposed by the EPC, which is the development of the ability to think, is defined in terms of rational powers, ten to be exact (Marek & Cavallo, 1997). From most fundamental to most complex, they are recalling, comparing, inferring, generalizing, deducing, classifying, analyzing, imagining, synthesizing, and evaluating. These ten rational powers enable students to apply logical thinking to evidence presented to them and think in a coordinated way. These are also some of the fundamentals of inquiry learning.

*Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993) suggests the use of inquiry in K-12 science instruction to emphasize problem-solving and critical thinking in a real-world context. In the 20 years since *Benchmarks*, we have gained a better understanding of how students learn and develop competence over time (Padilla & Cooper, 2012). In alignment with the Common Core State Standards Initiative (CCSSI, 2010), the focus is depth and retention as opposed “coverage.”

Rather than using the term ‘inquiry’, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council [NRC], 2011) uses the term ‘practices’ meaning that engaging in “inquiry requires coordination both of knowledge and skills simultaneously” (NRC, 2011, p. 3-1). *A Framework* also explains that the integration of content and practice means a corresponding change in college-level science courses.

The necessity for college-readiness in science is a key component for the development of the *Next Generation Science Standards* (NGSS) (National Research Council [NRC], 2013). In fact, postsecondary science faculty at two- and four-year colleges believes that if students met the NGSS, they will be prepared for college-level science courses (Padilla & Cooper, 2012). Of particular interest is students’ ability to apply their understanding of science, to make connections to new content, and to extend their knowledge of science. Unfortunately, while scientific inquiry has been accepted as an improvement to science education reform, few classrooms are implementing it even though science education reform and standards indicate that inquiry can be both a learning goal and a teachable approach (AAAS, 1993; NRC, 1996).

**Implementing Inquiry in the K-12 Classroom**

In order for teachers to implement inquiry skills into their classrooms, they must first have a good understanding of what inquiry means for themselves (Mumba, Mejia, Chabalengula, & Mbewe, 2010). Teachers report several reasons for not implementing inquiry into their science classrooms. The most commonly cited reason is time constraints (Gengarelly & Abrams, 2009; Mumba et al., 2010), in addition to other reasons such as classroom management problems (Mumba et al., 2010), and their beliefs about science (Gengarelly & Abrams, 2009).

Focusing on the lack of inquiry experience that teachers have, research suggests that some teachers know what it is, but they are not comfortable using inquiry as a teaching approach; others are not quite sure what inquiry is exactly. Some teachers believe that just incorporating activities in their classrooms counts as scientific inquiry (Passmore, Stewart, & Cartier, 2010). While true inquiry almost always involves direct-experience activities, just doing such activities does not always constitute inquiry-based learning.
In order to help teachers with their understanding of inquiry and implementing it into their science classrooms, programs are being developed to integrate scientists and science teachers in a collaborative effort to guide teachers during their struggles (Gengarelly & Abrams, 2009; Jeanpierre, Oberhauser, & Freeman, 2005; Mumba et al., 2010; O’Neill & Polman, 2004). The National Science Foundation put forth an initiative to pair graduate-level scientists (those working on an MS or PhD in their perspective scientific field) with science teachers in elementary, middle school, and high school called the Graduate Teaching Fellows in K-12 Initiative (GK-12 Project) (Gengarelly & Abrams, 2009; Mumba et al., 2010).

The GK-12 Project used graduate student fellows rather than veteran scientists so that the fellows could share their own troubleshooting experiences with the teachers and therefore be able to demonstrate empathy toward the teachers. The fellows served as a source of content knowledge and also as role models for both teachers and students in order to foster a positive attitude toward science (Mumba et al., 2010).

Technologically Mediated Instruction Strategies for Inquiry

Technology has become such an integral part of most classrooms in recent years. Students are carrying smart phones, tablets, and laptop computers with them everywhere. Curriculum needs to incorporate a breadth of technologies to teaching strategies in order to stay in touch with up and coming students. Inquiry has evolved into practices involving depth of information by the use of personal response systems (clickers) and case-based learning in science courses (Wolter, Lundeberg, Kang, & Herreid, 2011). These types of studies are especially useful in large lecture classes (Cotner, Fall, Wick, Walker, & Baepler, 2008).

One of the most obvious effects clickers have on student learning is that they provide immediate feedback and can promote class interaction. Immediate feedback plays an important role in student interaction because it not only informs the instructor of any misconceptions the students are having, which can then be quickly corrected; it also gives students a chance to discuss with each other why the correct answer is what it is. Class discussions can create some level of discourse, which can also be useful for student learning (Cotner et al., 2008). Students reported being more engaged when the instruction centers more on discussion (Wolter et al., 2011).

Wolter et al. (2011) also explains how case-based instruction, which can also utilize clickers, increases student participation and understanding of science concepts. Case-based instruction helps students make personal connections between the scientific content and a context that means something to them in the real world. Students think more clearly and more deeply when the scientific information, through the use of case studies, provides real-world meaning (Savery, 2006; Wolter et al., 2011). By incorporating relatable social issues to students, they are able to assimilate science content and contexts. Rather than being an “accidental learner” their understanding of the content is replaced with a more constructivist approach to learning (Hainline, Gaines, Long Feather, Padilla, & Terry, 2010) just as the pioneers of constructivism, Dewey, Piaget, and Vygotsky, described all those years ago.

Conclusions

It is a little easier to incorporate inquiry into a laboratory setting; it is more challenging in a lecture-only situation. In either case, incorporating real-world issues into a science curriculum can promote the students’ desire to pursue learning, to build upon their existing knowledge, and reflect upon and assimilate that knowledge (Nava-Whitehead et al., 2011). Inquiry-based learning, or Dewey’s view of ‘learning by doing’ (1933), is an important tool for teachers because it: (a) generates interest in the
learner; (b) becomes intrinsically worthwhile to the learner; and (c) presents problems that awaken new curiosity and creates a demand for information (Giles & Eyler, 1994).

If we are to have any hope of incorporating inquiry into science classroom practice, which would lead more importantly to scientifically literate students, then we need to continue to develop programs that help teachers with their understanding of inquiry and guide teachers during their struggles of implementation such as the GK-12 Project. There are also workshops for learning how to incorporate clickers (Crossgrove & Curran, 2008) and case studies into science classrooms (Herreid, 2005). There are also workshops that offer instruction for inquiry-based teaching (Collier, Johnson, Nyberg, & Lockwood, 2014; Jeanpierre et al., 2005; O’Neill & Polman, 2004).

Dewey (1938) emphasized the importance of authentic learning. The interrelatedness of concepts and ideas are best learned when real-life situations are brought into the learning environment (Rivers Murphy, 2014). Using inquiry-based learning to connect meaningful and relevant life experiences with students’ academic learning can result in useful skills that prepare students to be successful in life. The use of inquiry is constantly evolving to shape in-depth learning, especially in science (Wolter et al., 2011).

References


Undergraduate Research as an Innovative Learning Experience: Student Perspectives on Professional Impacts

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Introduction

Learning environments for innovative college science teaching at the undergraduate level are not limited to the classroom space. Students in higher education (especially at research-intensive universities) often have the opportunity to participate in authentic research with graduate students, post-doctoral researchers, and faculty mentors as a means of skills-based instruction (Russell, Hancock & McCullough, 2007). This is a form of innovative college science teaching that often serves as a skill-based apprenticeship into the research profession. Recent policy documents highlight the importance of these experiences to student learning and professional education, especially in the science, technology, engineering and mathematics (STEM) fields (i.e. AAAS, 2012). The waning interest in STEM fields of American students and the decreasing competitiveness of STEM graduates in the global workforce are currently important concerns in STEM education and policy (PCAST, 2012). One of the most important objectives of these programs is to solidify student interest, thus promoting retention in the STEM pipeline and increasing the likelihood of matriculation into STEM careers (Adedokun et al., 2012; Ernsting & Akrabawi, 2007; Russell et al., 2007; Villarejo, Barlow, Kogan, Veazey, & Sweeney, 2008; Yaffe, Bender, & Sechrest, 2014).
It has been argued that engaging students in science research as part of their educational experience is one of the most critical components to “plugging leaks” in the STEM pipeline as well as ensuring those students who matriculate are properly prepared for STEM careers (AAAS, 2011; Seymour, Hunter, Laursen, & Deantoni, 2004). In response, opportunities for undergraduate science students to participate in authentic research projects during their post-secondary education are becoming increasingly commonplace in the United States (Russell, et al., 2007; Sadler, Burgin, McKinney, & Ponjuan, 2010). In a recent report, students in STEM fields report up to 53% participation rates in some form of guided or independent research during the course of their undergraduate careers (Russell et al., 2007). This has also led to an increase in funding opportunities for Undergraduate Research Experiences (UREs) from institutions such as the National Science Foundation, National Institutes of Health, and Howard Hughes Medical Institute. For many students, this apprenticed experience transcends their typical understanding of science learning.

If science educators, education researchers, and policy makers are committed to ensuring a workforce in the United States prepared for the global economy, the impacts of innovative instruction within the authentic science laboratory on the STEM pipeline must be considered. There is a body of literature on the role that UREs have on student success and retention in STEM careers (Adedokun et al. 2012; Villarejo et al., 2008). However, this is often limited to evaluative studies. In addition, there is limited qualitative work that carefully highlights the voices of students and rich experiences that they have within their UREs.

To further add to the above discourse, the current literature regarding the impact of UREs on STEM pipeline retention and matriculation into STEM careers is briefly reviewed. This provides a theoretical lens for the manuscript. Following this, we provide a brief discussion of data collected from a project in which participants of a structured URE were asked to reflect on the impact that URE participation had (or will have) on their career goals. By situating the study in a single setting, we offer this data as an abbreviated case study in how the innovative learning experiences of UREs might impact STEM retention and career choice. We conclude with a brief discussion of the implications of the data and the current literature discourse upon the future of teaching and research in UREs.

We organize the review below in a somewhat longitudinal “pipeline” manner. To do this, we first highlight studies that examine development of student interest in research-based STEM careers. We then move on to studies documenting student matriculation into graduate school and subsequently research-based careers. We conclude with a discussion of major themes related to the innovative instructional environment provided by UREs. As recent reviews of UR programs exist (see Sadler et al., 2010 and Sadler & McKinney, 2010) our intent is not to recreate these syntheses. We narrow the focus of the following section to the impacts of UREs on STEM pipeline retention within the last fourteen years and integrate literature from the last several years not included in Sadler’s recent reviews.

**Impacts of UREs on STEM Persistence and Career Paths**

*Participant Interest and Perceptions of STEM Careers*
For many students, upon entrance into college or university, their perceptions of what it means to be in a research-based STEM career is often idealistic and vague. As such, several studies examine the evolution of student perceptions of and interest in research-based STEM careers as they progress through their undergraduate education (in general) and through UREs (more specifically). Student maintenance of interest is hypothesized to influence persistence as well as future career choices. Numerous studies report that participation in UREs led to an increased interest in research as a potential career path (Gonzalez-Espada & LaDue, 2006; Harrison, Dunbar, Ratmansky, Boyd & Lopatto, 2011; Pacifi & Thomson, 2011; Russell et al., 2007). For example Ernsting and Akrabawi (2007) increased commitment to providing UREs for their undergraduates, which then led to a significant increase in students reporting an interest in pursuing research-based careers (from 1.3% to 16.7%) over time. Much of this research is limited in that it is self-report survey data, however.

Undergraduate research experiences also serve to help participants clarify their perceptions of what it means to be a research scientist. In a series of longitudinal qualitative studies documenting the progression UR participants at four institutions, Hunter, Seymour and colleagues have documented changes in various perceptual variables of UR participants that have the potential to be directly related to STEM career matriculation (Hunter, Laursen & Seymour, 2007; Seymour et al., 2004; Thiry, Laursen, & Hunter, 2011). These researchers (as well as others) have noted that UR participants felt that the experiences had left them better prepared for graduate school (Nandozie, Ishyama & Chon, 2001; Schwartz, 2012), given them a better understanding of the role of graduate school in their personal career development (Russell et al., 2007; Ward, Bennett, & Bauer, 2002), and helped clarify their decision to pursue scientific careers (Gonzalez-Espada & LaDue, 2006; Harrison et al., 2011; Pacifi & Thomson, 2011; Russell et al., 2007). With many UR programs loosely based on an apprenticeship model of education, with faculty as the target “expert”, it is of little surprise that participants gain a better understanding of the goals, norms, and expectations of this community of practice (Gardner, Forrester, Jeffry, Fierzli, & Shea, in press).

Pacifi & Thompson (2011) compared students (n = 26 surveys, and 11 sub-sample interviews) initial expectations of the objectives of a URE with the resulting perceptions of the outcomes after completion of the program. This research, although possessing a limited sample size, does help to parse out some of the direct effects of UREs on student perceptions through a unique pre-post design. Despite little change in pre- to post-interest in STEM careers, participants noted that the URE assisted them with entry into graduate school at much high levels than they initially expected.

The collective work, although informative, suffers from two research design flaws. The first is sampling bias. There should be little surprise when it is discovered that samples of students who actively and voluntarily seek out UR opportunities also have high interest and STEM career ambitions (Sadler et al., 2010). Second, although these studies attempt to demonstrate correlational evidence of the relationship of UREs to student interest and perceptions regarding
STEM careers, there is often little detail about what specific aspects of the undergraduate experience lead to these perceptions. Many of the studies fall short of providing even the most rudimentary descriptions of the structure of their particular URE. Because of this last limitation, it is difficult to know if it is the URE holistically or particular components of these experiences that might lead to participant persistence in the STEM pipeline.

**Participant Matriculation to Graduate School and STEM Careers**

There is gathering evidence that participation in UR helps clarify participant interest as well as perceptions of the role research will play in their future careers. However, self-reports of perceived increase in interest is only one aspect of this work, while measuring actual matriculation is perhaps more meaningful. Studies have demonstrated correlations between UR research participation and matriculation into graduate school (Hathaway, Nagda, & Gregerman, 2002). Two studies are highlighted below that have attempted to empirically examine the differential rates of graduate school attendance of UR participants with matched equivalent groups. These studies are particularly notable as they tend to deal with the sampling bias limitations noted above.

Slovacek, Wittinghill, Flenoury and Wiseman (2012) conducted an empirical study with a demographically matched sample of \( n = 183 \) undergraduate students who participated in an UR program (Minorities Opportunities in Research Experience, MORE) and a matched sample of students at their institution who did not. It was found that over half of the MORE participants went on to pursue a Masters or Ph.D. in a research field (in contrast to only 14% of non-MORE participants). In addition, participation in UR was a strong significant predictor for graduate school acceptance (logistic regression model, beta = 1.83; odds ratio 6.23). Similarly, Bauer and Bennett (2003) found in a matched comparison study that participants in UREs had a 67% probability of attending graduate school in comparison to non-UR participants (with a 57% probability of attending graduate school). The researchers also demonstrated that UR participants had a 42% probability of pursuing a Ph.D. in comparison to the non-UR participants, who had a probability of pursuing a research Ph.D. of 23%.

Completion of graduate school is the final gateway for many research-based careers. Some studies have attempted to measure rates of matriculation and the impact of UR on entry to these fields. In an extension of the above study, Brauer and Bennett (2003) found that 33% of past non-UR participants were in careers not related to their major as compared to the UR participants, who were more likely to stay in their major field of study. Adding clarity to this work, Yaffe, Bender, & Sechrest (2014) surveyed a large sample (\( n = 378 \)) of past UR participant and found high levels of job satisfactions within this group indicating that commitment to STEM careers.

**Aspects of UREs that Lead to Persistence**

*The Development of Self-Efficacy to Conduct Research*

Several recent studies have attempted to deal with the inherent selection bias problem of research design in this field by conducting matched comparison studies (Bauer & Bennett, 2003; Slovacek et al., 2012). Less work has been done to rectify the second major design flaw in these studies, that is, what is it about UREs specifically that lead to STEM student persistence? There are two
relevant ways to rephrase this question in the context of educational research: 1) Are there specific aspects of effective URE programs that lead to greater persistence? 2) What specific aspects of UREs are developing skills, habits of mind, or affective characteristics in participants that lead to greater persistence? The first research question focuses on the learning environment of the program itself. The second focuses on the development of the UR participant. The work discussed below has begun to attempt and answer some of these questions.

In two related studies, researchers attempted to examine what characteristics of participants, developed during UREs, might be particularly important in STEM persistence. Chemers, Zurbriggen, Syed, Goza & Bearman (2011) created a path analysis model for both undergraduate- and graduate-level researchers to demonstrate the importance of self-efficacy and science identity development as predictors of a commitment to a science career (using a mediation model as their empirical framework). The importance of self-efficacy in maintaining a STEM career trajectory is mirrored in a study by Strayhorn (2010) who also utilized path analysis to demonstrate the relationship between these variables. Results from these studies demonstrate the importance of helping students develop self-efficacy to conduct science research and be carefully integrated into a science community of practice as means of promoting persistence (Gardner et al., in press).

Recent work by Adedokun and colleagues (2014) has demonstrated that the length of time in which participants are involved in a the UR program could have a relatively large impact on perceived research skills, awareness of career options, research confidence, and understanding of the research process. In previous work Adedokun, Bessenbacher, Parker, Kirkam, & Burgess (2013) demonstrated the relationship between research skills, research self-efficacy and aspirations for research careers. Students who rated their ability to complete certain laboratory tasks and their perceived confidence to perform authentic research (both components of self-efficacy) as being strong predictors of aspirations for research careers.

The Mentor-Mentee Relationship

One of the most important aspect of the learning environment of UREs seems to be the way in which the mentor interacts and effects student learning (Russell et al., 2007). When a sub-sample of interview participants were asked the primary influences for their current career choices, personal interest was noted first, followed closely by influence of an academic mentor on their career paths (Yaffe et al., 2014). Other studies highlight the importance of the role the faculty mentor (as well as graduate students and post-doctoral researchers acting as mentors) plays in either encouraging or discouraging persistence in research fields (Gardner et al., in press). It appears this relationship is almost as important as the URE work itself.

The persistence of an effective mentor seems to be even more important for women and underrepresented minorities. Persistence of these groups appears to be heavily influenced by the mentor, who is ideally an individual (or individuals) with which these participants can identify. Slovacek et al.’s, (2012) comparative study demonstrated that the MORE research program increased the likelihood of participants (who were 79% Hispanic or African American) future pursuit of STEM careers. Such work was clarified by Hathway et al., (2002) who noted that in their study of UR participants and non-participants at a single institution, minority participation in UR lead to an increase likelihood of them pursuing a STEM careers. Interestingly, this statistical relationship was not seen in the white students.
It appears that a careful consideration of the role that mentors play in undergraduate research is critical for planning and design of UREs. Although some research has looked at the participant perceptions of their mentors, little work has focused on the perceptions of the faculty and graduate mentors who participate in UREs. Effective mentoring requires buy-in to the program, which can be demanding. Many faculty feel like UREs often leave them struggling to weigh the altruistic benefits of participation with the emotional, financial and professional costs endured in training and preparing novice researchers (Schwartz, 2012).

The Case: Howard Hughes Research Scholars

In order to further investigate the relationship between undergraduate research experiences and future career choice as well as to give URE graduates who are currently in STEM careers a voice, we conducted a qualitative interview study in a research project sponsored by the Howard Hughes Medical Institute (HHMI). The program is carefully described and the potential points of student development are highlighted.

The Howard Hughes Research Scholars (HHRS) was a URE program at a large southeastern public research university sponsored by the Howard Hughes Medical Institute (HHMI). The primary goal of the program was preparing undergraduate life science majors for matriculation into STEM careers through immersion in year-long authentic research experiences. Research scholars had an opportunity to develop an original research question and enact this project under the guidance of a faculty mentor. The programmatic objectives of the project were to: 1) increase the number and diversity of students participating in undergraduate life sciences research, 2) encourage students to become involved in scientific careers, and 3) enhance the quality of the undergraduate research experiences.

Outstanding sophomore and junior students were selected to become HHRS Fellows on the basis of research proposals, college transcripts, recommendations from faculty, and interviews with the HHMI Grant Director and HHRS Program Coordinator. Once selected, they were paired with a faculty mentor who supervised an independent research project. Fellows received three course credits as well as a stipend while participating in the program. Participants were encouraged to present their findings in organized laboratory groups, at scientific meetings, and at the university’s Undergraduate Research Symposium. In addition, students were encouraged to attend workshops and develop skills in communication, networking, leadership, and negotiation.

Some examples of research project completed by the HHRS scholars include the following: Gamma-aminobutyric acid (GABA) distribution across fish phenotypes, Using insulin-like growth factor-I (IGF-I) as a growth biomarker in vertebrates, Light-dependent growth patterns in soybean, The ability of nitric oxide to regulate the action of Rev-Erb genes, Examining reproductive regulatory genes and cell specialization in C. elegans, Examining copulation latency and sleeping patterns of Drosophila through genetic mapping, and Mapping mutations that effect central nervous system midline development in Drosophila.

Over the course of the four-year period of the grant, 22 students participated in the program in overlapping cohorts. Students report learning and implementing a variety of laboratory and field research techniques including: writing up laboratory data, assisting graduate students in duties, developing research protocols, performing safety tests, ordering supplies, mixing and maintaining chemicals, analyzing and gathering data, and mentoring incoming undergraduates.
Data Collection and Analysis

Two data sources were used to gather and triangulate information for the HHRS program. First, a contact list for previous and current participants in the program was obtained from HHRS Program Coordinator and previous participants were contacted over email and asked to fill out a short survey. Since one of the major objectives of this project is to encourage participants to pursue scientific careers (objective 2), it was considered important to understand where past participants currently are in their academic and career paths. The survey asked about their current work and academic status and for them to reflect upon the HHRS scholar programs’ effect upon these career aspects. Five of the eleven previous participants returned a survey (45% response rate).

Finally all current HHRS participants were invited to participate in a semi-structured interview in order to get a sense of their experiences in the program as it concluded. Of the current students, six out of eleven (55% response rate) agreed to participate in a semi-structured interview each of which lasted approximately one hour. Demographics of all the HHRS scholars are shown in Table 1.

Table 1: Demographics of HHRS Scholars

<table>
<thead>
<tr>
<th>Gender</th>
<th>22.73%</th>
<th>77.27%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Class Standing</th>
<th>0.00%</th>
<th>4.50%</th>
<th>72.72%</th>
<th>22.78%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshmen</td>
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<tr>
<td>Sophomore</td>
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<tr>
<td>Junior</td>
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<td></td>
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<tr>
<td>Senior</td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Field of Study</th>
<th>31.81%</th>
<th>18.18%</th>
<th>13.63%</th>
<th>22.72%</th>
<th>4.54%</th>
<th>9.09%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td></td>
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<td></td>
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<tr>
<td>Zoology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Biomedical</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Biochemistry</td>
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<td></td>
<td></td>
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<tr>
<td>Environmental</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Science</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Microbiology</td>
<td></td>
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</tr>
</tbody>
</table>

Current and Future Career Paths

The survey of previous HHRS participants asked about their current academic and employment status. The current status of those who replied is outlined below.

Alumni 1: Currently working as a biomaterials analyst at private company.
Alumni 2: Currently working as a laboratory technician at an ecological research facility.
Alumni 3: Currently working as a scientist at a pharmacogenetics laboratory.
Alumni 4: Currently working as a research technician for an undisclosed company.
Alumni 5: Currently pursuing a B.S. in biomedical engineering.

The students currently in the program were asked in the interview about their career goals following graduation. Below is a list of the career goals of the current HHRS students who were interviewed.

HHRS 1: Taking a year off and applying to medical school to pursue a dual M.D./Ph.D. in human genetics.
HHRS 2: Applied to M.S. programs at several top universities in genetic counseling for human disease.
HHRS 3: Has been accepted to a Ph.D. program in microbiology.
HHRS 4: Is applying for medical school, but wants to work on the clinical side and not the research side.
HHRS 5: Is applying for schools as a Physician’s Assistant.
HHRS 6: May go to medical school in the future, but is currently applying to corporate positions in biological research.

All the students appear to be planning to pursue science related degrees, but there appears to be some trepidation and uncertainty in their choice of research as a focal point. Although many of the alumni appear to be in jobs in which research or research skills are an integral part of their position, the current HHRS scholars appear to be using the research as a stepping stone into other careers (such as medical or PA school) that might see research as favorable for admittance, but do not require this as a part of their position.

Benefits and Weaknesses of the HHRS URE Program

In order to gain more knowledge on the specific aspects of the program that might have influenced STEM persistence, current students were asked in the interview what they felt were the biggest positives and negatives of the program. Previous HHRS scholars were also asked what they thought might have been done differently with the program as well as to reflect on specific benefits they felt the program provided them. On the survey, HHRS alumni were asked to choose from a list of 25 benefits they felt the HHRS project provided them (Table 2, adapted from Seymour et al., 2004). Alumni were also asked to provide additional responses if they felt there were any.

The interviews were analyzed qualitatively using content analysis. Both current and alumni HHRS students cited several benefits to the program. The most cited benefit (all mentioned some aspect of this) of the program for the current students related to the fact that while in the lab they increased their content knowledge in a relevant and “non-abstract” way. In addition, they also learned that research is difficult and less about procedural knowledge as it is driven by persistence to overcome failures and solve complex problems. This result was mirrored in the HHRS alumni who unanimously cited that the program increased their understanding of the nature of science and the research process. Four current students cited that the experience helped them focus their future academic and career goals. This is not to say that all students planned to pursue research careers, in fact various students realized that they wanted to pursue careers that had more of a “human” element. The results were different from the alumni, in that most of them felt that the research experience had less impact on their current career choices. Additional
benefits included: money earned (three students), learning the nature of science and the politics of research laboratories (two students), and learning how to critically analyze primary literature. Finally, all alumni said they valued their interactions with a collaborative group of peers in the HHRS program. They liked the fact that they had a network of other individuals who were going through the same process as they were and appreciated the contacts this would create for their future careers. HHRS alumni also ranked this as an important attribute of the program.

In general, both HHRS alumni and current students were highly complementary of their undergraduate research experience and the opportunities it provided them. For the most part HHRS alumni were positive, and the negative gains cited were often process skills (communication, technology use, etc.) that students did not acquire because they were not directly part or their apprenticeship. The only weakness of the program that was mentioned by more than one current participant, was mentor guidance. This included lack of ability of the mentor to motivate the student, clearly communicate goals, and to be responsive to the participants needs. One student in particular felt that her mentor prioritized her time in the lab above all her other academic demands. One other weakness mentioned by both current and alumni HHRS students was the confusion regarding how their work would be used for publication and presentations and their roles as authors.

Table 2: Content analysis responses from HHRS alumni regarding positives and negatives of the HHRS research program from a reflective perspective. The proportion of students that noted a particular aspect was positive are noted.

<table>
<thead>
<tr>
<th>The HHRS Research Experience…</th>
<th>% Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Established collegial working relationships with mentors and peers</td>
<td>100%</td>
</tr>
<tr>
<td>Increased your knowledge of science and science work</td>
<td>100%</td>
</tr>
<tr>
<td>Validated your interest in science</td>
<td>100%</td>
</tr>
<tr>
<td>Provided you with opportunities to network</td>
<td>100%</td>
</tr>
<tr>
<td>Enhanced your CV</td>
<td>100%</td>
</tr>
<tr>
<td>Increased your confidence in your ability to do research</td>
<td>80%</td>
</tr>
<tr>
<td>Made you feel like a scientist</td>
<td>80%</td>
</tr>
<tr>
<td>Increased your ability to problem solve and think critically</td>
<td>80%</td>
</tr>
<tr>
<td>Improved your laboratory/field technique</td>
<td>80%</td>
</tr>
<tr>
<td>Improved your ability to comprehend scientific literature</td>
<td>80%</td>
</tr>
<tr>
<td>Improved your ability to work collaboratively</td>
<td>80%</td>
</tr>
<tr>
<td>Provided you with an authentic research experience</td>
<td>80%</td>
</tr>
<tr>
<td>Provided you with new professional experience</td>
<td>80%</td>
</tr>
<tr>
<td>Increased your independent decision making and control of learning</td>
<td>80%</td>
</tr>
<tr>
<td>Increased confidence in your ability to contribute to science</td>
<td>60%</td>
</tr>
<tr>
<td>Increased confidence in your ability to present/defend research</td>
<td>60%</td>
</tr>
<tr>
<td>Increased your knowledge of potential career options in science</td>
<td>60%</td>
</tr>
<tr>
<td>Increased your ability to take greater responsibility in research</td>
<td>60%</td>
</tr>
<tr>
<td>Gave you a good job to make some extra money</td>
<td>60%</td>
</tr>
<tr>
<td>Validated your intention to pursue a graduate degree in science</td>
<td>40%</td>
</tr>
<tr>
<td>Increased your enthusiasm for science</td>
<td>40%</td>
</tr>
<tr>
<td>Improved your communication skills</td>
<td>20%</td>
</tr>
<tr>
<td>Improved your organizational skills</td>
<td>20%</td>
</tr>
</tbody>
</table>
Improved your ability to use a computer and other technology 20%

Discussion

In the following section we discuss the findings of this particular study and how they align with the original objectives of the program as well as the literature discussed in the opening of the manuscript.

Objective 1: Did the program increase the number and diversity of students participating in undergraduate life sciences research?

The project has and continues to have large proportions of women in their research programs, but could certainly increase its minority population in future inceptions. In the context of the literature, it is also important to consider how women and underrepresented minority participants are being matched with mentor(s) as this can have a significant effect on their perceptions and persistence in programs (Gardner et al., in press; Russell et al., 2007; Slovacek et al., 2012; Yaffe et al., 2014). Often students are assigned to mentors based on the mentors’ availability and the research interests of the student themselves. Assigned faculty then shift the brunt of the mentoring responsibilities on graduate students or post-docs (Gardner et al., in press). Research and development of UREs should carefully consider how participants are being assigned and interacting with mentors in order to maintain participant interest and persistence.

Objective 2: Did the program encourage students to become involved in scientific careers?

As seen by numerous other research studies, the HHRS program does not necessarily encourage students to become involved in scientific careers so much as help them solidify and refine their own career goals within science. This is a finding that has been noted in many educational research studies and is due to self-selection bias inherent in these programs. The issue revolves around the fact that students who participate in these intense research programs likely already have career goals related to science (Sadler et al., 2010).

If it is truly a goal of URE programs to encourage students to become involved in scientific careers, perhaps scholars should be recruited outside of the sciences. By getting students in internships who may still be “on the fence” with what they would like to do for careers, these programs could encourage them to make science a careers. Of course, this comes with other issues such as the preparation of these students for advanced laboratory work, etc.

In addition, research has demonstrated that student interest in science careers is often negotiated and developed at the middle grades (Kier, Blanchard, Osborne, & Albert, 2014). The question has to be asked if engaging students in authentic scientific research at the undergraduate level is “too late” to encourage non-committed students to become involved in scientific careers? However, it is difficult to know what is developmentally appropriate and what counts as “authentic” research at the 6-12 level. Is participation in such informal science experiences such as science camps or science competitions enough to promote interest and persistence in STEM careers at these levels (Forrester, 2010; Kong, Dabney, & Tai, 2014)?
**Objective 3:** Does the program enhance the quality of the undergraduate research experiences?

The program appears to be doing an excellent job at providing students with opportunities to complete high-quality research projects and engage in a diversity of research experiences. Two areas that seem to be of concern and might be targeted for future inceptions of the program have to do with student research dissemination and mentor relationships. Students appear to be communicating their research in limited settings and several participants cited limited or strained relationships with their mentors.

Research examining specific *components* of UREs and the role this plays in matriculation of students into STEM careers is needed. What is it about UREs that are particularly salient to participants in shifting their focus to STEM careers or clarifying their professional goals? As stated above, one of these components might be to more explicitly define the roles of the mentors and the researcher-mentor relationship prior to placing students. Mentors should be made clear of their responsibilities in the program and be held accountable for achieving those responsibilities. In addition, prior to starting in apprenticeships, students should be made aware of the explicit expectations of the mentor and then have conversations of any potential conflicts with their mentor or the program coordinator. Finally, considerations for the constraints of the faculty mentor need to be considered as well.

**Conclusions**

In the preceding, we have discussed a specific example of a specific undergraduate research experience as an innovative learning environments. Student experience and skill-based and content-based learning have been shown to be significant predictors of matriculation into STEM careers. Our data (supported by the literature) show that many participants in UREs learn a lot of about research skills and content but also clarify their own professional goals. However, much of this work (including our own) is limited by a self-selection bias in which participants often voluntarily self-select into UREs and therefore are likely already focused on research careers in STEM.

We also propose two areas of future research that might be needed to parse how the meaningful impacts of UREs as a form of innovative science teaching. Much work is needed to understand the components of the both UR participants and the programs themselves that lead to successful persistence in the STEM pipeline. The role of the mentor and its impact on the student experience has only been minimally examined despite its impact on the experience. Undergraduate research experiences appear to be a practically and theoretically important educational experience in which important learning objectives can be achieved, but more empirical work is needed.
References


Two Sides of the Coin: How a Departmental Culture of Inquiry Teaching and Undergraduate Research go Hand in Hand

(Integrating and Building Undergraduate Research into the Department Coursework and Curriculum)

Kerry L. Cheesman, PhD
Robert M Geist Chair and Professor, Biological and Environmental Sciences Department, Capital University, Columbus, OH

“What we have to learn to do, we learn by doing.” Aristotle

“We don’t receive enduring understanding, curiosity and wisdom automatically, we must discover them for ourselves after a journey that no one can take for us or spare us.” Philosopher Marcel Proust

For more than two decades, science educators at many levels have called for an increase in the amount of inquiry-based teaching that is done in the science classroom and laboratory. Publications such as Science Teaching reconsidered (National Research Council, 1997), Reshaping Undergraduate Science and Engineering Education (Sigma Xi, 2000), BIO 2010 (National Research Council, 2003), Vision and Change (American Association for the Advancement of Science, 2011), and Science for All Americans (American Association for the Advancement of Science, 2013) are but a few of the multitude of calls for action. Researchers have shown over and over again that inquiry works, and that traditional lecture-based teaching is much less effective (National Research Council, 2000 and 2002). Yet, researchers have also indicated that only a small (but growing) number of faculty in this country are using inquiry teaching, even to a small degree. At the same time, organizations such as the Council for Undergraduate Research (CUR) and the National Conferences for Undergraduate Research (NCUR) have extended the call for faculty to engage students in more hands-on research activities (Hakim, 2000), and studies such as BIO 2010 (National Research Council, 2003) have indicated that we cannot prepare future effective scientists and physicians without an increase in opportunities for undergraduate research.

These two actions are not opposed to each other. In fact, they wonderfully support each other, like two sides of the same coin. Both are important, and each strengthens and supports the other (Healey, 2005; Jenkins and Healey, 2005; Jenkins, Healey and Zetter, 2007; Healey and Jenkins, 2009). In our department, we have worked for nearly two decades to increase both inquiry and undergraduate research for our students, and clearly the effect is magnified many fold beyond what might be expected.
Inquiry Teaching

What is Inquiry?

HANDS-ON + MINDS-ON = INQUIRY
To understand why this is important in educating the next generation of scientists, one needs to understand what is meant by “inquiry”. This term has been used in a variety of ways by a number of authors, and no one definition fits all models. One broad definition is this: *Scientific Inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work* (National Research Council, 1996). We can go further and state that inquiry:

- Is a process by which students build or construct knowledge
- Requires students to take active roles (inquiry is student-centered learning)
- Is a process that stimulates critical thinking
- Is about asking and discovering
- Is knowledge placed in context

It is important to realize that inquiry is a continuum, that there are varieties of ways to do inquiry, and that no one model fits all scenarios of teaching (Fig. 1). As seen in the following model, inquiry can be mostly teacher driven (known as guided inquiry), or nearly completely student driven (known as open inquiry).

![Inquiry Continuum Diagram]

Figure 1. The inquiry continuum. As one moves from structured (teacher directed) to open (student directed), student engagement and long-term retention of information increases.

So if one teaches with a focus on inquiry, what does that mean? How are inquiry classrooms different than traditional (lecture-based) classrooms? Table 1 (below) shows the similarities and differences:

<table>
<thead>
<tr>
<th>Focus</th>
<th>Engagement and Assessment</th>
<th>Inquiry Variations</th>
<th>Structured</th>
<th>Guided</th>
<th>Learner Directed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Topic &amp; Expansion</td>
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</tr>
<tr>
<td>Question</td>
<td></td>
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</tr>
<tr>
<td>Materials</td>
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</tr>
<tr>
<td>Procedures</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Analysis and Communication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conclusions</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

![Inquiry Variations Table]

![Inquiry Continuum Diagram]

Figure 1. The inquiry continuum. As one moves from structured (teacher directed) to open (student directed), student engagement and long-term retention of information increases.
Table 1. General characteristics of traditional and inquiry classrooms.

<table>
<thead>
<tr>
<th>Traditional Classrooms</th>
<th>Inquiry Classrooms</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Teacher centered</td>
<td>• Student centered</td>
</tr>
<tr>
<td>• Passive learner</td>
<td>• Active learner</td>
</tr>
<tr>
<td>• Emphasis on right answers</td>
<td>• Alternative hypotheses are elicited</td>
</tr>
<tr>
<td>• Rhetoric of conclusions</td>
<td>• Conceptual and process oriented</td>
</tr>
<tr>
<td>• Lots of memorization</td>
<td>• Student has prior experiences that can be built upon</td>
</tr>
<tr>
<td>• Students are empty vessels that need to be filled</td>
<td>• Group work/peer teaching are the norm</td>
</tr>
<tr>
<td>• Students work as individuals</td>
<td></td>
</tr>
</tbody>
</table>

As we move toward inquiry-based teaching, our classrooms look different from traditional classrooms. Students are working together, finding alternative hypotheses, posing questions and solving problems. Our classrooms are dynamic, often noisy.

Inquiry teaching is (in part) based upon the idea that retention of information is very poor in traditional lecture classrooms, and significantly better as the learning becomes more hands-on (McNeal and D’Avanzo, 1997; National Research Council, 1997; Ambrose et al., 2010). Note that cooperative learning groups and teaching one another are methods that lead to the highest retention of knowledge (Figure 2). Why? Because they are active rather than passive forms of learning.

Figure 2. A synthesis of what research has shown regarding the retention of knowledge with various teaching methodologies.
component of inquiry knowledge is known as constructivism. This paradigm states that people construct their own understanding and knowledge of the world through experiencing things and reflecting on those experiences. When we encounter something new, we have to reconcile it with our previous ideas and experience, maybe changing what we believe, or maybe discarding the new information as irrelevant. In any case, we are active creators of our own knowledge. To do this, we must ask questions, explore, and assess what we know.

In the classroom, the constructivist view of learning can point towards a number of different teaching practices. In the most general sense, it usually means encouraging students to use active techniques (experiments, real-world problem solving, cooperative learning) to create more knowledge and then to reflect on and talk about what they are doing and how their understanding is changing. The teacher makes sure s/he understands the students' preexisting conceptions, and guides the activity to address them and then build on them.

Constructivist teachers encourage students to constantly assess how the activity is helping them gain understanding. By questioning themselves and their strategies, students in the constructivist classroom ideally become "expert learners." This gives them ever-broadening tools to keep learning. With a well-planned classroom environment, students learn how to learn. This may ultimately become a spiral; when students continuously reflect on their experiences, they find their ideas gaining in complexity and power, and they develop increasingly strong abilities to integrate new information. One of the teacher's main roles becomes to encourage this learning and reflection process (Cheesman, 2013).

**Bloom’s Taxonomy**

Inquiry is also based in part on Bloom’s Taxonomy (Bloom et al., 1956; update Anderson and Krathwohl, 2001). That taxonomy is centered on the idea that analyzing, evaluating, and creating are important ways of demonstrating knowledge – these three are referred to as “higher-order” ways of thinking (Figure 3). As was noted above, when we engage in hands-on activities of creating, we remember the knowledge much better than we do when we simply memorize facts and regurgitate them.

**Learning Cycles**

To create classrooms where learning is active and ties to prior knowledge are constructed, we need to understand learning cycle theory. There have been many versions of the learning cycle published over the years, but the one we have found to be most successful for our students as we make our classrooms more inquiry-based is the 5E learning cycle (credited to Roger Bybee and
the Biological Sciences Curriculum Study in 1997) (Figure 4). In this model there are 5 stages that a classroom goes through in exploring a particular topic:

- **ENGAGE**- use to motivate the class in the topic
- **EXPLORE**- encourages the students (in teams) to examine the topic
- **EXPLAIN**- allows students to describe to others what their team discovered
- **EXTEND or ELABORATE**- permits students to expand on the topic to include other areas
- **EVALUATE**- provides the students with a means of assessing what has been learned

Note on the model to the right, that each of the five are interconnected, and that the arrows move in both directions. Evaluation (a term many educators think of as negative, but should be thought of as a positive) is connected to all stages of the cycle rather than being just at the end (e.g: give a test).

A recent study of the effectiveness of the 5-E model in curriculum development and use (Wilson *et al.*, 2010) found that students taught using inquiry-based materials reached significantly higher levels of achievement than students experiencing commonplace teaching. This finding was consistent for measures of both scientific reasoning and the construction and critique of scientific arguments.

**Putting it all Together**

As we connect the ideas of scientific inquiry and those of constructivism, we discover that they are components of the same picture. Classrooms that are inquiry-based and those labeled as constructivist are both attempting to create an active atmosphere for learning, that moves from being teacher-centered to student-centered. Table 2 shows another way to encapsulate these ideas:
Table 2. A comparison of the characteristics of traditional and inquiry classrooms.

<table>
<thead>
<tr>
<th>Traditional Classrooms</th>
<th>Inquiry Classrooms</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Curriculum begins with the parts of the whole. Emphasizes basic skills.</td>
<td>• Curriculum emphasizes big concepts, beginning with the whole and expanding to include the parts.</td>
</tr>
<tr>
<td>• Strict adherence to a fixed curriculum is highly valued.</td>
<td>• Pursuit of student questions and interests is valued.</td>
</tr>
<tr>
<td>• Materials are primarily textbooks and workbooks.</td>
<td>• Materials include primary sources of material and manipulative materials.</td>
</tr>
<tr>
<td>• Learning is based on repetition.</td>
<td>• Learning is interactive, building on what the student already knows.</td>
</tr>
<tr>
<td>• Teachers disseminate information to students; students are recipients of knowledge.</td>
<td>• Teachers have a dialogue with students, helping students construct their own knowledge.</td>
</tr>
<tr>
<td>• Teacher's role is directive, rooted in authority.</td>
<td>• Teacher's role is interactive, rooted in negotiation.</td>
</tr>
<tr>
<td>• Assessment is through testing, correct answers.</td>
<td>• Assessment includes student works, observations, and points of view, as well as tests. Process is as important as product.</td>
</tr>
<tr>
<td>• Knowledge is seen as inert.</td>
<td>• Knowledge is seen as dynamic, ever changing with our experiences.</td>
</tr>
<tr>
<td>• Students work primarily alone.</td>
<td></td>
</tr>
</tbody>
</table>

Why is inquiry important?
Inquiry teaching shows students how knowledge is actually gained. It lets students take ownership of the knowledge. It helps students learn to work effectively with others. And (of course) we all ENJOY discovery!
Inquiry Teaching creates high expectations among students, and a respect for diverse talents and learning styles. It creates coherence in learning and synthesizing experiences. Inquiry teaching allows for ongoing practice of learned skills while at the same time creating room for integration of education and experience.

When and Where Does Inquiry Take Place?
If we truly want our students to learn, then inquiry is not an option. Neither is waiting until they reach small upper-division courses where they can work more independently. We lose way too many students at the freshman level because they perceive science as being all about memorizing and learning lots of facts. They miss the fun and the joy of scientific discovery because they are lost in the vast amount of material being thrown at them.
Inquiry in the classroom (and the laboratory) needs to begin Day 1. It’s not something that should be an add-on or a second thought. It needs to be a way of teaching and thinking, and we simply can’t wait until a later time to begin the process. Day 1 of the freshman year should be the start of their inquiry journey, and it should never end. Inquiry teaching must continue through their entire undergraduate experience, and on into the graduate experience. It should
continue into careers in the sciences, and spill over (as a way of thinking and doing) into all aspects of adult life.

Inquiry teaching should be seamless between the classroom experience and the laboratory experiences of each course. Inquiry should be seamless between freshman, sophomore, and upper-division courses. And inquiry teaching should seamlessly integrate between the classroom experience and undergraduate research experiences (Cheesman, 2009). In short, there should be no time or place in the undergraduate experience where a student is not being exposed to scientific inquiry.

**Undergraduate Research**

Research Derives from Inquiry
Once inquiry is established, then research interest (the other side of the coin) can be built. Research derives from quality inquiry teaching, and involves much of the same set of skills as found in classroom inquiry – collaboration, synthesis, and creativity. Research also involves high expectations – both on the part of the student and on the part of the faculty member.

Some definitions of undergraduate research include:

- scholarly, creative, or investigative activities
- diligent and systematic inquiry or investigation to discover facts or principles
- an increase in the sum of knowledge, enhanced design, or enriched artistic ability
- student-faculty collaboration to examine, create, or share new knowledge or works

Research comes out of questions posed by students – student-driven, student-led, and team approaches. Many of those questions are raised as a result of the inquiry teaching that they have been exposed to. When research questions arise in this way, rather than from faculty who wish to pursue their own research interests, students take more ownership of the research, and it becomes a greater learning tool for all involved.

Undergraduate Research may take a lot of different directions. It might, for instance, be:

- an investigative study that leads to insight that is new to the discipline or new to the learner
- an assignment in a course that is built on discovery
- a curricular unit in which the learner’s investigations are shared with peers
- a formal research project for academic credit
- an interdisciplinary team project addressing a real-world problem from a variety of disciplinary perspectives
- a summer interdisciplinary undergraduate research (replacing summer employment)
- a capstone experience for an undergraduate

A particularly important point here is that publishable research is ONE model for undergraduates, not the ONLY model. Too often faculty are not willing to open their minds to the possibility of doing research with undergraduates because they are too concerned with whether or not it can be published. The primary focus of research at this level should be to build upon and expand the inquiry methods used in the classroom.
What do students learn? Students learn that research can be challenging but FUN, and they generally feel good about their accomplishments. Students have a greater sense of science and its role in the modern world. Students also become better advocates for science in their families and their communities.

A study published by the University of Delaware (1997) addressed the question of whether undergraduate research makes a difference to students. Their results indicated that students:

- learned more through research
  - 73%
- learned as much through research
  - 25%
- learned more through courses
  - 2%
- increased their technical skills
  - 96%
- increased their independence
  - 57%
- gained insight into graduate school
  - 45%
- learned teamwork and valued it
  - 43%
- learned to work with obstacles and ambiguities
  - 37%
- learned to think creatively/synthetically
  - 32%
- gained self-confidence
  - 28%
- improved their communications skills
  - 24%
• gained understanding of “knowledge”  

24%

Studies at the University of Michigan (1998-2002) and SUNY-Stony Brook (2001) reflect similar results, noting that undergraduate research plays an important role in retention of undergraduate science majors. From these studies and others we can conclude that the benefits to students of participating in undergraduate research include:

• a close working relationship with one or more faculty mentors  
• critical thinking, creative and problem-solving skills  
• the ability to work on task independently and with groups  
• generate leading edge proficiency in their fields  
• increased employability or greater access to graduate and professional schools  
• links to corporate and non-profit centers of support  
• involvement in tangible community service and civic responsibility

Our Efforts as a Department
Based upon the available data about inquiry teaching, in 1994 we began a two decade-long process of converting a department that was entirely traditional in its approach to teaching into an inquiry- and research-based department. We began by focusing (in baby steps) on creating inquiry-driven classrooms. Undergraduate research followed almost without effort, as students who had been nurtured in inquiry thinking began to get excited about doing research. As newer faculty have been hired into the department, an emphasis on both inquiry teaching and undergraduate research have become a standard expectation.

Following are just a few examples of changes made to make our classrooms and laboratories more inquiry-based:

Classroom Activities

Biol 151 (Foundations of Modern Biology):

• Acting out protein structure and DNA replication  
• Taking a virtual trip to the Galapagos to better understand natural selection  
• Creating comics to evaluate understanding of biochemical concepts

Biol 100 (Non-Majors’ General Biology):

• Using case studies to tie real-world patients to concepts of metabolism and biochemistry  
• Creating family pedigrees, applying concepts and evaluating probabilities  
• Classification of hypothetical creatures
Biol 270 (Genetics):

- Using case studies to illustrate the relevance of knowledge, and help students connect to real-world applications
- Using “clickers” to check daily understanding and adjust content
- Creating education flyers to inform the public about diseases
- Analyzing the bioethics of various genetic procedures

Laboratory Activities

Biol 151 and 152 (Foundations of Modern Biology):

- Preparation of a new lab manual based on inquiry
- Fall semester long-term inquiry projects – campus trees (5 weeks), ecosystem flasks (10 weeks)
- Spring semester long-term inquiry projects – Winogradsky columns (6 weeks), wine production (8 weeks)

Biol 100 (Non-Majors’ General Biology):

- Preparation of a new lab manual based on inquiry
- Using hypothetical traits on Mr and Mrs Potato Head to learn the concepts of Mendelian genetics
- Isolating DNA from split peas and then modifying the procedure to determine the purpose for each step/ingredient

Biol 270 (Genetics):

- Preparation of a new lab manual based on inquiry
- Prepare an unknown karyotype, determine the disease, and write a letter to the parents of the child explaining what was found
- Analyze foods from the supermarket to determine which use genetically modified ingredients

Biol 410 (Reef Biology, Ecuador Biology, etc)

- Develop a detailed research proposal and carry it out

Campus Symposium
For the past 19 years, our university has had an Undergraduate Scholarship Symposium each spring. Students who have been engaged in research of all types present their work through a combination of oral and poster presentations. The Biological Sciences Department was an early proponent of the symposium, and committee members from the initial task force to the present
have come from the department. In most years the department has led in the number of presentations and the number of faculty supporting undergraduate research.

**Including inquiry and research in field and travel courses**
Perhaps the easiest place to incorporate both inquiry and research is in field based courses such as environmental science and ecology, and in study/travel courses. Our department takes a number of trips with students to Costa Rica, Ecuador, Panama, Cuba, etc, and inquiry plays a large role in the teaching of these courses. In those courses that are of sufficient length, field research is also included and tied to the specific locale of the course.

**One Specific Example of Inquiry and Research Being Tied Together**
As the topic of genetically-modified food was being discussed in a sophomore-level genetics class several years ago, and small groups were searching for information about crops in the US, students were surprised to learn how much of our corn and soybean crops are indeed genetically modified. A question was posed by one group asking how we would know whether the foods we are eating daily are modified or not. The response was for the group to try to find out. A week later the group approached me outside of class, saying that since there were no labeling laws in the US, it was impossible to know. That week in lab we were doing an inquiry lab about genetically modified food using a standard commercially available assay kit. The group asked if they could do follow-up research and look at some of their favorite snack foods. That began a student-led research project that over the course of six years has produced 14 presentations at national and regional meetings, and four publications. More than 20 undergraduate students have been involved in various aspects of the research project since its inception, and most of those have gone on to graduate or professional school. Three have won university-level research awards. One inquiry question, derived from and followed by inquiry teaching in the classroom and laboratory, led to an amazing undergraduate research project that is still in high gear.

**Our Model**

In order to “institutionalize” inquiry teaching and undergraduate research, we have derived the following model for our department (Figure 5). The key is seamless integration of both inquiry and research throughout the undergraduate experience, starting day one with the freshman level courses and continuing through graduation.
Figure 5. A model showing how our Biological Sciences Department has integrated inquiry teaching and undergraduate research throughout the four year curriculum.

What Difference has it Made?

Once students became accustomed to inquiry teaching, we found that students have been more excited about upper division classes that are inquiry based and filled them more rapidly than those which were still being taught in traditional formats. Students have also become more engaged in undergraduate research opportunities, often encouraging faculty to expand the opportunities available, and encouraging others around them to join in research projects. In addition, many more students have been applying to and gaining admission to both graduate (MS and PhD) and professional (MD, DO, DDS, PharmD, etc.) programs than did before the conversion efforts.

Another change that has been tracked is the number of students participating in regional and national professional meetings. Compared to the number participating before the conversion, we have seen more than a 4,000% increase during the most recent 5 year span. Clearly inquiry teaching makes a difference!
Obstacles to Inquiry and UG Research

There are many reasons why inquiry teaching has not gained traction in all departments, and why it takes so long for departments desiring to become inquiry- and research-based to actually do so. Some of the obstacles include:

- Credit-hours are generally the central measure of faculty productivity, rather than how well students are learning
- Tenure and promotion guidelines often omit student-faculty collaborative publications and student research projects supervised
- Competition is valued over collaboration, and inquiry is collaborative by nature
- Neither faculty nor administrators truly grasp what inquiry is or means, and thus are unwilling to invest time and energy in transforming basic courses. Comments frequently heard include:
  a. “Undergraduates are not capable of doing research in my discipline. They don’t know enough or have the research skills needed.”
  b. “UR requires too much time.”
  c. “UR is too expensive.”
  d. “My discipline rejects research publications that are jointly written.”
  e. “If I use inquiry-based elements in my courses, I can’t cover as much material.”
- To build a culture of inquiry and research, all faculty in the department need to have a buy-in. One rotten apple can spoil the batch.
- Many faculty have a hard time distinguishing undergraduate research and its learning potential from graduate research and its publishing mandate
- Most undergraduate faculty are on 9-month contracts, and there is rarely additional money to do summer research with undergraduates; released time to do undergraduate research is even rarer
- Money for undergraduate research (supplies, student stipends, faculty stipends) is often lacking

Ways to Encourage Faculty, Administrators and Students

- Encourage faculty to be inquiry teachers
- Place research posters in the hallway
  o Indicate those who went to graduate schools
- Publish comments from alumni
- Refer to interviews with medical graduate schools
  o Get alumni to tell their stories
  o Get admissions personnel to espouse the virtues of research
- Make research FUN

Conclusions
Research is an important element in the undergraduate experience. Inquiry teaching (starting on day 1) can set the stage for broader inquiry known as research. When faculty teach in an inquiry
fashion, one question leads to another and to another and pretty soon students are engaged in research without having been pressured or pushed into doing so.

Research that is the idea of the student (or a group of students) is more likely to be of long-term interest than that chosen by the faculty. Students take ownership. They see it as an extension of the questions (inquiry) they posed in class or in the laboratory. Research that they take ownership of becomes a vehicle for better learning and possibly for presentations and publications – which set these students apart from their peers at other universities. Research that sets a student apart from their peers often makes the student a more viable graduate or professional school candidate.

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CHAPTER 3
Distilling Best Practices for Teaching and Learning in Anatomy and Physiology

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Advances in teaching anatomy and physiology have historically been held back by the discipline’s close association to health care. Progress in the health sciences is slow and carefully scrutinized; likewise changes in the teaching of anatomy and physiology are slow, and resistance to change substantial (Silverthorn, et al., 2006). Lecture has been the dominant mode of instruction for several hundred years. With prodding from national policy documents such as Vision and Change in Undergraduate Biology Education (AAAS, 2009), and perhaps from changes to the Medical College Admissions Test (MCAT) to emphasize problem solving over rote memorization, changes in teaching practice in the anatomy and physiology classroom are starting to appear.

Data for this article originated from a survey of 35 high school anatomy and physiology (A & P) instructors who were participants in a dual enrollment program at the University of Minnesota. (See Jensen, et al., (2013) for a complete description of the program.) While most A & P courses are taught in higher education settings, it is increasingly likely to be found in the high schools, and results of this survey should be applicable to all entry-level A & P courses. Additionally, it must be noted that these subjects, high school teachers, are more likely to try novel teaching practices than college instructors because they, unlike most college instructors, have completed coursework requirements in pedagogy for licensure. The 35 teachers in this study were asked to complete a simple questionnaire during an on-campus workshop that asked about best practices in teaching anatomy and physiology. Specifically, it requested them to select and rank three pedagogical approaches for promoting student learning in their A & P courses. The prompt was followed by an extensive, alphabetized, list of choices, including lecture, lecture with PowerPoint, and several more.

What follows is a description of the three most popular forms of instruction to promote student learning in entry-level anatomy and physiology as reported by high school instructors in a dual enrollment program. All three have a theme of “the social nature of knowledge” in that they all promote conversations that engage students in the language of A & P.

1. Inquiry Based Teaching and Learning

Inquiry based methods focus on student problem solving; they require students to “figure things out,” as opposed to being told what to know (i.e., lecturing or “teaching by telling”). Because of the vast quantities of information in A & P courses (textbooks typically are 1200 pages or more), PowerPoint has been a common teaching tool in the A & P classroom, and instructors have often
relented to the pressure of “covering the material” via lecturing as opposed to the much slower, and difficult, inquiry-based approach (Silverthorn, et al., 2006)

The POGIL (Processes Oriented Guided Inquiry Learning) Project has begun to develop materials to promote inquiry in the A & P classroom. More specifically, POGIL Project member Patrick Brown (Brown, 2010), as well as Murray Jensen and Allison Mattheis (2013), have initiated curriculum development projects targeting entry-level A & P courses. The POGIL method is based on guided inquiry; students are provided clues within the curriculum, as well as from the instructor, as they engage in problem solving activities with the goal of producing a conceptual understanding of a topic. (Appendix 1 contains an example POGIL activity on levels of organization). Guided inquiry is a step away from the much more complex open inquiry that replicates the culture of a research program where little, if any, assistance is provided to students as they engage in the learning process.

The theoretical underpinnings of the POGIL approach are cooperative group learning and the constructivist learning theory. While completing a POGIL activity, students work in small cooperative groups with each member given a specific role. Common roles include a facilitator (reading the activity out loud), a recorder of answers (documenting the group’s final answers), and a designated doubter (who promotes careful thought by saying, for example, “are we sure of this answer?”). To facilitate the group roles and dynamics, many instructors use role cards provided by the POGIL Program (Hanson, 2006). While no data exists to support this claim, high school instructors seem to be more adept at facilitating cooperative groups and enforcing group roles than college instructors. The reason for this difference probably relates to the ages and maturity levels of their students (16 to 18 for high school instructors, and 18 to 23 for college level) and also to the educational background of the high school instructors, who have had several education and psychology courses, as compared to college instructors, who are discipline experts but often lack formal background in education.

The constructivist learning theory, often accredited to Lev Vygotsy (1962), posits that a social learning environment expedites student learning. Historically, the anatomy and physiology classroom has been quiet, with only the voice of the lecturer being heard; the instructor tells the students the facts and details known by the experts in the discipline, and students quietly record the information in their notebooks or computers. Constructivism, however, states that teaching is not as simple as telling students what to know. Rather, meaningful learning, or what is commonly called conceptual learning, is facilitated by student-to-student conversation using the language of the discipline. For example, for students to learn the core principles of anatomy and physiology, such as homeostasis and energy flow, they must engage in discussions using the language of the discipline; they must pose and answer questions to each other and the instructor. POGIL curriculum materials, as well as others such as medically based case studies developed by the National Center for Case Study Teaching in Science, offer fodder for student discussion. A limitation to the POGIL approach, and other curriculum resources that promote inquiry, is that instructor must be experienced with managing the social learning environment. To help facilitate the skills required, the POGIL program offers yearly workshops to help instructors begin to develop the skill sets required to implement the inquiry-based materials.
2. Cooperative Quizzes

Cooperative quizzes are learning tools that, like the POGIL method, promote learning through social interactions between students. The method involves students engaging in two separate activities. First, students take a quiz on an individual basis and turn in their answer sheets to the instructors. There is nothing novel about this first step in that it is simply a traditional quiz involving any type of assessment question (e.g., short answer, multiple choice, essay, etc.). Second, after completing the individual section, students are arranged in clusters of two or three, ideally seated around a small table or desk, to again take the same quiz in a group setting. As recommended by researchers in cooperative learning (see, for example, Johnson, et al., 1992), the instructor assigns roles to each member. The most common roles implemented during a cooperative quiz are the same as those used in a POGIL activity: a reader, recorder, and a doubter. All students in a group sign and complete only one answer sheet. The use of one answer sheet per group compels students to discuss ideas and make decisions on final answers to record and submit. If the cognitive level of the question is easy, little discussion ensues. However, if students are challenged, student conversation is potentially rich and sometimes even contentious. The resolution of conflict is consistent with the student behaviors recommended by constructivists to promote conceptual learning. Grading cooperative quizzes is accomplished by using the average points earned on the group and individual portions of the activity.

Two challenges faced by instructors while implementing cooperative quizzes are 1) determining group composition (determining which students should and should not work together) and 2) constructing quizzes with questions that will promote vibrant conversation between students. Topics in human physiology, as opposed to anatomy, seem to promote productive discussions. Quiz questions focusing on physiological processes can often take on three different modes, each representing different levels of difficulty. Most easy are questions that provide a list of steps in a physiological process – but the list is out of order. Students, in this case, must re-arrange the steps to show the correct order. The second level of difficulty is for students to write out the steps in order using the correct terminology (example, write out steps involved in muscle contraction starting with depolarization of the muscle cell membrane and ending with the movement of z-lines). The most difficult level involves students writing out steps and also supplementing answers with drawings.

Cooperative quizzes are easy to implement, and unlike inquiry-based teaching, do not require specialized curriculum materials. Any quiz can be made into a cooperative quiz by following to the two steps described above.

3. Using a Common Theme Throughout the Course

All A & P textbooks are organized by body systems - starting with integumentary and ending with reproduction. Most instructors give exams after the completion of a chapter or a body system, thus making a clear and sharp division between body systems. This approach is efficient, but does not promote the interrelatedness of the body systems, which all work together to support life. Additionally, the approach does little to promote a deeper understanding of physiology. Instructors who completed the instructional practices survey were all participants in a sponsored program where “food” was designated as a theme throughout the course. Money from a small grant was used for all students, and teachers, to acquire the book In Defense of Food (Pollan, 2008) and curriculum materials were developed to show how topics in the book,
such as Type 2 diabetes and atherosclerosis, were related to almost every body system. (For a more complete description of the program, see Jensen, et al., 2013) By the end of the course, students were to be experts, or at least as “expert” as reasonable for high school students, at answering questions relating to healthy and unhealthy diets, caloric balance, atherosclerosis, and the many medical complications related to obesity. At years end many of the students were “foodies” who frequently read nutrition labels and advocated healthy eating habits to friends and families. The grant ended in 2013, but many of the instructors continue to use “food” as a common theme throughout their A & P courses, and still require their students to read In Defense of Food.

The use of food as a common theme gives students easy and relevant topics for conversation. Issues such as junk food, caffeine, fast food, quality of school lunch programs, etc., are all highly germane to high school youth and easily promote lively discussions that include the language of anatomy and physiology.

Some instructors in the dual enrollment program have added “exercise” to the food theme in the course. The fact that many of the high school A & P teachers are also coach athletes makes this addition an easy and logical development. However, the group has yet to find a trade book similar to Pollan’s In Defense of Food related to exercise. Many exercise books do exist, but none have been found at an academic level that compliments entry-level A & P courses.

Conclusion: Promote the Social Nature of Knowledge

The three teaching methods listed here were selected by means of an informal survey of 35 high school A &P teachers. The list could be easily viewed as a “what is popular,” as opposed to “what is effective,” list of teaching strategies. However, all three approaches complement the findings of a large meta-analysis published by Freeman, et al., in the Proceeding of the National Academy of Science (Freeman, et al., 2014 ). Freeman’s analysis, which included the results from 225 peer-reviewed studies, demonstrated the superiority of active learning over traditional lecture methods as measured by both increased exam performance and reduced failure rates.

Additionally, all three pedagogical methods above are related to Lev Vygotsiy’s social constructive theory of learning and understanding in that they all promote student conversations. Student conversations during class time that utilize the language of the discipline represent a drastic change from the traditional A & P classroom utilizing lecture and PowerPoint. To promote change, not only are more inquiry-based curriculum materials needed, instructors must learn how to facilitate student conversation. Cooperative quizzes might be a good place to start, since they are easy to implement and promote student conversation.
References:


Appendix 1: Levels of Organization POGIL Activity
Levels of Organization
Instructor’s Guide

Time to Completion
Estimated Time Requirement: 20 - 30 minutes

Prior Knowledge
- None related directly to human anatomy and physiology.
- Completion of a high school chemistry course (i.e. basic definitions of atoms and molecules)
- This is an easy activity!

Content Objectives
- Students will be able to list the levels of organization and provide examples of each.
- Students will develop a working definition of tissues and organs.

Process Objectives
- Communication. Students are required to “brainstorm” and discuss different ideas.
- Teamwork. This activity requires students to brainstorm and come to a consensus.

Implementation Notes for Instructors
- The cover sheet for this activity is optional, but may be useful if students are not yet familiar with the structure of POGIL or have not been working in groups.
- This activity is intended for the first day of an introductory course in human anatomy and physiology and requires no student preparation. The goal of the activity is to set a tone in the classroom that student-student interaction will be expected, and also can demonstrate to students that the instructor will not be lecturing on a regular basis.
- The first day of class frequently involves many logistical details (e.g., review of the course syllabus), and this short activity is designed to accommodate those time constraints.
- Instructors may want to add a discussion with students about the POGIL process after this activity.
Student Roles

- Student roles are explained on the “optional” first page (which might be used on the first day of class). Normally, student roles will be explained on the teacher’s guide, but for this first activity it might be necessary for students to read about the different roles used within a group.
- During the activity, be sure to walk around the room and reinforce student roles. Example: “Who is your reader?”
- **Reader** – this person will read out loud the text below.
- **Recorder** – this person decides what to “write down” as your group’s answers. All students in the group should write down answers, but it is the recorder’s job to decide what to write down – which is frequently done after a group discussion. The recorder should also say things like “are we sure of this?” or “does that sound accurate?” The recorder is also the group’s spokesperson during class discussions.
- **Facilitator** – This person keeps track of time, decides when the group should move on to the next question, and promotes / encourages all group members to contribute to the group’s discussion. They will also be responsible for looking things up in the textbook or on the Internet when necessary.

Note: “Roles” are an important part of any group activity. Assigning roles will help your group accomplish goals (such as completing the assignment) effectively and accurately.
Levels of Organization

Notes for Students

- This activity will be completed in groups of three.
- Do not use the Internet or your textbooks unless instructed to do so.

Procedure

1) Before beginning the activity, find three people you do not know and form a group of three.

2) Arrange yourselves in a circle and share the following introductory information:

a) Name
b) Favorite food
c) Favorite subject or class
d) Least favorite subject or class

3) Assign group roles:

- **READER**- this person will read out loud the text below.

- **RECORER**- this person decides what to record as your group’s answers. All students in the group should write down answers, but it is the recorder’s job to decide what to record. This is frequently done after a group discussion. The recorder should also say things like, “Are we sure of this?” or “Does that sound accurate?” The recorder is also the group’s spokesperson during class discussions.

- **FACILITATOR**-This person keeps track of time, decides when the group should move on to the next question, and promotes/encourages all group members to contribute to the group’s discussion. They will also be responsible for looking things up in the textbook or on the Internet when necessary.
Levels of Organization

Model 1: Anatomy and Levels of Organization

An anatomist is a person who studies the structure of a living thing – how all the little things are organized into bigger things. The smallest living structures are cells, but there are things even smaller than a cell (such as atoms and molecules). Figure 1 shows the levels of organization used by anatomists. Table 1 names examples of each of the levels of organization shown in Figure 1.

Figure 1: Levels of Organization in the Human Body

<table>
<thead>
<tr>
<th>Level of Organization</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atom</td>
<td>Carbon</td>
</tr>
<tr>
<td>Molecule</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>Cell</td>
<td>Stomach Cell</td>
</tr>
<tr>
<td>Tissue</td>
<td>Epithelial Tissue</td>
</tr>
<tr>
<td>Organ</td>
<td>Stomach</td>
</tr>
<tr>
<td>Organ System</td>
<td>Digestive System</td>
</tr>
<tr>
<td>Organism</td>
<td>YOU</td>
</tr>
</tbody>
</table>
QUESTIONS:

1. Using the list above, identify two terms that describe components that are smaller than cells and four that are larger than cells.

<table>
<thead>
<tr>
<th>Smaller than a cell</th>
<th>Larger than a cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Molecules</td>
<td>1 Tissues</td>
</tr>
<tr>
<td>2 Atom</td>
<td>2 Organs</td>
</tr>
<tr>
<td>3 Organ Systems</td>
<td>4 Organism</td>
</tr>
</tbody>
</table>

2. What are two examples from the list above that can be found inside a cell?
   *Atoms such as carbon and molecules such as carbon dioxide can be found inside cells*

3. Classify the following images and label with the appropriate level of organization.

4. Circle “TRUE” or “FALSE” for the following statements:
   a) Organs are composed of multiple tissues types.
      TRUE or FALSE  true
   b) Tissues are composed of multiple cell types.
      TRUE or FALSE  true
   c) Tissues are composed of multiple organ types.
      TRUE or FALSE  false
      *Tissues are less complex; they are lower on “levels of organization” graphic. A follow-up question might be, “What is more complex, an organism or a molecule?”

5. Spend 60 seconds working individually to write definitions for the two terms below. After 60 seconds, discuss your definitions with the group and decide who has the best definition.
a) Tissue: *Example: a collection of different cells working for a common function.*

b) Organ: *Example: a collection of different tissues working for a common function.* (Note: some anatomists require an “organ” to have all four tissue types: connective, epithelial, muscle, and nerve.)
6. Without using books or the Internet, complete the chart by identifying the organ systems associated with the example organs listed: (the first row is completed as an example. If you cannot identify the organ system, leave the box blank)

<table>
<thead>
<tr>
<th>Organ</th>
<th>Organ System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femur</td>
<td>Skeletal System</td>
</tr>
<tr>
<td>Heart</td>
<td>cardiovascular</td>
</tr>
<tr>
<td>Brain</td>
<td>nervous</td>
</tr>
<tr>
<td>Skin</td>
<td>integumentary</td>
</tr>
<tr>
<td>Pituitary Gland</td>
<td>endocrine</td>
</tr>
<tr>
<td>Lungs</td>
<td>respiratory</td>
</tr>
<tr>
<td>Stomach</td>
<td>digestive</td>
</tr>
<tr>
<td>Spleen and Appendix</td>
<td>lymphatic</td>
</tr>
<tr>
<td>Uterus</td>
<td>reproductive</td>
</tr>
<tr>
<td>Kidney</td>
<td>urinary</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>muscular</td>
</tr>
</tbody>
</table>

**CHALLENGE QUESTIONS:**

7. Organs are sometimes shared by two or more systems - for example, your mouth can be considered a part of both the digestive and the respiratory systems. Without using your book or the Internet, try to name 3 organs that are shared by two or more body systems, and identify those body systems.

**Example:** Organ: Mouth

What two systems? Digestive & Respiratory Systems
1: Organ: male urethra

What two systems? urinary & reproductive
2: Organ: brain

What two systems? nervous and respiratory
3: Organ: pancreas

What two systems? digestive and endocrine
Note: many other examples exist

8. With your group, consider the following statements and determine if they are true or not. If they are NOT true, describe why (list exceptions that exist).

a) Within the body, all atoms combine to form molecules.
   This is not a true statement. For example, there are potassium and sodium ions that do not form into molecules. Note: there may be some discussion about whether ions are atoms or not, depending on the students’ chemistry background.
b) Within the body, all molecules in the body can be found inside cells.

This is not a true statement. For example, there are hormones, such as insulin, on the outside of a cell; there is glucose that is outside a cell; etc. Should be noted that even if a molecule is outside a cell, it will often interact, or even move into the cell. (Example: insulin will bind with cells, and glucose will move into a cell.) There are many other examples such as extracellular fluids, proteins in blood, etc.
Successfully Flipping the Classroom for Organic Chemistry  
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Introduction

The changing demographics of students enrolling at institutions of higher education continue to present a tremendous challenge to the system. Our challenge as educators is to develop methods to engage this expanding population of students with highly diverse needs and backgrounds while still ensuring that the rigor of an academic degree is maintained. In fact, there is a general call for more accountability from higher education to develop valid methods to measure and report student attainment of specific learning outcomes to better support the value of the degrees being conferred. It is in this context that we report the results of the redesign of organic chemistry at the University of North Texas (UNT), which is based on student-centered pedagogy that has increased student engagement, attainment, and performance, while simultaneously providing a framework for validated assessment of content mastery.

UNT has a total enrollment of more than 36,000 students making it the 5th largest in the state of Texas and among the 30 largest in the United States. UNT has a highly diverse student population with African American and Hispanic students representing 15% and 21% of the student body as of the spring of 2015 (Figure 1). While UNT is not a member of either Historically Black Colleges and Universities (HBCU) or Hispanic Association of Colleges and Universities (HACU), it is one of the largest producers of baccalaureate degrees for students from underrepresented groups. This is especially significant in the context of the course redesign described here, given the need for a more diverse STEM workforce.

![Figure 1. Undergraduate enrollment by ethnicity at UNT during the spring 2015 semester.](image)

Methods

NextGen principles

This course is part of a much larger initiative at UNT called the NextGen program, which is designed to increase student performance and engagement in large enrollment courses. The NextGen course redesign program focuses on the seamless alignment of course objectives with instructional strategies, and assessment (Figure 2). The program is predicated on the use of a three-level model to quantitatively assess student attainment of course objectives (Carriveau, 2010). First, broad learning outcomes called Goals are written for the course. Goals are too broad to be assessed directly, so a series of more focused learning outcomes that break down the Goal into more measurable sub-Goals, called General Learning Outcomes (GLOs), are then written for each Goal. The GLOs are then broken down into specific
measurable outcomes called “specific” Learning Outcomes (sLOs), with a lower case “s” to differentiate it from the term Student Learning Outcome (SLO) that refers to all the levels of outcomes. Test items are then written for each sLO to probe student mastery. The principle is based on the assumption that if students master all of the sLOs for a particular GLO, then one can conclude mastery of the GLO and thus mastery of the Goal to which the GLOs are linked. Again, if students demonstrate mastery of every sLO for a given GLO, then one can quantify student attainment at each of the three levels. Table 2 contains an example of the three level structure of a Goal and its accompanying GLOs and sLOs for the course.

![Diagram](image)

**Figure 2.** NextGen course redesign focuses on aligning course objectives with instructional strategies and assessment.

**The flipped classroom**
The course utilized the flipped, or inverted, classroom (a form of blended learning) where students take in lecture materials outside of regular class time (Bergmann & Sams, 2012; Lage, Platt, & Treglia, 2000; Mazur, 1991; Schultz, Duffield, Rasmussen, & Wageman, 2014). The podcasts used to replace lectures were not simple recordings of traditional lectures (Figure 3). Instead, they were produced in much the same way as other podcast materials commonly found online, such as the ©Khan Academy’s videos. Each podcast focused on a single topic and ranged from 3-20 minutes in length. Podcasts were created by first generating a Microsoft® PowerPoint backbone that could then be animated using a ©Hitachi StarBoard display. A webcam showing Petros (lead author, instructor) explaining the material was positioned in the lower left corner of the screen and the lesson, including the StarBoard animation, was recorded by screen capture using Microsoft® Media Encoder™. Media Encoder™ was the only screen capture program tested that would record both the StarBoard animation and the webcam feed simultaneously. Individual clips were then assembled into complete podcasts via Windows Movie Maker, which were converted to .mp4 files via Freemake.
Figure 3. Static example of podcast format showing animation (in red) being recorded via screen capture with webcam feed explaining the material being recorded simultaneously.

After recording and posting podcast lecture materials, in-class time was then used entirely for peer-led instruction, which is one of a large number of pedagogical techniques that have been shown to increase student engagement and performance (Table 1). The course was relocated from a traditional lecture hall in the Chemistry Building to another building on campus that had a classroom with reconfigurable furniture to accommodate small group work (Figure 4). The classroom selected had a maximum capacity of 96 students, which was problematic because the course routinely enrolled ~150 students per semester. A decision was made to make the course 50% online, thus reducing the number of hours of in-class time from 4 to 2. In this format, two groups of 96 students could each meet 2 hours per week in the classroom selected. The course enrolled 192 students for the 2013/2014 and 2014/2015 academic years. Each group of 96 students was further divided into 16 groups of six that would constitute teams for peer-led instruction.
<table>
<thead>
<tr>
<th>Types of active learning with feedback</th>
<th>Examples of studies that demonstrate enhanced learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing</td>
<td>(Steele, 2003)</td>
</tr>
<tr>
<td>One-minute papers</td>
<td>(Almer, Jones, &amp; Moeckel, 1998; Chizmar &amp; Ostrosky, 1998; Rivard &amp; Straw, 2000)</td>
</tr>
<tr>
<td>Clickers</td>
<td>(Smith et al., 2009; Smith, Wood, Krauter, &amp; Knight, 2011)</td>
</tr>
<tr>
<td>Problem-based learning</td>
<td>(Capon &amp; Kuhn, 2004; R. W. Preszler, Dawe, Shuster, &amp; Shuster, 2007)</td>
</tr>
<tr>
<td>Case studies</td>
<td>(Ralph W. Preszler, 2009)</td>
</tr>
<tr>
<td>Analytical challenge before lecture</td>
<td>(Schwartz &amp; Bransford, 1998)</td>
</tr>
<tr>
<td>Group tests</td>
<td>(Cortright, Collins, Rodenbaugh, &amp; DiCarlo, 2003; Klappa, 2009)</td>
</tr>
<tr>
<td>Problem sets in groups</td>
<td>(Cortright, Collins, &amp; DiCarlo, 2005)</td>
</tr>
<tr>
<td>Concept mapping</td>
<td>(Fonseca, Extremina, &amp; Fonseca, 2004; R. Preszler, 2004; Yarden, Marbach-Ad, &amp; Gershoni, 2004)</td>
</tr>
<tr>
<td>Writing with peer review</td>
<td>(Pelaez, 2002)</td>
</tr>
<tr>
<td>Computer simulations and games</td>
<td>(Harris et al., 2009; C. N. McDaniel et al., 2007; Traver, Kalsher, Diwan, &amp; Warden, 2001)</td>
</tr>
<tr>
<td>Combination of active learning methods</td>
<td>(Freeman et al., 2007; O’Sullivan &amp; Copper, 2003)</td>
</tr>
</tbody>
</table>

Each student was expected to attend class 2 hours per week, during which time they would work on problem sets with 5 other teammates. Students worked together on problem sets in class, but were each responsible for uploading their own answer set online through ExamSoft® (discussed below). Attendance was made mandatory and any student absent from class received a zero for that day’s problem set. The classroom format was highly amenable to this attendance policy because one could simply survey the classroom for tables with less than 6 students. Teams were initially assigned using the random enroll function in Blackboard Learn™. After three semesters of using this random enroll method, we began utilizing the ©Comprehensive Assessment of Team Member Effectiveness (CATME) program, which uses scientific algorithms for generating more effective teams (http://www.catme.org). The students take a CATME team-maker survey that includes both basic demographic information and instructor specific questions. Each of the criteria can be weighted during team formation depending on the preferences of the instructor (Ohland et al., 2012). The program also offers general advice for forming more effective teams based on research in this area. Students were also required to submit peer evaluations of their group through CATME, which includes a rater calibration exercise (Loughry, Ohland, & Woehr, 2014; Ohland et al., 2012) to educate students on important aspects of effective teamwork, one of the most frequently cited qualities desired in future employees.

Assessment
ExamSoft® was utilized for both formative and summative assessment. Each question written for exams and problem sets in ExamSoft® was tagged with a corresponding sLO, SLO, and GLO (Figure 5). Four regular semester exams were administered online in UNT’s computer testing facility. Students were also expected to upload individual answer sets for ~25 team assignments using ExamSoft®. Validation of assessment materials was conducted using standard methods. For multiple-choice items, face validity was achieved by (1) adhering to best practices for item writing, (2) validating each item through item analysis, and (3) linking each item to a specific learning objective. ExamSoft® provides a secure testing environment allowing questions to be reused in future offerings of the course. After each exam, the students did not receive a copy of their completed exam. Students had a brief period after the exam (5 min) to review questions answered incorrectly, but never saw the questions after that time. Instead, ExamSoft® generated a report for each student based on their mastery of course learning objectives (an example is shown in Figure 6). ExamSoft® also includes a longitudinal analysis feature that allows
student attainment data to be analyzed at any time during the course. Student attainment of course objectives was analyzed at the conclusion of each semester and used to guide further redesign (Table 2). An additional summative assessment was conducted using the final exam for the second-semester course, which was the online Organic 2012 exam from the American Chemical Society Exam Institute covering material from both semesters of the course. This exam allows the instructor to evaluate the overall effectiveness of the course and gives students a realistic view of their competitiveness nationally for other subsequent exams containing material from the course, such as the MCAT.

Figure 5. Example of assessment item tagged with corresponding learning objectives in ExamSoft®.
Figure 6. Example of report sent to students after taking an exam in ExamSoft® at UNT’s computer testing facility.

Table 2. Longitudinal analysis of student attainment of course objectives.

<table>
<thead>
<tr>
<th>Learning Objective</th>
<th># Assessments</th>
<th># Items</th>
<th>Group Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Students will understand molecular structure and its implication for basic chemical reactivity</td>
<td>11</td>
<td>66</td>
<td>73.36%</td>
</tr>
<tr>
<td>1.1 Students will know and apply the naming system for organic compounds</td>
<td>11</td>
<td>23</td>
<td>71.06%</td>
</tr>
<tr>
<td>1.1.1 Students will recognize and correctly name molecules containing functional groups</td>
<td>9</td>
<td>23</td>
<td>71.24%</td>
</tr>
<tr>
<td>1.1.2 Students will correctly name stereoisomers</td>
<td>2</td>
<td>1</td>
<td>70.56%</td>
</tr>
<tr>
<td>1.2 Students will understand the relationship between structure, hybridization, resonance, and aromaticity</td>
<td>2</td>
<td>21</td>
<td>81.80%</td>
</tr>
<tr>
<td>1.2.1 Students will identify the correct hybridization state for C, N, O and other relevant atoms</td>
<td>2</td>
<td>18</td>
<td>81.19%</td>
</tr>
<tr>
<td>1.2.2 Students will identify factors that lead to stabilization in resonance structures</td>
<td>2</td>
<td>3</td>
<td>84.86%</td>
</tr>
<tr>
<td>1.3 Students will understand the role of acidity/basicity in reactions</td>
<td>4</td>
<td>23</td>
<td>70.67%</td>
</tr>
<tr>
<td>1.3.1 Students will predict products of an acid/base reaction</td>
<td>2</td>
<td>2</td>
<td>73.89%</td>
</tr>
<tr>
<td>1.3.2 Students will identify acid/base conjugate pairs</td>
<td>2</td>
<td>6</td>
<td>89.73%</td>
</tr>
<tr>
<td>1.3.3 Students will use pKa values to predict relative acidity</td>
<td>4</td>
<td>15</td>
<td>66.86%</td>
</tr>
</tbody>
</table>
Results

A total of 252 podcasts covering the entire year of organic chemistry were recorded and posted on UNT’s iTunesU site. Students were instructed to view a certain set of podcasts (a detailed timeline was contained in the syllabus) prior to coming to class that day, which would be used for problem-solving sessions related to the assigned content. Approximately 1,000 multiple choice questions were written in ExamSoft® including both exam questions and questions used for in-class problem sets. Student mastery of course learning objectives was monitored throughout the semester and used to increase student attainment in areas where they seemed to struggle. For example, student performance on their fourth exam one semester was well below expectations (top row, Figure 7). Results were analyzed according to sLO and subsequent instructional materials generated for those learning objectives where student attainment was low. The students were allowed to retake a similar exam where performance increased to an acceptable level (bottom row, Figure 7).

![Fourth Exam Performance (split into two section)](image)

![Remediation Assignment Performance (sections combined)](image)

Figure 7. Test results indicating the need for instructor intervention (top) and outcome of the intervention (bottom).

Student performance on an ACS final exam has been monitored since the 2010/2011 academic year (one year prior to redesign effort). Podcasts were introduced during the first year of the redesign (2011/2012), but were used only as a supplement to traditional lecture. Student engagement was low and the attendance was ~50%. Only a modest improvement in student performance was observed on the ACS final (Figure 8A). During the second year of redesign (2012/2013), the traditional lecture was abandoned entirely in favor of instructor-led problem-solving sessions. Student engagement remained low and the attendance rate was still ~50%; however, a significant increase in student performance on the ACS final was observed.

The NextGen redesign launched in 2013/2014, and included peer-led problem-solving sessions instead of instructor-led ones. The instructor, one teaching assistant, and one supplemental instructor patrolled the room while students were working through problem sets to answer questions as they arose. Student attendance improved to ~70%, and a further increase in student performance was observed on the ACS final exam. While student engagement was significantly higher, students in some groups were still not fully participating in group activities. During the final year (2014/2015), attendance was made mandatory and peer evaluations became part the students’ overall grade (5-10%) to encourage greater participation in
team activities. Students became highly engaged in the peer-led problem-solving sessions, and overall attendance reached ~90%. Results on the ACS final were similar to the prior year of the NextGen offering in terms of percentage of students scoring at or above the national average; however, the mean score for the class increased by 1.5 additional correct answers in year two (33 vs. 34.5). Over the same two-year period, students enrolled in both semesters of the sequence significantly outperformed those enrolled in only the second semester on the ACS final exam (Figure 8B). A pre-course assessment administered on the first day of class in the spring 2015 revealed that students enrolled in the NextGen course the previous fall semester came into the second semester course better prepared than those enrolling in the second semester only (Figure 8C).

Finally, at the same time that student performance improved, a remarkable increase in student success (students receiving a grade of A, B, or C) was observed with the incorporation of engaged student learning activities. Prior to the NextGen launch the success rate hovered around 65-70%, which anecdotally is not uncommon for a course in organic chemistry. However, this rate improved to as high as 90% during 2013/2014, and has remained significantly improved over the initial two years of the NextGen offering (Table 3).

Figure 8. (A) Students scoring at or above the national average on ACS Organic Chemistry standardized exam during course redesign, (B) or based on enrollment in one or both semesters in the flipped course, and (C) student performance on a 10 question pre-course survey administered on the first day of the second semester course during spring 2015.


<table>
<thead>
<tr>
<th></th>
<th>number of students receiving A, B, or C</th>
<th>number of students registered</th>
<th>Success rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014/2015</td>
<td>323</td>
<td>382</td>
<td>85</td>
</tr>
<tr>
<td>2013/2014</td>
<td>338</td>
<td>377</td>
<td>90</td>
</tr>
<tr>
<td>2012/2013</td>
<td>202</td>
<td>285</td>
<td>71</td>
</tr>
<tr>
<td>2011/2012</td>
<td>208</td>
<td>291</td>
<td>71</td>
</tr>
<tr>
<td>2010/2011</td>
<td>161</td>
<td>248</td>
<td>65</td>
</tr>
<tr>
<td>2009/2010</td>
<td>141</td>
<td>218</td>
<td>65</td>
</tr>
</tbody>
</table>

2 A paper version of the exam (OR04) was administered 2011-2013 and was changed to an online version (OR12O) beginning in 2014.
Discussion and Conclusion

A major benefit for this course redesign has been the generation of a list of Goals, GLOs, and sLOs for the course (contained in the course syllabus) giving students a set of concrete expectations for the course. This level of transparency aids the students in focusing their efforts on the material deemed most important by the instructor. Ideally, these objectives would be agreed upon by the broader community in a particular field of study; however, as is the case with organic chemistry, such a set of objectives has not yet been identified in many cases. There is growing support for this movement, and the future of education will likely include the convergence of course specific objectives (organic chemistry) with discipline specific objectives (Tuning Chemistry) and degree objectives (Degree Qualifications Profile, DQP). This course has begun an effort to address the convergence of these broad and varying objectives through student-centered course design and validated assessment methods.

Another benefit of the course format was the impact on the instructor’s interaction with individual students. Teaching a course with an enrollment of over 150 students each semester brings a challenge in name and face recognition and mentoring availability. How can one effectively guide a student if one not only doesn’t know their name, but doesn’t know their major or career goals? The flipped classroom and small-group analysis of problem sets method of teaching allows the instructor to engage the students directly, frequently, and allows them to feel more confident approaching him/her with questions about course material and broader academic choices.

The utilization of ExamSoft® for formative and summative assessment provided several key benefits. First, each assessment item could be tied to a specific learning objective thereby facilitating real time monitoring of student attainment. Second, the majority of graded work was administered through the program, which virtually eliminated the burden of grading individual assignments. Third, because the program provides a secure testing environment, exam questions could be reused in future offerings of the course without compromising academic rigor. Fourth, a summative, longitudinal analysis of student attainment facilitated redesign in areas where student mastery of specific concepts fell short of expectations.

Setting expectations for the flipped classroom turned out to be extremely important. Some of the students enrolled in the first semester of the NextGen offering expressed concern over the approach, and communicated their dissatisfaction through student evaluations. In later semesters, the course format and expectations were clearly communicated to the students prior to the first day of class to avoid any surprises, which resulted in increased satisfaction (and student evaluations). Students not wishing to engage with their peers in mastering the course material could simply choose other sections of the course that were taught in traditional lecture format. Students were also instructed to treat the podcast lecture materials just as they would a traditional lecture where note taking is crucial. An added benefit of the podcast lectures is that the students can rewind if they don’t understand a topic or view the material later in the semester, if they have not mastered its content. Students registered for the second-semester course were granted access to both semesters’ podcasts, and all students were encouraged to download personal copies that could be used as a refresher after they completed the course if needed. While the course has not yet achieved this level of detail, each podcast could be tied to its corresponding sLO aiding the students in navigating the material to achieve content mastery. In this sense, the instructor acts as a guide in providing both the individual pieces of information that the students must know and the assimilation of those facts into useful knowledge that can be used to solve problems. The inclusion of activities related to teamwork and peer evaluation through the CATME program also gave students an opportunity to hone and refine many of the “soft skills” in high demand by employers.

The identification of underperforming students enrolling in the second-semester course brings an additional set of challenges. Future efforts will focus on remediation activities to boost this group’s performance. With the national effort to increase student performance and retention in STEM majors, this course redesign offers one potential solution to the efflux of students from STEM disciplines. The
A redesigned course has engaged students at a deeper level and allows them to utilize their full arsenal of skills (teamwork skills included) in successfully navigating the course. Future work will include a direct comparison of student learning in this course with two other sections being taught in traditional lecture format by different instructors at UNT and the translation of this format to a local community college to examine whether the approach is scalable.

There are a wide variety of initiatives that offer opportunities to advance studies in the STEM disciplines, but it is up to individual instructors to develop fundamental approaches to engage and retain today’s students. The flipped organic chemistry classroom discussed in this chapter is one example that has proven to be successful. Without engaging students, new learning will not occur. This is especially true in a discipline that is a noted foundational course for many STEM degrees (e.g., biology, chemistry, biochemistry, physics, engineering, kinesiology, etc.) Chemistry is known as the central science, and chemistry student success (or lack thereof) may decide unwillingly a career choice for many undergraduate students. As educators, we must prepare our students to face the challenges of tomorrow’s technology-driven careers by providing them with a curriculum that serves to engage and motivate them. STEM education is paramount to students' success at home and on the global market (Arvizu, 2015).

**Literature Cited**


Bergmann, J., & Sams, A. (2012). *Flip your classroom reach every student in every class every day* (1st ed.). Eugene, Or., Alexandria, Va.: International Society for Technology in Education; ASCD.


How do we know that our students are actually learning what we teach? We gain some insight into their conceptual understanding by administering “big,” often high-stakes, assessments: tests, mid-terms, and final exams. These snap shots yield information about student performance at the end of a unit of study or course. While this summative information can be illustrative, it falls short primarily because it demonstrates students’ knowledge or skills after-the-fact, that is, after they are supposed to have learned content or honed abilities. As such, it is often used as an end point rather than a measure to inform instructors’ next steps in the classroom. To enhance teaching and learning, more frequent formative assessments are necessary. These quick (and often non-graded) assessments serve as tools to gauge students’ understandings and guide instructional decisions. The purpose of this paper is to provide a rationale for using formative assessments and describe several ways to check for understanding in higher education environments.

Introduction

This marks the beginning of my fourteenth year in education. I began my career as a high school English teacher, teaching students 17 and 18 years old, adolescents who are similar in many ways to college students. I now am a full-time faculty member in Teacher Education at a public comprehensive college in New York State. My undergraduate and graduate studies in English, secondary education, special education, and educational theory, practice, and leadership serve me well at this institution. Not only did I study content but also how learners learn and how to effectively teach. Similarly, most of my colleagues in Teacher Education have completed coursework in Arts and Sciences and human development, curriculum, and pedagogy; in addition, many have experience teaching in P-12 settings. However, this cannot be said unequivocally of faculty across the campus. In fact, “college teachers typically have little training in pedagogy during their doctoral programs and, thus, are unaware of newer pedagogical research” (Feden, 2012, p. 5-6). As a result, college instructors may not utilize or may under utilize the research-based strategies that enhance educational outcomes for students.

From the Research

Current research in cognitive science emphasizes the importance of learner engagement, and studies in teaching practice support the use of multiple strategies, tailored to the needs of students. Bransford, Brown, Cocking, Donovan, and Pellegrino (as cited in Feden, 2012), reported that, among other things, instructors need to “integrate metacognitive skill building into their courses” (p. 6). Such metacognitive strategies both engage learners and are differentiated. Metacognition is thinking about thinking: knowing what one knows, what one doesn’t know, and how to enhance one’s thinking to maximize learning. Dirkes (1985) describes three basic metacognitive strategies. One is at the center of this paper: planning, monitoring, and
evaluating thinking processes. I position metacognition within the discussion of formative assessment and checking for understanding.

Bain’s (2004) research on college teaching-learning supports the need for frequent, formative assessments. This is one of the tools that nationally renowned teachers of excellence use to encourage “deep learning.” It is also the focus of this paper. Deep learning is characterized by “students’ ability to think about their own thinking (metacognition), to reason with concepts and information they encounter, to use the information widely, and to relate it to previous learning and experience” (as cited in Feden, 2012, p. 7). These are the critical thinking, self-regulation, and problem-solving skills and abilities we want our college students to enhance.

**Pedagogical Preparation for Higher Education Faculty: A Challenge and a Need**

Higher education faculty, particularly those outside of Teacher Education programs, often have minimal pedagogical preparation. Their undergraduate and graduate education primarily centered on content knowledge, not teaching content—more aptly stated, not teaching adolescent and adult learners. Jensen (2011) highlights the stark difference in P-12 teacher preparation and post-secondary instructor preparation. State licensure/certification bodies require that P-12 teachers have “an understanding of the learner and the process of learning; an understanding of the content knowledge; and an understanding of the appropriate and effective instructional practices” (Jensen, 2011, p. 30). This requires pre-service teachers to complete coursework in their respective subject area and in educational theory and practice in order to receive a Bachelor’s or Master’s degree. Moreover, P-12 licensure/certification exams typically assess both a candidate’s content knowledge and his/her pedagogical knowledge via standardized exams and performance-based assessments. This is not typical for post-secondary instructors. College faculty must demonstrate teaching ability, but they usually are not mandated to receive pedagogical training.

Plush and Kehrwald (2014) write about minimal pedagogical training as it pertains to novice college faculty. This population faces unique challenges. Often, they have little formal training in university teaching, experienced the traditional lecture format as students, and may not have opportunities or support to improve their teaching (Plush & Kehrwald, 2014). Consequently, these instructors continue to teach like they were taught or find it difficult to explore best practices and experiment with student-centered pedagogy. Why does this matter? Pedagogical preparation is important in two ways. First, some research suggest that pedagogical training positively affects student learning; second, pre-service teachers are observing and internalizing the instructional practice demonstrated by undergraduate and graduate course instructors, which in turn, influences their practice in P-12 classrooms.

Romm, Gordon-Messer, and Kosinski-Collins (2010) discuss pedagogical training as it relates to the field of science. They claim that “Scientists gain respect and recognition in their field by attending conferences, presenting posters, and publishing primary literature. When expected to teach, however, scientists are often placed into classrooms without proper mentoring or training” (Romm et al., 2010, p. 80). Furthermore, they contend that “an ability to educate in the sciences is not inherent and must be cultivated” (Romm et al., 2010, p. 80). This implies that educators can be taught innovative theory and practices and that such new learning can reform their pedagogy. Such explicit instruction of effective science educators can develop instructors’ skills
and change their beliefs and behaviors (Gibbs & Coffey, 2004). In this way, the teaching and learning process is dynamic and responsive, able to adjust to improve student outcomes.

Numerous studies indicate that pedagogical preparation is related to enhanced teaching and learning outcomes. Postareff, Lindbloom-Ylanne and Nevgi (2008) demonstrated that college faculty who voluntarily participated in pedagogical courses adopted more learner-centered teaching practices. Martin and Lueckenhansen (2005) reported that instructors with “more sophisticated understanding of their subject matter and of teaching and learning” were more likely to adjust their teaching to positively affect student learning (p. 407). Lawson, Benford, Bloom, Carlson, Falconer, Hestenes, Judson, Piburn, Sawada, Turley, and Wyckoff (2002) found “reformed teaching” (teaching that is learner-centered, based on recommendations of the American Association for the Advancement of Science, and introduced through summer pedagogical training) was correlated with improved student achievement in several undergraduate math and science courses. Moreover, they concluded that such reformed teaching was especially important for pre-service teachers who were “more likely to incorporate those reforms into their own teaching practices after graduation” (Lawson et al., 2002, p. 393). This same notion is echoed by Laronde and MacLeod (2012). In other words, pre-service teachers who had learner-centered best practices modeled for them in their teacher preparation programs were more likely to use similar instructional practices in their own classrooms.

**Assessment as a Marker of Good Teaching**

Such best practices are not new. Chickering and Gamson (1999) proposed seven principles for good practice in undergraduate education, one of which is providing prompt feedback, a type of formative assessment. Similarly, Ramsden, Margetson, Martin, and Clark (as cited in Duarte, 2013) found that good teachers, among other things, “assess student learning appropriately and provide meaningful feedback” (p. 2). Likewise, *Making Quality Count in Undergraduate Education*, a 1995 report published by the Education Commission of the States refers to “assessment and prompt feedback” as one of twelve attributes of quality learning experiences in undergraduate education (as cited in Chickering & Gamson, 1999, p. 78). Race (2010), for example, concentrated on seven factors that underpin successful learning. Two of these factors are particularly relevant here: learning through feedback and learning by assessing. The use of formative assessment and feedback were found effective because of their relationships to student growth. Black and Wiliam’s (1998) meta-analysis of over 250 studies on feedback revealed that effective feedback “produced significant benefits in learning and achievement across all content areas, knowledge and skill types, and levels of education” (Nicol & Macfarlane-Dick, 2006, p. 204).

The field of P-12 education has shifted from a teacher-centered focus to a learner-centered focus, thereby emphasizing engagement of students and educational outcomes for students. This means attention is paid to what students learn and how deeply they understand concepts, not simply that content was taught or delivered. This switch is occurring at a slower pace in higher education, where many instructors still use traditional ways of teaching and assessing (Feden, 2012). Specifically, many professors continue to rely on end-of-semester exams to evaluate student competency rather than “snap shots” of student performance throughout the semester to drive instruction, thus affecting student outcomes. Accreditation bodies (such as Middle States Commission on Higher Education [MSCHE] and Council for the Accreditation of Educator Preparation [CAEP]) require degree programs to demonstrate impact on student learning.
outcomes. It makes sense, then, that individual faculty members adopt practices aligned with such accrediting goals. One way to affect student learning is through formative assessment.

Formative Assessment

What Is Formative Assessment and Why Use it?

Fisher and Frey (2007) define formative assessment as an ongoing process of “assessments, reviews, and observations in a classroom” (p. 4). The results of which “are used to modify and validate instruction” (Fisher & Frey, 2007, p. 4). This builds on Sadler’s (1998) definition of formative assessment as assessment that is “specifically intended to generate feedback on performance to improve and accelerate learning” (p. 7). Formative assessments can be used by both instructors (to inform instructional practice and provide student feedback) and students (to gauge their progress by examining results on frequent knowledge-based, skill-based, and performance-based measures). This differs greatly from summative assessment, where the goal is to evaluate, judge, or make a determination concerning student competency and the quality of student performance. Conducted at the end of a unit, summative assessments are typically used for grading purposes. Unlike formative assessments, they are not intended to improve the teaching-learning process.

As previously discussed, metacognition, self-regulation, and assessment are complementary. Formative assessment, that is, assessment for learning, should help students understand what they know, what they are trying to learn, and how they can close the gap between the two (Stiggins, 2014). Numerous studies reveal ways in which formative assessment does just this. Formative assessments used in undergraduate biology, geosciences, and health science courses have been found to significantly improve student performance and attitude (Kitchen, King, Robinson, Sudweeks, Bradshaw & Bell, 2006; Nelson, Robinson, Bell & Bradshaw, 2009). Carrillo-de-la-Pena, Bailles, Caseras, Martinez, Ortet & Perez, 2009; Smith, 2007).

Performance was defined in several ways. Carrillo-de-la-Pena et al. (2009) found that students who participated in mid-term formative assessments earned better final exam scores than those who did not; additionally, a greater percentage of students who took mid-term formative assessments passed the summative exam. While passing mid-term scores were positively associated with passing summative exam scores, that was not true of poor scores. A better predictor of success was participation, alone, which indicates that students used effective feedback via the formative assessment to diminish the gap between what they knew and should have known by the end of the course. This notion of using feedback was also discussed by Smith (2007). He pointed out the importance of both instructors and students using formative assessment data to inform their teaching and learning practices. When effective changes were made, positive results were reported on exams. Other factors of performance were enhanced by formative assessments. These include correlations with developing higher-order thinking skills (e.g., analyzing experimental results and applying concepts in innovative ways) and positive attitudes about studying science in college (Nelson et al., 2009; Kitchen et al., 2006). As Smith (2007) concludes, “The implementation of frequent and diverse assessments, although increasing the workload for students (and grading and feedback obligations for the professor) also improve student attitudes toward, the course, the content, and the instructor” (p. 34).

Checking for Understanding
I believe most college faculty would agree that the instructor plays a significant role in the classroom. What he/she decides to include in or exclude from the lesson influences students and their educational experience. Employing formative assessments in the classroom is one strategy instructors can use to positively affect students’ learning. One way to systematically approach formative assessment is through checking for understanding. Checking for understanding provides opportunities to correct misconceptions, fosters metacognition, deepens assessment, and promotes good teaching (Fisher & Frey, 2007). Ultimately, it improves learning. Using a pre-test post-test design, Vosniadou, Ioannides, Dimitrakopoulou, and Papademetriou (2001) found that students who experienced checks for understanding during a physics lesson had a significantly greater increase in scores than their peers who did not experience checks for understanding.

Simply put, checking for understanding is a quick, explicit, effective, regular way to determine if students are “with you,” if they “get it,” and to tailor instruction to support learner success. It can take on myriad forms including using oral language, questions, writing, and projects to name a few. It is additionally flexible in that multiple strategies can be used and adapted to assess particular conceptual understandings and skills, thereby making it useful in all subject areas and with diverse learners. So what might this look like in a college science classroom? What follows are descriptions and applications of several strategies I have used with graduate and undergraduate students in a teacher preparation program. Among my students are myriad science majors, pursuing New York State adolescence education certification in Biology, Earth Science, Chemistry and Physics. I believe that these same strategies can be adapted for the college science classroom.

Strategies for the College Science Classroom

3-2-1.

The 3-2-1 activity was initially designed as a reading comprehension strategy. It provides students a structured way to engage with a text or as Zygouris-Coe, Wiggins, and Smith (2011) claim, a way for students to “interact meaningfully with and develop understanding of text” (p. 381). Essentially, it has three components: a summarization section, an intriguing insights section, and a questions section. After reading, students write down three things they discovered, two things they found interesting, and one question they still have. This information can be used by the instructor to check students’ understandings of “big ideas” and the evidence used by students to support their claims. It provides students an opportunity to share what they found intriguing, thereby helping students make a personal connection to the text. It also highlights areas where students have misconceptions or need additional clarification. Summarization, engaging with a text, and formulating questions are important ways by which students construct meaning (Zygouris-Coe et al., 2011).

I have used this strategy as an in-class activity to check for understanding during and after a lecture and as a homework assignment. In both cases, it shaped my instruction. The summaries provide a cursory glimpse of students’ conceptual understandings. Although they are not in depth, such summaries indicate if students are “heading in the right direction” or “way off track.” Their intriguing findings and questions serve as stepping stones for future lessons, new connections to be made, or re-teaching that may be necessary. I have modified this strategy in several ways, sometimes leaving the prompts broad and other times making them specific to a
theme or concept. For instance, I may have students identify three novel ideas, two details (for each) that pertain to the novel idea, and one question (for each) to explore to better understand the novel idea. Or, I might have students list three essential qualities of a concept, two non-essential qualities of that concept, and one statement about how their understanding of that concept has become more nuanced. Another possibility is as follows. Given two concepts, have students describe three ways in which the concepts are similar, discuss two ways in which they differ, and explain how they will apply their new understanding to an upcoming project or assignment. As indicated in the previous examples, the 3-2-1 strategy can be altered to prompt Higher Order Thinking, it can be adapted to meet the needs of the instructor, and it can be used by both instructors and students to inform teaching and learning.

**Concept maps.**

Concept maps are “graphical tools for organizing and representing knowledge” (Novak & Canas, 2008, p. 1). They are constructed in a particular manner: in a hierarchical fashion where the subsuming concept appears at the top and more specific concepts beneath; each concept, the less general and the more general, is written inside an oval; each oval is connected by a unidirectional line, the arrow indicating the direction of the relationship between the concepts; a propositional phrase or “linking words” are written on the line to describe the relationship between the concepts; and cross-links, unidirectional lines (with arrows and linking words indicating relationships) that illustrate links between concepts in different sections of the concept map.

Novak and Gowin (2002) maintain that concept maps are a powerful tool to facilitate “meaningful learning,” that is learning that occurs when individuals “choose to relate new knowledge to relevant concepts and propositions they already know” (p. 7). They describe four roles of concepts maps: in teaching, learning, curriculum, and governance. Two roles are particularly relevant to this article.

For the learner, they help to make evident the key concepts or propositions to be learned, and also suggest linkages between the new knowledge and what he or she already knows. For the teacher, concepts maps can be used to determine pathways for organizing meanings and for negotiating meanings with students, as well as to point out students’ misconceptions. (Novak & Gowin, 2002, p. 23)

Such concept maps can be given pre-made to students to guide their conceptual formation or be used as evaluation tools where students put on paper the concepts that exist in their minds. As an evaluation tool, concept maps can illuminate the depth of students’ conceptual understandings or the root of their misconceptions. This information can be used to inform instruction. Concept maps can be used at the beginning, middle, and end of units. Because concept maps serve as a model of meaning-construction and because conceptual understandings are perpetually information, concept maps are never complete. This quality makes them especially useful when monitoring students’ conceptual understandings and providing feedback to enhance student learning outcomes.

**Card sort.**

The card sort strategy is similar to a concept map in that it provides a visual representation of students’ conceptual understandings. It works best with concepts that have clear relationships to one another (Lipton & Wellman, 2004). It can be used to foster meaningful conversations at all
stages of teaching-learning. At the beginning of a unit, it can be a tool to test prior knowledge; at
the end of a unit, it can be a tool to review concepts, illustrate developed schema, and reinforce
understandings (“Card Sort,” n.d.).
Card sorts have the following features: 1) the instructor selects important concepts and related
terms or vocabulary and writes them on index cards (one per index card); 2) students are
separated into pairs or small groups; 3) groups are given a set of cards to sort; 4) students sort
cards into meaningful categories based on the concepts’ perceived relationships; 5) students
generate labels for each category; 6) groups discuss their categories and labels, explaining their
rationales for each. This activity can be varied in numerous ways. For example, groups could
sort cards multiple times, showing different configurations; or students can create the cards to be
sorted as a homework assignment, then swap with other groups in class to sort and categorize;
and pictures on cards also could be used to complement or replace words (Lipton & Wellman,
2004; “Card Sort,” n.d.). I have used this strategy in each variation above, adapted to the needs
of students and my intended goals.

RAFT.
RAFT stands for “role,” “audience,” “format,” and “topic.” Initially, I used this strategy when I
taught high school English. It helped my students organize their ideas while paying attention to
important writing attributes like voice, audience, coherence, and elaboration. Now, I use this in
the college classroom. A RAFT activity includes four components: the role (of the writer), the
audience (to whom the writing is addressed), the format (the style of the writing), and the topic
(the subject or point of the writing). It offers students creative ways to demonstrate
understanding and can promote perspective-taking (Fisher & Frey, 2007; Fisher, Frey, & Kwon,
2011). In a college science classroom, a RAFT activity might be a concerned citizen (role)
delivering a speech (format) to a local political organization (audience) about the economic and
environmental effects of hydraulic fracturing (topic).

It is typical for instructors to create multiple RAFT descriptions for a single lesson. Students
may work in small collaborative groups or independently to complete the activity. This strategy
can be differentiated to meet the needs of diverse learners. Instructors can use evidence from the
RAFT to gauge students’ use of details when supporting claims and determine next steps in the
classroom. If multiple students have common misunderstandings, whole class re-teaching may
be necessary; if a single student has misunderstandings, an invitation to study group or office
hours may be warranted.

KWL.
A KWL chart can be completed as whole class, in small collaborative groups, or individually. It
is constructed vertically with three columns, from left to right, “K,” “W,” and “L.” Students first
list what they already know about a given topic. Then they write what they want to learn about
that topic. After students have studied a particular concept, they record what they have learned.
Finally, students review the “K” column, correcting inaccuracies and elaborating on ideas with
new knowledge. They also review the “W” column, checking that all wonderings were
addressed and raising questions that still need to be answered.
This strategy can be used before, during, and after a unit is taught. As a formative assessment, it provides information about 1) students’ prior knowledge, which instructors can use to determine how to teach concepts; and 2) students’ “final” understandings, which may reveal partial or misconceptions that need to be addressed by the instructor. The KWL chart can be adapted by adding an “H” column between the “W” and “L” columns, requiring students to describe how they will locate and use sources to find the answers to their questions. Or, an “S” column can be inserted after the “L” column, where students list what they still need to find out. Both of these modifications scaffold students in becoming more independent, self-regulated learners (“KWL,” n.d.; “KWL Charts,” n.d.).

Exit Slip.

An exit slip is a written student response to a teacher posed question. It is used at the end of a lesson, where students share their understanding of that lesson before exiting the classroom, hence the name “exit slip.” Instructors can use this informal measure to gauge how well students understand a particular topic and plan following lessons accordingly. Exit slips can be broad (e.g., “What is one new thing you learned today?” “What are you most confused about regarding today’s lesson?” “Using a scale, where 0 represents ‘completely lost,’ 2 represents ‘somewhat understand it,’ and 4 represents ‘can apply it,’ rate your current level of competence.”) or specific (e.g., “Describe the process of photosynthesis” or “Explain how the theories presented in this lesson apply to your research project”). They can engage students at all levels of Bloom’s Taxonomy.

An exit slip is used in the following way. With approximately 10 minutes of class remaining, provide students a prompt to respond to. The prompt may be stated orally or presented visually (on an overhead or slip of paper). Collect exit slips before students leave the classroom. Review the exit slips to check for understanding. Plan consecutive lessons based on students’ understandings, attending to individual students and class-wide trends. You may choose to even share, anonymous, exit slips with the class. “Exit slips are easy to use and take little time away from instruction. Many teachers use them routinely—even daily—and attest to their positive influence on student achievement” (Marzano, 2012, p. 81).

Conclusion

The purpose of this paper was to provide an argument for using formative assessment in higher education and present several strategies to check for understanding. The strategies discussed here do not constitute an exhaustive list; they include activities I have used in my own college classroom with science and non-science majors in a teacher preparation program. I believe that these strategies also can be used in college science classrooms. (For additional information on evidence-based practices in education, go to the “What Works Clearinghouse” at http://ies.ed.gov/ncee/wwc/)

Checking for understanding requires a philosophical shift for some instructors. Gone are the days of delivering content and evaluating student retention of information via end-of-the-semester exams. Today, the focus is on learning outcomes, student growth, and the impact teaching has on learning. That means instructors need to use multiple measures throughout the semester to gauge student learning and make instructional decisions. As Jay McTighe (2007) asserts, “ongoing assessment and adjustment are the key to improved performance” (p. vii).
Checking for understanding often employs quick, non-graded measures to provide snapshots of student performance. These measures are numerous and can be adapted to diverse learners and content. Students can use this data as feedback to determine what they actually know and where they still need to master content and skills. Instructors can use this data to determine and implement class-wide or individual instructional shifts to enhance learning. When used as data to drive instruction, checking for understanding can positively affect student learning.

References

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Professional Development with Innovative Co-Teaching

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In 1985, Project 2061, which produced Science for All Americans, identified the scientific, technological, and mathematical skills that were necessary to produce a critically thinking, scientifically literate population upon the next return of Halley’s Comet (Rutherford and Ahlgren, 1990). The Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993) identified the critical learning goals, and the National Science Education Standards (NSES) outlined the essential content and standards for K-12 education (National Research Council, 1996). By 2011, a new framework for science education had been developed (National Research Council, 2012), and in 2013, the Next Generation Science Standards (NGSS) sought to further improve K-12 science learning by focusing upon what students should be able to do (performance expectations), in addition to the required content in the form of disciplinary core ideas, scientific and engineering practices, and crosscutting concepts (Achieve, Inc., 2013).

However, in order for students to be taught science effectively, their teachers must have the science content knowledge, pedagogical tools, and confidence to successfully model scientific practices and inquiry skills. In particular, teachers’ science content preparation strongly influences classroom culture and teaching practices (Supovitz and Turner, 2000). Other than initial teacher preparation programs, professional development programs can positively impact science teaching and learning (Banilower, Boyd, Pasley, and Weiss, 2006). Therefore, we targeted in-service middle school (grades 6-8) teachers of science in a professional development program in order to improve their students’ science content knowledge, critical thinking skills, and attitudes toward science and scientists. The Teacher Academy in the Natural Sciences (TANS) provided content instruction and inquiry investigations in three natural science disciplines: chemistry, geosciences, and physics. Six university scientists led TANS instruction, which also included hands-on performance tasks, and application of Differentiated Instruction and Understanding by Design (Tomlinson and McTighe, 2006). A unique component of the TANS project facilitated direct interaction between the university scientists and students of participating TANS teachers. Co-teaching, with lesson implementation by both the TANS middle school teacher and a University scientist, resulted in a unique collaborative experience. University scientists gained greater understanding of classroom restraints faced by middle school teachers (e.g., time, facilities, materials), and middle school teachers directly observed scientists’ pedagogical practices. Middle school students learned from both scientist and teacher, and had some misconceptions of university scientists (e.g., aloof, boring) challenged and overturned during the experience.
Relevant Research

Professional Development Programs

While some science teacher professional development (PD) programs reported great successes, not all programs were equally effective. Problematic variables include complex work interactions of participating teachers, which often are not considered in the PD program design (Opfer and Pedder, 2011). However, professional development programs in physical science resulted in teacher participants incorporating the PD workshop activities and strategies in their own classrooms (Donnelly and Argyle, 2011). When scientists were included in a middle school PD program, teachers implemented science as a process within their own classrooms (Morrison and Estes, 2007). Scientists within PD programs also resulted in greater teacher confidence and deeper understanding for including inquiry in classrooms (Lotter, Harwood, and Bonner, 2007). Another PD program that incorporated a two-week summer inquiry institute with university scientists documented that participating teachers increased their inquiry practices in their classrooms (Jeanpierre, Oberhauser, and Freeman, 2005).

Programs that focused on discipline-specific content instead of a broad, generic approach were more likely to lead to improved teachers’ knowledge and skills (Garet, Porter, Desimone, Birman, and Suk Yoon, 2001). The amount of professional development is important, and strongly linked to inquiry teaching and investigative classroom culture (Supovitz and Turner, 2000). Other research studies documented that longitudinal teacher professional development programs lead to success. In a 3-year elementary and middle school PD program, participants increased inquiry-based instruction in their classrooms (Lakshmanan, Heath, Perlmutter, and Elder, 2011).

In addition to professional development programs supporting improved teachers’ knowledge and skills, it also translates into improved student learning. In science and mathematics professional development, the students of participating teachers showed significant positive effects in their achievement (Blank and de las Alas, 2009). In a professional development hands-on science program, the students of teacher participants scored 10.1% higher on standard science examinations than non-participating teachers’ students (Silverstein, Dubner, Miller, Glied, and Loike, 2009).

Co-teaching Outcomes

Our TANS professional development model included co-teaching as a way to promote better pedagogy. Co-teaching has many facets, and has been utilized in a variety of settings. College instructors co-taught a multidisciplinary educational methods course in order to gain content knowledge and pedagogical techniques in another discipline, with the eventual goal of being able to singly teach the course (Kalchman and Kozoll, 2012). In this context, co-teaching provided professional development for the instructors involved (Duchardt, Marlow, Inman, Christensen, and Reves, 1999). In another model, a university professor served as a “professor-in-residence” for a sixth grade social studies class, and pre-service teachers were able to observe an expert modelling effective instruction, and ultimately co-plan and co-teach with the expert (Burstein, 2009). This model is not atypical, since often a pre-service teacher and a classroom teacher are
partnered in the co-teaching experience, with each participant acting as an equal in the classroom to maximize the learning opportunities for the students (Murphy and Beggs, 2010).

Co-teaching can facilitate instructors’ reflective practice (Brody, 1994), and it has the potential to enrich students’ learning experiences (Crow and Smith, 2005). Some co-teaching experiences have been designed with the goal of improving student learning (Dugan and Letterman, 2008). Engineering faculty partnering with Gifted and Talented graduate student interns resulted in improved Summer Enrichment Workshop mini-courses for middle school students (Newman and Hubner, 2012). The engineering expert not only collaborated in planning and teaching science lessons, but was available to model problem solving and provide immediate corrective feedback for the graduate students (Newman and Hubner, 2012). While systematic studies showed that co-teaching resulted in positive benefits for all participants (Murphy and Beggs, 2012), the available research indicates that when professors are involved with co-teaching, the partnering co-teacher is a university colleague or a pre-service teacher or graduate student. The Teacher Academy in the Natural Sciences implemented an innovative use of co-teaching, in which a University scientist partnered with an in-service middle school teacher.

**Teacher Academy in the Natural Sciences (TANS)**

The Teacher Academy in the Natural Sciences (TANS) was funded as a Mississippi Mathematics and Science Partnership (MSP) and administered through Mississippi State University (MSU), a high activity research university in the southern US (Clary, Dunne, Saebo, Elder, Tucker, Beard, Wax, and Winter, 2014). The TANS program was implemented between 2010 and 2013.

TANS attempted to meet the needs of high-needs districts (N =35; n = 31 public districts, n = 4 independent districts), which are defined as having a high percentage of children of low-income households, a high percentage of minority children, and/or middle schools with under-trained science teachers. TANS goals were to provide content and instructional strategies for effective science teaching, and increase student science knowledge and science enthusiasm. An early decision was made to focus on the natural sciences (chemistry, geosciences, and physics), since the leadership team’s previous interactions with science teachers in the state professional development programs revealed that teachers were more comfortable with the life sciences, but struggled with content, pedagogical content knowledge, and instructional confidence in the natural sciences. The TANS leadership team designed the professional development program based on best practices and outcomes in the literature, and focused upon middle school teachers of science (grades 6-8).

TANS opted to hold annual intensive discipline-specific professional development for teachers, assigning participants to one of the cohorts in physics, geosciences, or chemistry. By retaining the original group of teacher participants, and rotating cohorts through the disciplines, participants should receive sustained professional development in all three content areas by the conclusion of the three year program. In practice, some of the original participants were promoted, relocated, or retired, and were replaced with new participants. At the conclusion of the program in 2013, the TANS program impacted 81 teachers (n = 52, 55, 52). Using a quasi-experimental research design, TANS also recruited 50 middle grade teachers of science who did not participate in TANS, or any other MSP professional development program, to serve as a control group.
The TANS program included an intensive, 80 hour summer session with three professional days (Saturdays) during the regular school year. Content instruction was also extended during the academic year through the use of two online science modules, administered by a national science organization. TANS teachers were encouraged to participate in the Mississippi Science Teachers Association annual conference. Participating TANS teachers were required to conduct annual science outreach with the families of their students, or the greater community. TANS teachers were also required to conduct an annual professional development session with their non-participating TANS colleagues. All TANS teachers annually co-taught a lesson in their middle school science classes with University faculty. TANS teachers received funds to cover their travel and time as well as approximately $1200 worth of professional development supplies.

Within the TANS academy, each content discipline (chemistry, geosciences, physics) was taught by two University faculty, who provided mini-lectures, inquiry-based laboratory experiences, and field excursions. Hands-on performance tasks were included in all three years of the program. The State agency required the incorporation of Understanding by Design (UbD) in the PD program. Therefore, TANS teachers met collectively each day during the 10-day summer session to review and extend UbD and Differentiated Instruction (DI) in year 1, and apply UbD/DI in their instruction with the required state science competencies (grades 6-8) in years 2 and 3 (Tomlinson and McTighe, 2006).

Co-Teaching: Methods and Implementation

Co-teaching was a unique part of the TANS program. In the original project grant application, the team noted that university faculty and middle school teachers would implement the content learned by the TANS teachers during the summer academy within the middle school science classroom. TANS teachers and their principals signed contracts, acknowledging all required elements of the TANS program, including co-teaching events. (The second half of the TANS teachers’ stipend was granted after all required elements and documentation were submitted.) In the TANS summer session, scheduling for co-teaching began, and if dates could not be determined before the end of the session, TANS teachers were instructed to contact their TANS instructors and set up a co-teaching event. To optimize travel, University faculty attempted to group teachers from farther geographic areas into one trip to a distant region (Figure 1).

The content chosen for the co-teaching event was determined by the teacher’s curriculum plans, and the required grade level science competencies in the 2010 Mississippi Science Framework (Mississippi Department of Education, 2010). TANS teachers had to address the content area in which they were enrolled in during the previous summer session; if a teacher had been part of the TANS-Chemistry cohort, then s/he needed to plan a co-teaching event with the Chemistry faculty who led their cohort. Once the co-teaching event was scheduled, TANS teachers and University scientists determined the content to be taught, and then co-planned the activities and determined their respective roles for the lesson. Teachers were encouraged to provide a general lesson outline one week before the co-teaching event, and e-mail or fax a lesson plan, hand-outs, and/or PowerPoint presentations at least 2 days before the scheduled date.
During the academic year Saturday sessions, TANS teachers were reminded to *utilize the university faculty to their fullest*. Other guidelines included the introduction of the MSU professor to the classroom, and writing his/her name on the board. The lesson should allow time for students to ask questions, since this may be the students’ only contact with a University scientist. Both TANS teacher and professor were expected to teach, and equal time should be considered for both (Figure 2). Co-teaching reporting forms were filled out by both the teacher and the scientist, and documented the school district, school, grade level, number of students in the class, and the Mississippi Department of Education science competencies and objectives that the lesson targeted. Co-teaching forms also included independent reflections about the experience from TANS teachers and University scientists, as well as teacher-recorded anonymous students’ remarks about the University faculty visit.

**Figure 1:** Geographic locations of the participating middle school teachers in the Teacher Academy in the Natural Sciences (TANS) in Year 1. Teachers were grouped geographically into cohorts so that co-teaching efforts could optimize university professors’ travel effectiveness.
Figure 2: In co-teaching, both the TANS teacher participant and the MSU professor taught lessons and worked directly with students. In this photograph, the University’s “Mr. Physics” Josh Winter works with middle school students in a physics laboratory investigation.

In addition to the co-teaching reporting forms, data were gathered about the co-teaching experiences through the end-of-year program surveys, as well as the concluding survey at the end of the TANS program’s third year.

Results

There were some growing pains associated with the co-teaching concept, and its implementation in TANS teachers’ schools. Initially, a few participating teachers thought that co-teaching was equivalent to a guest speaker, and were not prepared to work with the visiting university scientist when s/he came into the classroom. Scheduling could be difficult, given that the University faculty were located in the northeastern part of the State, while participating TANS teachers were dispersed throughout. Emergencies arose, and co-teaching visits that had been planned months in advance had to be rescheduled. Some co-teaching visits that were conducted in the Spring encountered an additional problematic variable. Supervisors at a few high-needs schools on probation allowed no outside visitors or content unless it directly addressed literacy or mathematics, subject areas which impacted a school’s score in the State’s high stakes testing. Therefore, lessons and activities on plate tectonics were often transformed into reading lessons.

For the most part, university faculty scientists visited one of the classrooms of each of the TANS teachers. Throughout the three years of the TANS program, co-teaching was implemented within 128 classrooms, and directly impacted 2,653 students. It was rare that the University scientist
was able to stay at the TANS teacher’s school the entire day, and co-teach in all of the teacher’s science classes. Therefore, if the impact of co-teaching—including the TANS teacher’s increased confidence level, improved scientific content knowledge, and extended pedagogical skills that resulted from co-teaching—is extended to all students taught by the TANS teacher whether they were directly co-taught by University faculty or not, the total number of students affected by TANS co-teaching over the three program years is approximately 13,200.

Analysis of Co-Teaching Reporting Forms

Co-teaching reporting forms documented the grade levels, number of students, and lessons that were implemented during the University scientists’ co-teaching events. University scientists and TANS teachers also independently reflected upon the experience, and TANS teachers anonymously recorded some of their students’ comments. We subjected data from the the co-teaching reporting forms to content analysis (Neuendorf, 2002), and two major themes emerged: 1) Co-teaching was beneficial for classroom instruction and learning. It illustrated alternative methods for teaching scientific concepts, and demonstrated that learning is a continuous process; and 2) Co-teaching experience positively affected students’ beliefs. They were inspired to have University scientists in the classroom, recognized that scientists were approachable, and came to believe that attending college was a possibility.

Benefits to classroom instruction and learning.

The vast majority of TANS teachers remarked that co-teaching was an entirely new experience, and that it proved very beneficial. One TANS teacher stated that co-teaching was “by far one of my most productive lessons. The students remained engaged in learning for the entire 50 minutes.” Another remarked that co-teaching resulted in a “much more successful lesson with them [MSU scientists] there.”

Co-teaching also benefited teachers by increasing their confidence and illustrating alternative new methods for teaching scientific content. One teacher commented that the MSU scientist “showed me how to relate the material to the students in a way that they can understand,” while another teacher commented that MSU scientists “expanded on my lessons.” One teacher stated that the MSU scientists’ “background knowledge is deeper than mine as a first year teacher and it helped greatly to be able to bounce questions off them to create better answers for my students.” Another TANS teacher stated, “It is having a positive impact on my teaching. I have learned about useful labs and how to teach the concepts of chemistry.” For some teachers, the TANS professional development program and co-teaching experiences solidified their relationship with University scientists, and they continued to communicate via e-mail to ask content questions, or relate questions that had been posed by their students.

Teachers regarded the MSU scientists as resources, and noted that “to have an experts [sic] advice was wonderful” and “I learned new thing about clouds I never knew before.” Co-teaching assisted teachers in “helping me improve” and seeing “the process simplified down to an explainable level.” Several TANS teachers remarked on the lasting effects of the lessons: Students can “still talk about it in detail,” and co-teaching lessons “helped them to understand the material we had been covering” Yet another teacher remarked that “numerous students felt like they were better able to apply the information after our co-teaching.”
A further benefit from co-teaching was that it illustrated that learning is a continuous process. A TANS teacher wrote, “I took the opportunity to explain [to my students] how much I had learned while attending my TANS classes this summer. I want them [my students] to realize that learning never stops and you can learn something everyday [sic].” One student noted, “It is good to know that our teachers have connections with college teachers to help them and us out in our class.”

**Positive effects on students’ beliefs and emotions.**

The second major theme to emerge was how co-teaching benefited middle school students beyond their learning of the content. Students felt honored and inspired from University scientists’ co-teaching visits, and altered some of their previous misconceptions of scientists. When University scientists visited the classrooms of the TANS teachers, teachers often recorded student excitement, engagement, and inspiration about the event. One student stated that “I was very impressed that they would take the time to visit us personally” and teachers recorded their students’ “amazement at someone at a university would come and take the time to teach them a lesson.” One teacher similarly recorded that “students were amazed to have real college professors come work with them” [italics added]. Several TANS teachers noted that students who did not experience co-teaching and get to interact with professors were disappointed, and often “jealous” of their peers.

The co-teaching events even impacted harder-to-reach students. One teacher commented that “one of our students said, ‘The only reason I came to school today was to meet the weather man from Ms. State [sic].’ This is a student that we struggle with at times just to get him to complete work.” Another teacher reflected that “some of the students that are generally hard to get to participate in discussion even joined in as [MSU professor] gave his demonstrations.”

Students learned that scientists were approachable, and that MSU scientists “totally changed the image that they had about all professors.” Teachers remarked that students were “impressed that he did not try to talk over their heads,” and that “kids took to the professors like ducks to water.” Another teacher noted that one student remarked “they didn’t act like professors . . . That is meant as a compliment.” Professors were understandable, and students noted that they “never made us feel dumb.” One student stated that “I like him better than Bill Nye.”

The results from these co-teaching interactions were extremely positive. A teacher noted that “one young man is now even more interested in considering a career in science. He thought scientists were boring but not after meeting [MSU scientist].” Teachers noted that MSU scientists provided “a positive role model and inspiration to students to pursue higher education.” Some students remarked that they “can’t wait to go to college if all teachers are like them [MSU scientists].”

The content also was enhanced because of the co-teaching event. A TANS teacher stated that “science mattered because college professors were interested in what they [students] were studying and showed how this information was useful in life beyond the classroom.” Another teacher remarked that “students feel like what they are learning is so much more important than what they had thought.” One student stated that the MSU scientists “made me like Science more.” Perhaps one TANS teacher summarized the effects on students best: “University scientists “made a last [sic] impression on these students.” Therefore, co-teaching events
elucidated new perspectives for both TANS teachers and students. The overall experiences were extremely positive for all involved.

**Analysis of End-of-Year TANS Surveys**

At the end of each professional development year, TANS teachers were asked about various aspects of the program. This brief survey asked participants which one element of the program they would change, and which was the most valuable learning experience they encountered. Teachers reflected positively on the inquiry learning, experiments, and co-teaching activities. One teacher remarked, “I learned a lot from performing the experiments. The labs were also the most beneficial activities since we covered chemistry while I was co-teaching.” Another teacher stated the most valuable experiences were “co-teaching with professors; useful hands-on activities that I have used in my classes, as demos, and during after school tutoring (weather tools, cookie tectons, constant velocities, and paper clip equations).” The comments further indicated that co-teaching enabled the participants to learn from a science professional: “The most valuable experience for me was the co-teaching. At my school, the administrators who evaluate me are not knowledgeable in science. Don’t change co-teaching.”

At the end of the TANS program, a final survey probed the value of the different components of the professional development program. On a 5 point scale, where 1 = not at all, 2 = a little bit; 3 = some; 4 = much; and 5 = extremely, teachers were asked to rate the co-teaching experience on its usefulness and/or impact on teaching. The average rating was 4.125 (N = 34 surveys), with 18 teachers ranking co-teaching as “extremely useful,” 13 teachers ranking co-teaching as having “much impact,” and only 3 ranking co-teaching as no impact (score of 1) or little impact (score of 2). When asked “which activities or materials had the greatest impact on your students?” four participants directly mentioned co-teaching. In addition to recognizing that co-teaching was helpful for content level understanding for themselves and their students, teachers also realized that the benefit was motivational in nature, too: “My students enjoyed the co-teaching and being able to interact with MSU professors.” “Co-teaching gave my students a realization that college is not impossible and professors are real people, too.”

**University Scientists’ Co-Teaching Reflections**

Not only did co-teaching impact participating middle school teachers and their students, but it also affected the University scientists. Faculty observed during co-teaching activities the teachers’ level of content knowledge, and co-teaching during the first and second years of the professional development program informed subsequent instruction in the summer sessions. In the final evaluation of the project, MSU scientists reflected, “Some of the changes implemented in Year 3 were informed by strategies implemented in Years 1 and 2 (e.g., order and streamlining of content). These resulted in maximization of the Year 3 summer session teacher experience. The teachers were eager to learn more hands-on activities to use in their classrooms to help facilitate conceptual understanding.”

Co-teaching experiences ultimately informed university instruction as well. One MSU scientist noted, “MSU faculty reflected that their co-teaching experiences in middle school science classrooms impacted their delivery of instruction in college science classrooms. The positive reception by middle school students to hands-on, inquiry activities translated into college science instruction.” Another faculty member stated, “Something that the MSU chemistry instructors
understood more deeply after spending time in middle school science classrooms was that students of all ages need to be able to relate to the material covered in class. These instructors have begun to integrate additional real-world examples into their MSU classes.” MSU scientists reported realizations from the three years of TANS that will impact the way they conduct future instruction.

University faculty also experienced first-hand the constraints and issues that science teachers in middle grades classrooms encounter daily. “The co-teaching visits were an eye-opener for the university scientists giving them a much better understanding of the problems middle school teachers are faced with on a daily basis.”

**Discussion**

Although co-teaching has been implemented between pre-service teachers and in-service teachers, and between pre-service teachers and University faculty, the TANS co-teaching concept appears to be unique in professional development programs. In TANS, the University scientists who instructed TANS middle school teachers during the professional development program visited the middle school science classrooms to actively implement a lesson alongside the teacher. Co-teaching was not simply an observation of an in-service teacher, or a scientist guest lecturer within a middle school science classroom, but a collaborative teaching event between a middle school science teacher and a University scientist.

All TANS data indicate that the co-teaching concept was successful. Participating TANS teachers ranked this activity high, and some teachers even identified it as one of the most important aspects of the TANS professional development program. Teachers noted that they learned new techniques as University scientists demonstrated alternative methods for engaging middle school students. University scientists also served as an expert science source. Likewise, middle school students were positively impacted. Several students noted that the MSU faculty did not fit their previous image of “scientists,” and that the MSU scientists were easy to understand, interesting, and inspirational.

MSU scientists also gained from the co-teaching experience. Lessons learned during co-teaching events were incorporated to improve instruction within the professional development program, and then translated beyond the professional development program to college level courses.

The relationships between middle school teachers and University scientists continued *beyond* the professional development program, and several TANS teachers continue to communicate with University scientists via e-mail. TANS teachers ask science content questions, or put their students in touch with the University scientists. TANS teachers and University scientists also continue to correspond to share resources and opportunities. Obviously, the bonds formed between TANS teachers and University scientists were substantial, and we suspect that the professional development comradery—including co-teaching—played a significant role.

Although the TANS experience was a positive one, more research is needed to discern the influence of University scientists on in-service middle school teachers of science, and their students. Whether or not co-teaching events had long-lasting impact on students’ future college plans has yet to be determined. Likewise, more research is needed to determine whether students who directly participated in co-teaching events experienced greater affective gains in their
attitudes toward science than their peers. Did direct access to a University scientist result in more positive student attitudes, or was the greater influence the participation of the middle school teacher within the professional development program?

Regardless, the Teacher Academy in the Natural Sciences research team proposes that co-teaching events result in numerous benefits for University scientists, middle school science teachers, and their students. The co-teaching concept should be further developed, implemented, and refined for optimum student impact.

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Using Controversy and Argumentation to Develop Students’ Critical Thinking Skills

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Instructors often default to teaching their classes in the manner in which they were taught. Most college instructors were once enrolled in a large science lecture course, where content was disseminated via lectures and student success was measured by performance on multiple-choice assessments. However, most college instructors realize that a successful science course depends on more than students’ recitation of memorized content, and should include students’ understanding of the nature of science, and application of critical thinking skills beyond the classroom walls. How can this be achieved in our college science classrooms?

Originally established by a botanist and biology education researcher (Wandersee), and a geologist and geoscience education researcher (Clary), the EarthScholars Research Group was formed to research a more authentic, interdisciplinary view of the scientific enterprise, and facilitate public science literacy. As a result, we wanted students to understand how scientists examine the natural world, and that science is not a linear progression of one discovery that leads to another, and then another. For scientific literacy to be achieved, students must be able to recognize the necessary restructuring and reorganizing required in the progression of scientific understanding. Scientists do not always agree, and arguments are essential to the process.

Incorporating controversies in the classroom can reveal the underpinnings of science, illustrate how scientists approach a topic, and facilitate critical examination of scientific content by our students. It is also important that students be able to effectively communicate in the scientific arena, voice their opinions, and justify them with scientifically-accepted research. We researched the implementation of controversies in science courses, spanning both traditional and online classrooms, and including historical controversies as well as current, modern ones. Multiple studies revealed that controversy and argumentation can develop students’ critical thinking skills.

Relevant Research

Incorporation of controversial topics in science classrooms is based upon research documenting best practices in science education. Forming the basis for our research program is constructivism, which promotes a “less is more, meaning over memorization, and understanding over awareness” position for effective science teaching and meaningful science learning (Mintzes, Wandersee, and Novak, 1998, 2000). In order to implement controversy and argumentation in the classroom, instructors must first realize that not all controversies are equal, and care must be taken to select only those topics whose positions can be researched scientifically. Controversies may also be past ones, since these can document how scientists previously debated a scientific construct that is now accepted by the general scientific community. Historical controversies, therefore, can illustrate the nature of science, and demonstrate that science evolves within cultural, social, and political constraints. With proper implementation, controversies can be used to model and develop effective argumentation skills, and lead to critical analysis of issues by our students.
Role of Controversies

Importantly, “controversy” for science classrooms should not include every topic over which there is a disagreement among students. Topics to be considered for science classroom implementation should only include legitimate scientific controversies, or extended argumentative engagements in which data and evidence are marshaled by scientists to make the case for reaching a particular scientific consensus about an issue of importance to the scientific community. Succinctly summarized, legitimate controversies are issues that are scientifically important, involve scientists on both sides of the discussion, and can be experimentally tested. Controversies may be formal or informal; local, national, or international in scope; active or dormant; and minor or pivotal (Clary and Wandersee, 2013).

Evolution, the age of the planet, and hydraulic fracturing are all considered controversial by some groups, although Darwinian evolution and the 4.6 billion year age of the planet are well established within the scientific community. However, when confrontations arise—either with scientifically accepted theories and facts as well as procedures and interpretations—general guidelines for teaching controversial issues can promote more respectful discussion. Duggan-Haas (2015) reminded instructors to 1) be nice, within limits; 2) complexify the simple—and move towards discussion of interdisciplinary controversies; 3) acknowledge and understand belief systems and inherent biases, but point out fallacies and target key points for discussion; 4) remember that persistence is necessary; and 5) include the local environment where possible.

History of Science

Michael Matthews (1994) researched the benefits of the history of science in the science classroom, and concluded that the history of science can hook students’ interest, and demonstrate the cultural, social, and political realms within which science developed. History of science can humanize the science curriculum (Jenkins, 1989). In a classic Science journal article, noted science historian Stephen G. Brush posed the question, “Should the history of science be rated ‘X’?” (Brush, 1974). He humorously speculated whether the way scientists actually behaved (according to historians) was a good model for teaching science standards. Although scientists made mistakes and sometimes behaved badly, Brush endorsed telling the entire story. The history of science promotes an enlightened and critical mind, portrays science concepts as human-made, presents the evolution of scientific ideas, prevents suspicion and resentment of science, and proves there is freedom of thought in science (Brush, 1974).

Not only do historical controversies in the history of science facilitate student understanding of the nature of science, but investigations of earlier controversies may also facilitate better understanding of current controversial issues, and suggest ways in which they can be solved (Brush, 1974). There are multiple methods by which historical controversies can be injected in science classrooms, but many methods have not been thoroughly tested (Stradling, Noctor, and Baines, 1984).
**Critical Thinking and Argumentation**

We should model the history of science and teach that scientific reasoning is complex, and not linear and unitary. This is echoed in the New Framework for K-12 Science Education (National Research Council [NRC], 2012). Furthermore, the process of critique and argumentation is an essential scientific practice (NRC, 2012). Rudwick (1985) noted that the scientific knowledge results from intense argument among a small group of ambitious researchers. In order to effectively include argumentation in our classrooms, we must provide opportunities to demonstrate that scientists often disagree, suggest alternative hypotheses and analyses, and compromise before consensus is reached. In order for our students to model scientific behavior, they must also learn to engage in effective scientific argumentation.

Argumentation in the classroom can promote meaningful learning (Driver, Newton, and Osborn, 2000; Erduran and Jimenez-Aleixandre, 2007; Sampson and Schleigh, 2012). The resulting authentic view of science reveals to our students how science progresses, and shows the warrants and backings of the scientific enterprise (Dushl and Osborne, 2002). With a fuller, deeper understanding of how science develops, students can critically evaluate the “final form science” that is typically presented in science textbooks (Duschl, 1994). Collaborative discourse and argumentation may even help consolidate learning gains (Nussbaum, 2008).

**EarthScholars Research**

Our research demonstrated that both historical controversies and modern ones can serve as effective portals in science classrooms to engage students, implement respectful disagreement, and hone argumentation skills. Our first systematic research with controversies was conducted in online classrooms, and specifically targeted climate change (Clary and Wandersee, 2012a). After observing some students’ spirited attempts to engage their colleagues in emotional discussions with little research base, we next developed the Historical Controversy Case Study (HCCS) model through which students could research historical arguments, defend positions, and reach a scientifically-positioned resolution. Students learn scientific research techniques and appropriate argumentation skills within a controversy that is not being deliberated in the public media. We finally extended our research into modern controversies, and developed a Modern Controversy Case Study (MCCS) approach, by which students become stakeholders in controversies by issue ownership, and strengthen the knowledge base of their opposing position of the controversy.

**Online Controversy Investigations**

Our online discussions of controversial issues formally began in 2010. However, the inspiration for the online discussions can be traced back to a capstone field course, in which online students demonstrated their content knowledge and skills by applying the concepts they had learned throughout an online program of study. Students performed application tasks exceptionally well, except when the discussion turned to climate change. The ideas voiced seemed to parallel those of popular media voices. Students acknowledged that they had not read the Intergovernmental Panel on Climate Change (IPCC)’s most recent report (IPCC, 2007), although they had strong opinions about the topic. Whereas students demonstrated multiple times that they could critically approach an issue in the field course, and use their skill sets to solve a problem, they were not approaching informal discussions on climate change with a similar critical mind.
Therefore, we designed a semester-long activity to engage students, develop their critical analysis skills, and build an online community of learners which is often missing in online courses (Clary and Wandersee, 2012a). Because climate change was often in the news, we chose to implement climate change discussions in the online classroom. However, we used original source material, scientific reports, scientific summaries, and some data graphics (Figure 1).

Students in four sections of an online Earth History course (N = 84) were asked to complete a self-assessment on their climate change knowledge, and reflect on their opinions and sources of their information. Students were then randomly assigned into discussion groups (N = 8, with 10-14 students/group). For each unit, resources were provided, along with two critical thinking questions. Since our previous online experience revealed that students will not participate in the online discussion board unless it affects their grade, we made the Online Climate Discussions worth 10% of the final course grade.

Figure 1. Students accessed multiple resources for each unit discussion on climate change. Peer-reviewed scientific articles, scientific summaries, and graphs were made available, including the atmospheric CO$_2$ emissions detected at Mauna Loa Observatory. (Image courtesy of NOAA.)

For each of 11 units, students accessed posted materials, analyzed them, conducted outside research, and debated the issue with their colleagues. In the initial unit discussions, the instructor would parachute in with comments to clarify the qualifications of a quoted source. (For example, if a student quoted a famous movie star, the instructor would ask what the science background was of the movie star.) Students began policing their own discussion groups for non-scientific opinions. One interesting conversation arose in the general discussion forum on the merits and biases of peer review.
At the end of the semester, student groups were asked to develop a group consensus on climate change, noting minor positions if needed. The group consensus was developed with the input of all group members, and represented the majority opinions. Students were again requested to access the Climate Change Survey at the end of the semester, and they also offered anonymous course feedback in an end-of-semester survey.

The process was intensive, but resulted in critical analysis of the climate change topic. The majority of students ended the semester with a broader, more scientifically literate view of the topic as well as the nature of science (Clary and Wandersee, 2012a). By the end of the semester, 62% of students utilized peer-reviewed scientific journals as their information sources. Although anonymous survey responses revealed that some students were absolutely certain that the instructor was a leftist liberal, or a right-wing Republican, most students remarked that they appreciated the “balance of information” and the presentation, which allowed them to critically analyze the issue and form their own opinions.

The sustained discussions seemed to facilitate students’ self-reflection, critical thinking, and greater awareness of scientific methodology (Clary and Wandersee, 2012a). However, some students voiced displeasure that the climate change controversy had consumed the entire semester. Therefore, we investigated quarterly, 3-week discussion units, on topics of climate change, biodiversity and human impact, the Gulf Oil Spill, and the geologic time scale. The online discussion processes were similar, although with only a 3-week unit on climate change, a group consensus was not required. The 2011 students (N = 76) surprisingly reported less enthusiasm for a diversity of topics, and exhibited persistent, non-scientific opinions in the final examination questions probing their climate change knowledge (Clary and Wandersee, 2012b).

We concluded that quarterly, 3-week topics were insufficient as far as depth of topic to optimize scientific literacy and promote critical analysis (Clary and Wandersee, 2012b). However, we still searched for optimal discussion length to streamline the process, and provide more than one topic to alleviate the monotony of a semester-long discussion. In 2012, we attempted two topics of required discussions, using a streamlined version of the earlier climate change discussions, and biodiversity and human impact, as the topics for investigation (Clary and Wandersee, 2014a). Students (N=64) were placed in discussion groups, accessed and analyzed materials, conducted outside research, and responded to the critical thinking questions. Each topic was implemented over 6 units, with 5 units of source materials and critical thinking questions, and one unit for group consensus summary. Students accessed and completed the Climate Change Survey, and offered feedback in the anonymous End-of-Semester survey. Final examination questions again probed students’ content knowledge of the controversial issues discussed within their groups.

**Historical Controversy Case Study (HCCS)**

Not only is climate change a modern issue that can be controversial with some audiences, but there have also been former climate controversies. We realized that Louis Agassiz’s proposal of glacial theory was initially met with skepticism, and it was only after thorough investigations—and decades of additional research—that the majority of the scientific community accepted his hypotheses (Clary and Wandersee, 2014b). Many scientists in the mid-1800s rejected the idea of former Ice Ages, including Henry De la Beche, who served as the first director of what would become the British Geological Survey. De la Beche even drew a scientific caricature challenging
Agassiz’s claims in a humorous fashion (Figure 2). While De la Beche was resistant to Agassiz’s hypothesis, William Buckland exhibited several scientific habits of mind. Although Buckland was first resistant to Glacial Theory, he became swayed with the evidence he observed in the field (Clary and Wandersee, 2014b).

Figure 2: Henry De la Beche obviously disagreed with Louis Agassiz’s proposal of former continental glaciations. Here, he drew the Sun with an eye patch over one eye. Where the Sun’s eye is covered, glaciers are calving in the background. The foreground reveals a shocked De la Beche (on the left) viewing a tropical scene with three ape-like figures. (De la Beche collection, National Museum of Wales).

We developed the Historical Controversy Case Study (HCCS) in which we used historical controversies to develop students’ analysis and argumentation skills (Clary and Wandersee, 2013). Since these issues have played out in historical arenas, they are typically free of modern political spin, although students must learn to detect the cultural and social influences on the controversy at the time it was active. Case studies can make the assigned science content interesting and help students synthesize the material (Honan and Rule, 2002).

In the Historical Controversy Case Study (HCCS) model, the entire class is focused on one controversy. First the controversy is overviewed, followed by student investigation, argumentation, and finally resolution (Clary and Wandersee, 2013). Teachers briefly overview the controversy, and student groups ferret out details—including the supporting evidence, data, and details for a minimum of two positions. Evidence and data must have been available at the time the controversy emerged; therefore, modern DNA evidence would not be acceptable to demonstrate that the Piltdown Man’s skull originated from different primates. Following the investigative phase, new groups are assigned for argumentation, with each new group having a
member (and therefore a copy of the data, details, and evidence) from the earlier groups. The argumentation groups defend their positions, and the class evaluates the presentation, being particularly careful to point out data misinterpretation or “bad science” (Clary and Wandersee, 2013).

If new information has been made available since the controversy was active, the instructor can present this during the resolution phase. This illustrates how science restructures and reorganizes when new data become available. Some controversies, although historical, are still not completely resolved. Whether Richard E. Byrd and Floyd Bennett actually flew over the North Pole as they claimed rests on whether the men’s calculations were correct, with not all data recorded (Figures 3, 4).

Figure 3: Richard Byrd and Floyd Bennett claimed to be the first men to fly over the North Pole in 1926 in the Josephine Ford, which was named after the daughter of their benefactor. Although the controversy of whether they made the historic flight or not has not been completely resolved, the Ford Museum in Dearborn, MI presents both sides of the controversy. (Photograph EarthScholars Research Group)

One of the premier controversies in the history of science is the Cope and Mash “dinosaur wars.” The feud participants came from very different backgrounds: Cope was self-taught, with a wealthy family, while Marsh was educated, but poor with a rich uncle, George Peabody. When Marsh bribed workers at Cope’s fossil excavation site to send new finds directly to him, the controversy was off to a heated start. In what became the “premier soap opera of paleontology,” the participants played out their hostilities in a public arena, quick to point out each other’s mistakes. They even went to the extreme of dynamiting fossil sites to prevent their rival from collecting at the site! (Clary, Wandersee, and Carpinelli, 2008).
In order to test the effectiveness of the Cope-Marsh controversy in the classroom, practicing teachers (N = 16) enrolled in an online science graduate course were tasked with researching the controversy, and developing an activity for their individual classrooms to demonstrate the nonlinear progression of scientific investigations (Clary, Wandersee, and Carpinelli, 2008). Within one activity, which was implemented in a middle school science classroom, students were tasked to prepare a written indictment or defense rebuttal of either Cope or Marsh. Importantly, students learned to frame a persuasive argument and hone their argumentation skills, since listing facts is not enough to convince a jury or a judge.

Figure 4: Exhibits in the Ford Museum in Dearborn, MI, importantly present both sides of the historical North Pole flight, and allow visitors to make their own conclusions. (Photograph EarthScholars Research Group).

Teachers who anonymously reflected (n = 13) upon the Cope-Marsh controversy case study at the end of the semester noted that the history was important to convey the human side of science to students, and illustrate scientific integrity’s value. Although Cope and Marsh allowed personal vendettas to supersede methodology, mistakes were eventually corrected, and the science advanced. With this historical worst case scenario, students still realized that the underlying foundations of the scientific process were validated, while recognizing that not all controversies were the result of simple disagreement over interpretations—sabotage can sometimes be involved (Clary, Wandersee, and Carpinelli, 2008).

Modern Controversy Case Study (MCCS)

In a graduate level ethics and philosophy course at a large university in the southern US, students (N=14) received an introduction to the history and philosophy of science through Kuhn (1962), Latour and Woolgar (1989), and investigations into the history of science within their own specific disciplines. Armed with some background knowledge and understanding of how
philosophers, sociologists, and historians interpret scientific arguments and controversies, we next requested that students identify modern scientific topics to investigate, analyze, and discuss.

The Modern Controversy Case Study (MCCS) approach we developed required students to identify three current geosciences ethics concerns. (The most contentious topic our students suggested at the beginning of the semester was “gun control,” and we had vocal individuals on both sides of the debate. However, for classroom investigation we defaulted to topics that directly paralleled the disciplinary foci of our students—geosciences.) From the students’ lists, we compiled the most-often mentioned topics, and developed position statements for each of the top 6 topics (Table 1, Figure 5). Students were asked to rank each position statement from 1 (disagree) to 10 (agree). Before students ranked the position statements, however, we asked for further discussion of topics that should be on the ranked list, and were not included. The class identified and developed position statements for three other topics (Table 1, Figure 6). Students recorded their agreement with position statements, and ranked controversies in the order of perceived importance. The top three categories to emerge from the surveys were climate change, mining, and geoscientists’ responsibility to the public. The secondary ethics controversies to emerge were hydraulic fracturing, and dams.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Position Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>δ Hydraulic fracturing</td>
<td>Fracking provides economic recovery of fossil fuels and should be pursued.</td>
</tr>
<tr>
<td>*Climate change</td>
<td>Earth is experiencing unprecedented warming because of anthropogenic activities.</td>
</tr>
<tr>
<td>Coal extraction</td>
<td>Clean coal technology provides the most effective use of fossil fuel resources.</td>
</tr>
<tr>
<td>*Geoscientists’ responsibility</td>
<td>Earth scientists should have no responsibility/liability to the general public when they provide feedback and/or information about a natural hazard.</td>
</tr>
<tr>
<td>*Mining</td>
<td>When great reserves of minerals exist, they should be mined and reclaimed regardless of location.</td>
</tr>
<tr>
<td>Industrial regulations</td>
<td>There is no effective “safe limit” for humans and the environment when it comes to industry.</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Groundwater should not be subjected to state and federal regulations.</td>
</tr>
<tr>
<td>δ Damming of rivers</td>
<td>Dams are functionally useful and outweigh any negative impacts.</td>
</tr>
<tr>
<td>Geospatial data</td>
<td>All geospatial data should be in the public domain.</td>
</tr>
</tbody>
</table>

Each student (N = 14) was assigned to a leadership role in one of the 5 controversies, with students receiving a leadership role in either their first or second ranked controversy. Students were also assigned to research a position in all of the other 4 controversies in which they had not been assigned as leader. We tried to assign students to positions that opposed their ranked position statements. Group leaders of each controversy organized their 1-hour presentation and discussion, and online discussions often extended classroom conversations. The classroom presentation/investigation involved a variety of discussions, activities and debates, and both sides
of the controversy were always included. Students anonymously ranked group members in their perceived contributions (with all members’ percentages summing to 100%) to determine effort and effectiveness of the group members. An earlier established classroom policy was also utilized: for the assignment of classroom participation grades for each class session, students anonymously ranked their peers (Maznevski, 1996). They had to justify rating any individual student at “C” or below.

Figure 5. When students in a philosophy and ethics course were asked to identify controversies that presented modern ethical dilemmas, a popular topic was climate change. Students had to rank their agreement with the position statement, “Earth is experiencing unprecedented warming because of anthropogenic activities.” (Photographs of Briksdal Glacier, Norway, courtesy of Ximonic, Simo Räsänen)

At the end of the semester, we provided an opportunity for students to reflect upon the controversies we investigated. All students again ranked the level of agreement on the 5 position statements, reflected whether their concluding views were different than their original views, and further identified the most important resource for each topic. We compared students’ ranks before and after the investigations and discussions, and subjected responses to content analysis (Neuendorf, 2002).

Our ranked comparison and student reflections both revealed minor position movement on the position statements. One student remarked, “I think the discussion changed my perceptions a little bit; however it couldn’t turn over the tables [sic],” while other students acknowledged with additional research and investigation, s/he knew more about the counter arguments: “I think I may have moved down a little, the more evidence I have the more I’m compelled to think there is a responsibility” (for geoscientists’ responsibility controversy); and “I learned more about the topic and read about the benefits, whereas before, my knowledge had been limited to opposition arguments” (for hydraulic fracturing controversy).

Classroom benefits emerged from greater student understanding of both sides of the controversy. One student remarked that although geoscientists should be able to speak without legal accountability in interviews, “I do think professionals should be mindful of the people they
serve” (for geoscientists’ responsibility controversy). Likewise, another student noted, “I had read a book about the Corps of Engineers and the damming of the MS River, and it was mostly against it. However, I now think it can be done wisely, though I think some areas should not be dammed” (for the damming of rivers controversy).

Figure 6: Although not a topic of consensus importance, the damming of rivers arose during the classroom discussion of important controversies. Students voted it as one of the top five modern ethical concerns. The Gold Ray Dam featured in this photograph is on the Rogue River, Oregon. (Image courtesy Finetooth, Wikimedia Commons)

Results

Online Controversy Investigations

Semester-long, sustained discussions in an online environment resulted in students’ critical analysis of the multifaceted issue of climate change, and broader, more scientific understanding (Clary and Wandersee, 2012a). However, reducing the online discussions to only 3 weeks of focus on one controversial issue did not produce comparable gains; many students’ responses documented non-scientific opinions at the end of the semester (Clary and Wandersee, 2012b). It appears that critical examination of several issues throughout the semester is not as effective as in-depth examination of one issue. We also hypothesized that perhaps the group consensus activity, in which groups had to summarize and compromise their opinions, may have had positive benefits in that students reviewed and consolidated the content that had been discussed over the various units. This component was missing in our quarterly, 3 week discussions.

When we next attempted to optimize and streamline online discussions of controversial issues, we implemented 6 week units, and covered two controversies within the semester. The group consensus was required for each controversy, necessitating compromise and assimilation within
the groups. Similar to the first, semester-long investigation, the Climate Change Survey measured student content knowledge and opinions on climate change at the end of the course. The results of the Climate Change Survey were positive: students’ climate literacy with 6-week discussion implementation was statistically similar ($p = 0.05$), as measured by the Climate Change Survey, to students who had semester-long climate change discussions (Clary and Wandersee, 2014a). (There were some differences between individual questions’ scores, but the overall performance was similar.) The group consensus reports between the two groups were also similar.

Differences were noted between the two groups in application questions on the final examination. Whereas 95% of 2010 students scored at 90% or above on an in-depth essay question on climate change, only 47.5% of 2012 students achieved 90% or better accuracy. There may be multiple reasons for this, including lack of consistent scoring between two years, and/or cognitive differences in student populations between the two years. However, the 2012 student performance hints at a transferability issue when controversial topics were implemented within 6 weeks, instead of extended throughout a semester. Whereas the shorter discussion forums achieved content literacy, and student critical analysis of climate change was observed within the discussion forums, critical analysis was not observed for the majority of students outside the discussion forum, on a timed final examination (Clary and Wandersee, 2014a).

Both the 6 unit and semester-long discussions of climate change resulted in greater student understanding of the climate change issue’s complexity, and the identification of reliable, scientific resources (Clary and Wandersee, 2012a, 2014a). With only three weeks of discussion dedicated to the climate change topic, non-scientific opinions persisted (Clary and Wandersee, 2012b).

**Historical Controversy Case Study (HCCS)**

Our research with historical controversies resulted with fewer non-scientific, often media-influenced, opinions. We found that Historical Controversy Case Studies (HCCS) are typically free of a modern political focus, and can help students learn to recognize bad science within a respectful, low pressure environment (Clary and Wandersee, 2013). Students tend to enter historical controversy study investigations with fewer opinions and emotional ties to the subject. In addition to being an interesting venue in which to better understand the role of controversy and argumentation, historical controversies can also serve as a portal in which students learn how to research, assemble information, and hone argumentation skills. The methodology learned in historical investigations is more likely to be subsequently utilized when the classrooms turns its attention to more modern conflicts (Clary and Wandersee, 2013). Even historical arguments about climate change can support critical analysis and student understanding of the nature of science. Although Glacial Theory was once considered a radical hypothesis, it became accepted by the scientific community through additional data collection and analysis (Clary and Wandersee, 2014b).

**Modern Controversy Case Study (MCCS)**

Similar to the online discussion of controversial issues, we incorporated modern controversial issues—including climate change—within traditional classroom forums. Within our Modern Controversy Case Studies (MCCS) implementation, two stable themes emerged through content
analysis: 1) The MCCS was effective for deepening students’ critical analysis and effective argumentation of controversial topics; and 2) The MCCS facilitated student understanding of the nature of science, and the complexity of controversies as well as the scientific enterprise as a whole. Class research investigations more effectively honed student analyses of scientific issues, helped them learn how to approach data critically, and helped students develop evidence-based arguments. Students acknowledged that they learned through the process, and were able critically examine an opposing position in the controversy. With the controversial use of fracking, one student noted, “I still don’t feel like this is something we should do, but I feel like I know more about this issue. I had no idea how long this has been occurring or truly how much water was used.” Students overwhelmingly acknowledged that controversy investigations resulted in greater understanding of the multivariate nature of controversies, and greater awareness of the news media’s univariate dichotomies. The student identification, research, and discussion of popular controversies provided ownership of the modern controversies to the students, deepened their understanding of the nature of science, and increased their understanding of the complexity of the issues.

Research into opposing positions ensured students were better versed in the controversy in order to take an informed stance. As one student summarized, “Good idea to make us research the ‘other’ side! It was much more work but was a valuable learning experience.” Because students had knowledge of both sides of the controversy—their incoming position as well as the opposing argument—classroom discussions and arguments emerged from scientific positions instead of only raw public emotion. One student noted, “There were quite a few issues that I really did not know very much about, and the debates helped me to become better informed on them.” As a result, the classroom environment was a respectful one in which the controversial topics were investigated.

Students had a large vested issue in the controversies: they suggested the controversies, voted on the importance of each controversy, and had knowledge of both sides of the controversial issues by the end of the classroom investigations. Students also owned their presentations, and evaluated their peers’ contributions on the classroom discussions. A positive, unanticipated benefit of the Modern Controversy Case Study method was that several students’ opinions on group work was swayed from an incoming negative opinion to a more positive one. One evaluation at the end-of-semester stated that s/he “really liked the group-based format—more than I’ve ever enjoyed group projects. Think rating members may be the difference to ensure all members pull their weight.” Another student echoed the sentiment, and stated, “1st time I’ve ever enjoyed group work. It was very worthwhile + constructive.”

Discussion

While the EarthScholars Research Group investigated the role of controversy and argumentation within online classrooms and traditional, face-to-face classroom delivery, and with both historical controversies and modern ones, there are several consistent variables that are important in all venues, and which resulted in positive benefits for students’ critical thinking skills, broadened understanding of controversial issues, and increased understanding of the nature of science. Effective controversy inclusion utilized research-based argumentation, source monitoring, and broader awareness of the controversy, including its complex and multivariate nature.
All controversies involved *research-based* argumentation. In order to defend a position in a controversy, students needed evidence, and the evidence had to be scientific, and documented. While historical controversies were less likely to inspire emotional arguments since they were typically removed from public media’s focus, students investigating historical controversies still had to conduct research in order to defend their positions. While historical case studies required the identification of supporting information that was current at the time the controversy played out, the online discussions and Modern Controversy Case Studies (MCCS) necessitated current, more extensive research in scientific, peer-reviewed journals so that students could cite sources to justify an opinion (online discussions), or in the case of the MCCS, *counter* their original opinions in the classroom discussions.

One positive benefit that arose in all controversy implementation studies was *student source monitoring of databases and references*. Although instructors initially had to question some sources and the background of “expert witness testimony,” students quickly followed the instructor’s lead. Whether in an online environment or a traditional, face-to-face classroom, students learned to check their peers’ sources, and challenge whether a source was scientific.

All controversy research likewise documented students’ broader understanding of a controversy. Students in online discussions acknowledged a greater awareness of their peers’ backgrounds and alternative viewpoints; one student noted “This discussion exercise on climate change has enabled me to see multiple perspectives on the ‘whys and hows.’ Every question asked was a learning opportunity for me” (Clary and Wandersee, 2012a). Likewise, students who researched Historical Controversy Case Studies (HCCS) became aware of the differing opinions during the time of the active controversy, and the supporting evidence cited by each side. However, the most intensive investigation that broadened greater understanding of controversial issues was the Alternative Position Research used in the Modern Controversy Case Study (MCCS) approach. Whereas students had incoming opinions on controversial issues, their assignment to research the position *counter* to their opinion provided opportunities for increased understanding that many issues are multifaceted.

Other variables seem to be correlated with successful critical analysis, but more research is needed to confirm the associations. Within online discussions, the length of controversy discussion influenced students’ understanding of the issues. While 3-week units were insufficient, both semester-long and 6-week units resulted in greater content knowledge of the issue. However, greater transferability of the issue to new scenarios was observed within the semester-long implementation. More research is needed to determine whether transferability is associated with length and depth of discussions, as well as critical analysis abilities.

Similarly, use of group consensus reports, in which students must summarize the controversy’s elements and the general group conclusion, appear to positively influence students’ content gains and critical analysis skills. However, more research is needed to delineate the group consensus influence, and whether this is an artifact of discussion length.

With graduate student courses, the *student ownership* in the controversies appears to positively influence critical thinking skills. Although we had not allowed students to choose historical or online controversies, the identification, discussion, and presentation of the top five modern controversies in the traditional graduate course were determined solely by the student population.
(With the online discussions, two controversies studied in 2013 were determined by survey of students in the 2012 course; however, students were allowed only to vote on their top choices among the 4 topics investigated.) Students were notably positive with the process, and affirmed that the control over the topics—as well as their feedback on their peers’ contribution—greatly contributed to the success of the process. Whether this method can be tailored and replicated within undergraduate courses, and whether the results will be similar, remains to be determined.

Controversy has an important role in college science classrooms. John Dewey (1922) wrote, “Conflict is the gadfly of thought. It stirs us to observation and memory. It instigates to invention. It shocks us out of sheep-like passivity, and sets us as noting and contriving . . . conflict is a ‘sine qua non’ of reflection and ingenuity” (p. 300). Johnson (1989) similarly noted that “controversy is the life blood of science.” We affirmed that using controversy as a vehicle to model effective argumentation and critical analysis has yielded numerous student benefits in our science courses, in online and traditional delivery venues, and with historical, as well as modern, controversy case studies. Additional research should help science instructors optimize the benefits to our students, and help them exit our science classrooms with improved understanding of the nature of science, communication skills, and critical thinking abilities. Our science classrooms are moving beyond the mere recitation of memorized material, and it is beneficial for our students.

References


Abstract

This essay describes the benefits of participating in a Critical Friends Group (CFG), a form of Professional Learning Community (PLC) that can be an effective forum for faculty to discuss and receive feedback on innovative teaching. Formed after a collaborative project to develop and facilitate a workshop for middle and high school teachers on Common Core State Standards, college faculty across several disciplines (from STEM and Humanities) found value in forming their own PLC and use of the CFG protocols to enhance their teaching effectiveness and scholarly output.

Introduction

It is 9:45 on a Monday morning. University faculty and students are busy going to classes and committee meetings, and preparing for the challenges of a new week. From different departments across campus, a group of faculty is trying to tie up loose ends in order to get to a meeting in the Department of Education. Seven faculty members arrive in staggered fashion to a small conference room. Faculty from Biology, Chemistry, Mathematics, English, and Education gather around a conference table, engaging in small talk about family, weekend activities, and a faculty member’s sabbatical projects. At 10:00, one faculty member alerts the group that it is time to start. Everyone quiets down immediately. This faculty member welcomes her colleagues to their monthly Critical Friends Group and gets the team moving through a “tuning protocol” that establishes the structure for their 50 minute meeting.
Cooking, gardening, eating, and the scholarship of teaching and learning brought this team together. The genesis of the group was a collaborative effort to develop and facilitate a summer workshop for middle and high school teachers on integrating English Language Arts with STEM courses using the themes of gardening and cooking. During the workshop, the faculty demonstrated model lessons, relying on pedagogies that they use in their college courses to foster interdisciplinary collaborations, incorporate a variety of texts, and work with integrated curricula. During the workshop, the faculty also modeled and used a particular form of a Professional Learning Community (PLC) called Critical Friends Group (CFG) to encourage middle and high school teachers to work together across disciplinary lines.

A serendipitous outcome of the faculty members’ collaboration on the workshop has been the development of their own ongoing PLC. Following the workshop, they started meeting as a CFG to foster their own teaching and professional development. Along the way they have discovered that, just like gardening, cooking, and eating, innovative teaching requires an element of risk-taking. One way to mediate that risk is to be part of an interdisciplinary CFG. This paper will provide a brief summary of the workshop and a description of CFG. Specific examples from the group will demonstrate how they have used CFG to enhance their teaching. Finally, the use of CFG to enrich professional development and function as a model of peer review will be discussed.

**A Gardening and Cooking Workshop: Improving Teacher Quality**

The project that served as the impetus of this work began as a collaboration of the Departments of Biology, Chemistry/Physics, English, and Education jointly with the Local Education Agencies of five diverse K-12 school districts, including both rural and urban districts. This collaboration was funded by the Tennessee Higher Education Commission to provide training on the Grade 6-12 Common Core State Standards (CCSS) in Reading: Literature and Informational Text as well as the Grade 6-12 CCSS in Literacy in Science & Technical Subjects. The themes of gardening, food, and cooking were used as the models to demonstrate how school gardens and food-related topics can enhance learning in both English and science courses and how collaboration can enhance student achievement (Edible Schoolyard Project, 2015; Nashville School Garden Coalition, 2015). The workshop focused on improving competency for participants in each area, harnessing the expertise of both science and English teachers to build PLCs using CFGs (National School Reform Faculty, 2014). The specific workshop objectives focused on teacher participants:

1) increasing knowledge of the CCSS 6-12 Reading: Literature and Informational Text Standards and their connection to the CCSS 6-12 ELA Standards in Science & Technical Areas;
2) increasing knowledge and instructional skills in the pedagogical areas of questioning, academic feedback, thinking, and problem solving;
3) applying increased knowledge (from objectives 1 & 2) to develop gardening and food-related lessons and materials using complex informational texts and appropriate pedagogical practices in science and English classes; and  
4) engaging in meaningful dialogues about cross-curricular planning within a CFG framework in at least four cross-disciplinary CFG sessions during AY 14-15.

Because the project brought together K-12 teachers from varying disciplines, it was important to familiarize all teachers with the CCSS in an engaging and non-threatening way. Each day of the workshop began with an interdisciplinary model lesson that connected two disciplines (e.g., Chemistry and English; Biology and English), with the K-12 teachers participating in the lessons as students and exploring disciplines other than their own in a comfortable environment using interactive, hands-on lessons. The lessons included food-centric activities like cheese tastings, creating cheese from milk in the chemistry lab, making pita bread, and using a botany key while assembling salads for lunch. Implementing an engaging, cross-disciplinary theme helped create an environment for all teachers to tackle the CCSS, a subject often seen as intimidating, as well as explore topics that were outside of their traditional teaching expertise.

Following the model lessons, deeper pedagogical study allowed participants to examine the problem solving and critical thinking processes that took place as a result of the lessons. Teams of teachers worked across disciplines to examine the use of thinking routines (Ritchhart & Church, 2011) to create a common language for critical thinking across disciplines. Exploring the processes of critical thinking can be daunting when tackling the process within one’s own discipline, and this workshop pushed participants to examine pedagogies not only within their own classroom but across their colleagues’ classrooms as well.

The participant teachers demonstrated a high level of enthusiasm in tackling the difficult elements of teaching across their disciplines. A key contributing factor, and perhaps the most significant aspect of the workshop, was the way in which the teachers came together across disciplines to form PLCs. A critical element that facilitated the creation of the PLCs was the instruction and use of CFG protocols. Using the CFG framework was just one of the objectives of the workshop, but it proved to be the cement that held the other objectives together.

Critical Friends as a Professional Learning Community

Teacher roles and responsibilities are changing with increased emphasis on accountability for student outcomes at both K-12 and college/university settings. Consequently, the idea of PLCs has spread in recent years with an emphasis on teacher-directed school improvement focused on improving practice and student outcomes (Curry, 2008; Vescio, Ross, & Adams, 2008). Professional Learning Communities are based on two key assumptions. First, teacher knowledge that is connected with classroom experiences is best explored and understood with others who have similar experiences. Second, teacher professional knowledge and student learning will increase when educators are actively involved in learning communities (Vescio et al., 2008).
As an initiative by the Annenberg Institute for School Reform and the National School Reform Faculty, a Critical Friends Group (CFG) is one method for educators to become engaged in professional development through a PLC. Within the context of CFGs, a critical friend is described as a “trusted person who asks provocative questions, provides data to be examined through another lens, and offers critiques of a person’s work as a friend” (Costa & Kallick, 1993, p. 50). Critical Friends Groups are different from traditional PLCs in that they provide specific norms and protocols for how meetings should proceed. Norms are the behavioral expectations or guidelines for group member behavior and participation. Protocols are structured guidelines or steps designed to support an efficient meeting that involves an honest and meaningful dialogue (National School Reform Faculty, 2014). Norms and protocols provide processes that are structured and efficient while supporting reflection and equitable participation of all CFG members. Research suggests that CFGs foster collaboration and communication, improve teacher professionalism, and can potentially change the thinking and practice of a teacher and impact student achievement (Fulton & Britton, 2011).

With the supporting structure of norms and protocols, educators can come together within a CFG to accomplish different goals, such as presenting a lesson in progress for feedback, examining student work for evidence of learning, or discussing a classroom-based incident. A CFG is usually a group of 6 to 12 people (National School Reform Faculty, 2014). Each group meeting has a facilitator and a presenter with the rest of the members participating in the processes. At the beginning of a CFG meeting, typically one person presents an overview (e.g., of a lesson being developed) that includes a focusing question addressing a specific aspect of teaching and learning. Examples of questions may include “How can I make this task more relevant and engaging?” or “What evidence do I have in this assessment that demonstrated student understanding or lack of understanding of …” or “What assessments will help me evaluate my learning objective?” Using a specific protocol, the CFG then engages in non-evaluative questioning, quiet reflection, discussion, and warm and cool feedback to address the presenter’s question. For an example of an interdisciplinary CFG, see https://www.teachingchannel.org/videos/reflection-on-student-work-ntn. For the purpose of the summer workshop and resulting faculty interdisciplinary PLC, faculty used a “Tuning Protocol” following the process outlined in Table 1 (National School Reform Faculty, 2014).

Table 1

<table>
<thead>
<tr>
<th>Event (Time)</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction (1 min)</td>
<td>Facilitator introduces protocol</td>
</tr>
<tr>
<td>Presentation (5 min)</td>
<td>Presenter shares focusing question and context</td>
</tr>
<tr>
<td>Clarifying Questions (2 min)</td>
<td>Participants ask questions to presenter to get more information</td>
</tr>
<tr>
<td>Individual Writing (3 min)</td>
<td>All take notes and write down ideas</td>
</tr>
<tr>
<td>Feedback to Presenter (6 min)</td>
<td>Participants provide warm and cool feedback to presenter, who remains silent</td>
</tr>
<tr>
<td>Reflection (5 min)</td>
<td>Presenter reflects aloud on feedback, participants remain silent</td>
</tr>
<tr>
<td>Open Conversation (5 min)</td>
<td>All discuss and extrapolate from the feedback and reflection</td>
</tr>
<tr>
<td>Debrief (3 min)</td>
<td>Facilitator closes session with summary</td>
</tr>
</tbody>
</table>

134
CFGs Encourage Innovative Teaching

In addition to providing a structured and efficient process for receiving respectful feedback on teaching, a CFG creates a safe place for faculty to explore the risks that come with innovative teaching. The nonjudgmental approach of the protocols results in less anxiety, a key factor if faculty feel vulnerable when describing a new lesson, failed assignment, or difficult classroom situation.

While CFGs do not have to be interdisciplinary, there are additional benefits to having a team composed of faculty from different academic areas. The perceived repercussions of exposing the risks associated with trying something different in teaching seems less precarious when exposed to faculty outside of one’s department. Also, perspectives from other disciplines can shed new light on innovations while surfacing naïve questions from colleagues less familiar with the content. New insights and shifts in focus from colleagues in other fields can encourage and push innovative teaching in unanticipated directions. Recognizing that all participants in the CFG bring an element of expertise to the discussion, members of the team develop a greater appreciation for and valuing of the work of colleagues in other disciplines.

Specific examples in which members of this team have been influenced by participation in the CFG include the following:

- The English professor was developing an experiential writing exercise that asked her students to be a “flâneur” (the French term for a walker who walks without a destination) as a way of paralleling the practice of informal writing. This sort of exercise would be considered risky in her home department since it asked students to do something (walk without purpose) that did not “look” like a typical English class. Presenting the draft assignment in the CFG meeting helped the professor tweak the assignment and gave her the confidence to try something new and uncertain.

- The chemist was developing a lesson on acids and bases using a variety of plant materials as indicators. After presenting the lesson at a CFG meeting using a tuning protocol, she was able to renovate the lesson to make it more accessible to K-12 students and teachers as well as broaden it to incorporate aspects of the liberal arts.

- An education professor in a K-12 teacher preparation program felt an increased responsibility to prepare teacher candidates for working in interdisciplinary teams after being part of the CFG. Through participation in the CFG, she was more prepared to speak to the risks and rewards that come about organically as teachers work with colleagues to develop integrated curriculum. Teacher candidates can hear firsthand about collaborating across disciplines, implementing lessons together, and
reflecting on the process through the use of a CFG protocol. Teacher candidates gain insight into what they will experience as first year teachers and what they can expect as they begin planning with teachers in other content areas.

- The biologist developed a rubric for reflective essays, a style of writing not often used in science courses, to assess service learning projects in biology and environmental science courses. She also revised a laboratory activity to incorporate a thinking exercise called “See Think Wonder” (Ritchhart & Church, 2011), where students hike at a local park and intentionally observe nature using a set of guiding questions. Feedback from the CFG provided feedback on and support for these changes in her teaching.

- A CFG group can be used also to affirm the practices that teachers are implementing. One of the education faculty questioned the relevancy and efficacy of an assignment and brought it to the CFG. The assignment had been a departure from what had traditionally been implemented in the course, and the instructor was starting to question the risk taken with this new assignment. She feared that this potential innovation was a futile exercise with her students. Feedback from the CFG helped her create more specific guidelines that kept the new assignment in place and gave her the confidence to continue to push her students to remain engaged in the assignment. Sometimes innovative teaching needs to be revisited for both adjustments and affirmations, and the CFG provided just that support for innovation.

- Collaborating in an interdisciplinary CFG can provide support when developing plans for future lessons as well. In a newly taught mathematics teaching methods course, apprentice teachers will explore counting and arithmetic in a different number base. Although exploring different number bases is a frequently used practice among mathematics educators for pre-service teachers (Danielson, 2010; Hopkins & Cady, 2007; Zazkis, 1999), few reports exist chronicling how the teachers express their changing emotions during the experiences. The apprentice teachers will write a reflection about their experiences, in addition to describing the mathematical activity. As part of a Writing Across the Curriculum initiative, a chemistry and an English professor will support the implementation of the writing activity for the mathematics teaching methods class. In the early planning stages, the professors within the CFG provided feedback on the quality of the draft writing prompts. As the lesson transitions from planning to implementation, the CFG colleagues will provide an additional set of feedback to create a meaningful learning experience for the apprentice teachers, extending this activity beyond what is in the established literature.

**Unanticipated Outcomes of a CFG**

In addition to being a safe place to explore teaching, a CFG can also provide an opportunity for professional development in other areas. This particular CFG frequently exchanges articles, books, and websites that relate to cooking, gardening, eating, and teaching that are relevant to their different disciplinary areas. Team members also forward along materials on other topics that will be of interest to colleagues in the CFG, thus expanding opportunities to expose students to a wider variety of resources. The team has developed numerous conference presentations and
papers, scholarly opportunities that may not have been available had they not been meeting as a CFG. Additional opportunities to connect with STEM teachers and to promote STEM-Humanities connections will further serve to foster innovative teaching and scholarship.

An additional unanticipated outcome of this CFG is the development of new teaching and research initiatives. As a result of working at the intersection of humanities, education, and STEM-fields, several faculty became interested in looking at the current status of STEM literacy of a broad group of students at their own institution. Faculty from mathematics, English, and chemistry jointly designed a research project that was presented to the CFG for feedback. Although the project is still in the planning stages, it will utilize a common STEM problem to assess a variety of essential learning outcomes, including quantitative literacy, written communication, and critical thinking. As the students being assessed will range from freshman, non-majors to graduate education majors, this information will be a good indicator of the current status of STEM literacy. This faculty group plans to use this initial study to contemplate future STEM literacy projects.

An important outcome of the CFG has been its incorporation into the broader discussion of peer review on this group’s campus. Traditionally on campuses across the country, faculty professional development occurs through orientations and campus-wide workshops. However, there has been a shift toward collaborative learning to facilitate processes for “continual improvement in university pedagogy” (Moore & Cater-Hicks, 2014, p. 1). As such, PLCs are being implemented within this paradigm shift (Moore & Carter-Hicks, 2014), and the CFG format has now been recognized by this group’s university as an acceptable model for meeting the requirements for the university-required peer review With the use of CFGs, the professional growth of faculty becomes a positive routine, supporting the perspective that “the best staff development happens in the workplace rather than in a workshop” (DuFour, 2004, p. 63).

**Final Thoughts on Risk and Innovation**

Innovative teaching requires a high degree of risk-taking and comfortableness with failure (Louis, Marks, & Kruse, 1996). One way to build the necessary confidence for experimental teaching is to belong to a community of reflective practitioners such as an interdisciplinary Critical Friends Group. The faculty collaboration described in this paper exemplifies collective work in a trusting environment that has facilitated inquiry and reflection, intentionally taking risks to address dilemmas in their own practice with an emphasis on improving teaching and student outcomes (Ball & Cohen, 1999).

*It is 9:45 on a Monday morning. Faculty from Biology, Chemistry, Mathematics, English, and Education gather around a conference table. At 10:00, one faculty member welcomes her colleagues to their monthly Critical Friends Group and gets the team moving through their “tuning protocol.” The presenter begins, “I want to create an assignment for my ethnobotany
course in which students create a photojournal for their final project. But I need help developing the details and connecting the assignment to the course goals..."
References


CHAPTER 4
Students Learn, You Save Time: The Exam Rewrite Option

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Abstract

I have used an optional exam rewrite as a way for students to learn from mistakes on exams, and earn back some missed points. They can rewrite up to 20 missed points, in considerably more detail than required for the actual exam, and earn back a maximum of ten points that are added directly to their grade. An assessment of the exam rewrite option in Spring 2014 showed that most students in three classes (79-96%) took advantage of the option to improve their grade (average improvement 7.5-9.2 points). Students overwhelmingly liked having that rewrite option available to them (>4.98 on a scale of 1-5) and strongly agreed that they learned from doing the rewrite (>4.5 on a scale of 1-5). I find that I actually save time grading because I expect the students to correct their mistakes, so I write very few corrections on exams.

Introduction

As educators, we have long recognized the advantages of rewriting or revising writing as a way to improve. If you cannot explain an idea clearly, you probably don’t understand it (McMillin, 2012). Most undergraduate majors require a writing intensive course that includes revision as a graduation requirement. On my campus, this course is known as an Advanced Writing Requirement. AWR courses require peer review and opportunities for revision. The course objectives are (AWR 2014):

1. Students will demonstrate the ability to synthesize ideas in writing.
2. Students will articulate clearly in writing concepts relevant to a particular discipline.
3. Students will use writing to communicate ideas to someone outside that particular discipline.
4. Students will demonstrate in their writing mastery of the basic rules of English or of some other spoken language.

Just as rewriting can lead to better writing and improved understanding, I have applied rewrites to exams as a way of improving student learning.

I used to spend many hours on grading student exams, writing in corrections, edits, suggestions and so on. But I was always frustrated by it because the students had no reason to learn from their mistakes, or even to read my carefully crafted responses. I began offering students optional exam rewrites as a way of turning exams into learning opportunities, and giving them a way to earn back some missed points. Along the way, I have learned that the students do learn from doing the rewrites themselves and that I actually spend less time now on grading. Since I expect them to find and correct their own errors, I write very little on exams. The rewrites are actually easy to grade; since they should be looking up the answers, they are usually correct, and do not
require me to write on them beyond noting the number of points earned back. Another advantage is that I seldom have to scale an exam; the rewrites do that for me for the students willing to take the initiative.

What I do write on exams is very minimal. I circle the correct answer for multiple choice questions, x-out wrong answers for short answer/matching/fill in, and for essays I indicate the part or parts that are wrong, and sometimes offer a hint by writing in a word or two to help focus their rewrite.

**Process**

Instructions are given to students on the syllabus, and I also review the instructions using specific examples from their first exam, after I return the graded exams. An example of instructions and specific examples is given below.

**Directions for Optional Exam Rewrite**

1. Rewrites are due one week from the date exams are returned or as announced.
2. Do your own work. You will probably have to look up answers; if you did not know the answer the first time, you probably still don’t know it. It takes work to get back the maximum number of points.
3. You may rewrite any questions or questions you choose for up to ½ of the points missed to a maximum of 20 points missed. Maximum points earned back can be +10. There is no guarantee of points. I begin grading with the first answer you present, and will not grade more than 20 points.
4. You may begin with any type of question; essay, multiple choice, or short answer. Answer questions you select sequentially by section. You do not need to copy the question, but clearly indicate the question number. Do not simply repeat the question and answer.
5. Attach your exam to your rewrites. Earned points are added directly to your exam score.

**Multiple Choice.** (All worth two points)

You have to explain what the correct answer is, and explain the real meaning of the wrong answer chosen. (There may be some exceptions, for example on pH, when all choices are variations of the same answer, then one explanation will suffice.) Give more than the minimum glossary response, and don’t just repeat information in the question.

1. The function of a control in an experiment is to:
   a. measure the amount of each chemical
   b. provide an alternative hypothesis
   c. hold temperature constant
   d. reduce the number of variables

Ex. The answer is d, let’s say you chose b. You would have to explain what is meant by controls and variables, and explain what an alternative hypothesis is and when you
would develop one. Choice c is an example of a control, not the function of a control. Answering “The function of a control in an experiment is to reduce the number of variables” earns no points because it just repeats the question.

Short Answer/ Fill-in/Matching.
You have to provide much more information than you would have done on the original question. One word answers are not enough on the rewrites.
1. Which Kingdom(s) have chloroplasts:

Ex. Say you answered K. Plants and K. Fungi. You would now have to add algae from the Kingdom Protist and explain that the fungi are non-photosynthetic.

Essay. Focus on the portion of the question you missed.
1. Life is limited by the availability of liquid water, as evidenced by the differences between a desert and a rainforest. a) Sketch the relationship between rainfall and species diversity. b) Is this an example of a positive or negative relationship? c) Is this a cause and effect relationship? (5 pts)

Ex. If you drew the graph correctly, but guessed wrong on whether it was a + or – relationship, select the correct one and explain it in more detail.

Attach your exam to your rewrites. Earned points are added directly to your exam score.

Assessment
I collected student feedback on the rewrite option in my classes from Spring 2014. The three classes were:

- **BIO202 Introduction to Microbiology.** A large, non-lab Microbiology course taken by nursing majors and as an option in General Education. n=79
- **BIO387 Pathology.** was a new course taught to senior Biology majors as an elective. n=19
- **BIO407 Immunology.** is a lecture course required of all Medical Technology majors and taken by Biology majors as an elective. n=24

An analysis of the grade reports (Tab. 1) showed that in all classes close to 80-95% of students took advantage of the exam rewrite option. The grade they earn on the rewrite is added directly to their exam score. Points awarded ranged from 0-10, with most students scoring at least 6.5 points. When asked about the usefulness of the Exam Rewrite Option (Tab. 2), nearly every student in every class thought it was useful, and the great majority of them felt they had actually learned some course content by doing the rewrites. On occasion, I will repeat a question from an earlier exam that most of the students missed the first time, and even though we did not review that material again, more students got the correct answer the second (or third) time around. I do offer the rewrite option on the 4th exam as well, but let students know if the rewrite will have any effect on their grade, so most of them do not do the rewrite; those results are skewed and I did not present them here.
Table 1. Proportion of students who used the exam rewrite option and their average points earned back.

<table>
<thead>
<tr>
<th>Course</th>
<th>% students rewrite 1st exam</th>
<th>Avg points 1st exam rewrite</th>
<th>% students rewrite 2nd exam</th>
<th>Avg points 2nd rewrite</th>
<th>% students rewrite 3rd exam</th>
<th>Avg points 3rd rewrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIO202</td>
<td>94%</td>
<td>7.5</td>
<td>95.3%</td>
<td>6.7</td>
<td>93%</td>
<td>6.6</td>
</tr>
<tr>
<td>BIO387</td>
<td>84%</td>
<td>8.7</td>
<td>89.5%</td>
<td>8.5</td>
<td>89.5%</td>
<td>7.65</td>
</tr>
<tr>
<td>BIO407</td>
<td>83%</td>
<td>8.4</td>
<td>79.3%</td>
<td>8.1</td>
<td>79.2%</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Table 2. Student opinion survey responses to the Exam Rewrite option questions, and response options.

<table>
<thead>
<tr>
<th>Course</th>
<th>n</th>
<th>The Exam Rewrite opportunity was useful. 1=SD---5=SA</th>
<th>How much did you learn from doing Rewrites. 1=Nothing—5=A lot</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIO202</td>
<td>79</td>
<td>4.987</td>
<td>4.684</td>
</tr>
<tr>
<td>BIO387</td>
<td>19</td>
<td>5.0</td>
<td>4.526</td>
</tr>
<tr>
<td>BIO407</td>
<td>24</td>
<td>5.0</td>
<td>4.727</td>
</tr>
</tbody>
</table>

Conclusions

I recommend you try using the exam rewrite option as a way of turning exams into learning experiences and saving time on grading. I have gradually evolved the process over time. I originally let them rewrite all the points they missed, but that proved to be a lot of work, and I felt students were using the exam rewrites to make up for a lack of studying. Students genuinely like having the opportunity to earn back some missed points and improving their score on exams, despite the significant amount of work it takes them to do a good job. Please contact me if you have any questions.

References


Let them see light

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Introduction

One topic that is a standard in a general biology course is photosynthesis. This involves explaining how visible light from within the electromagnetic spectrum (Figure 1) can be transformed into chemical energy. The range of this electromagnetic spectrum is wavelengths measuring from $10^{-14}$ to $10^4$ meters. In fact, as humans, we are only able to visualize the wavelengths within a very narrow range, that being approximately 380 to 750 nanometers (Molecular Expressions). Any wavelengths on either side of this range are invisible to us. Wavelengths can range in distance from a nanometer for gamma rays to over a kilometer for radio waves (Figure 1) (Wikiversity).

![The Electromagnetic Spectrum](https://www.science3d.org/sites/default/files/The-Electromagnetic-Spectrum.jpg)

Figure 1. Electromagnetic spectrum, with visible light being between approximately 380 to 750 nanometers. Image retrieved from https://www.science3d.org/sites/default/files/The-Electromagnetic-Spectrum.jpg

The sun emits the full electromagnetic spectrum; it is a thin band of visible light found within the electromagnetic spectrum that drives photosynthesis. But which visible light wavelengths are the best at driving this process of photosynthesis? We know that when light hits matter it is reflected, transmitted or absorbed. For photosynthesis to work, light must be absorbed. It was
German botanist, Theodor W. Engelmann that first revealed this in his 1883 experiment, he also determined the wavelengths of light that were needed for photosynthesis (Campbell Biology). He concluded that wavelengths found within the violet-blue and red electromagnetic spectrum were most important for photosynthesis. Light is absorbed by three different chloroplast pigments: chlorophyll $a$, chlorophyll $b$, and carotenoid (Figure 2). Chlorophyll $a$ is the most abundant in photosynthetic plants and absorbs light at wavelengths of 430 nm and 662 nm; chlorophyll $b$ absorbs light at wavelengths of 453 nm and 642 nm; finally carotenoids absorbs light at the wavelengths of 460 nm and 550 nm (McDaniel).

![Figure 2. Light absorbed by the chloroplast pigments and their corresponding wavelengths.](http://www.uic.edu/classes/bios/bios100/lectures/absorption-spectrum.jpg)

One of the challenges of teaching photosynthesis to general biology students is this whole idea of how white light is broken down into individual colors, each color with their own wavelength. As educators, we know that there are different learning styles (seven in all) and that most everyone has a mixture of these learning styles (Learning Styles). The visual learner needs to ‘see it to believe it’, this learner benefits from using colors, images, and maps to help organize their thoughts and to also communicate their thoughts/ideas to others. This activity is an easy one that best benefits the visual learner. Simply stated it takes the visible light and breaks it down into its individual colors.

**Activity**

Prior to the activity, each student in a Bio 101 General Biology lecture (~100 students) was surveyed with the following three questions: 1. What is the range in nanometers of visible light? 2. What light source (besides sunlight) provides a full spectrum of color? 3. What wavelengths are the best for photosynthesis? Additionally, each student was given a diffraction grating slide (Figure 3), which is used for determining the spectra from a variety of light sources. These diffraction grating slides are an inexpensive choice for activities and experiments pertaining to examining light and color. As light goes through the diffraction grating slide, it breaks the light down into the individual visible colors.
Finally, the students were also provided a copy of the visible portion of the electromagnetic spectrum (Figure 1) and the visible spectrum from a variety of light sources to use as for reference (Figure 4).

Most, if not all students have a cell phone, iPad, and/or digital camera that are capable of taking pictures. The students were instructed to take before (without the diffraction grating slide) and after pictures of artificial light sources that they selected. The ‘after’ pictures were taken by merely putting the diffraction grating slide in front of the lens of the cell phone, iPad, or camera (Figure 5). As a class, the students tested and provided examples of a wide collection of light sources which demonstrated a range of spectrums.
Besides submitting the before and after photos, each student was also required to provide a
title under each photo describing the light source (for the ‘before’ photo) and their thoughts on
the individual visible colors that were present or missing for the ‘after’ photo. In addition to
giving the students the requirements for this assignment, it was stressed that each student had the
freedom to push his/her creativity in regard to the selected light sources and how to photograph
them.

Results

A range and variety of pictures were taken for this assignment. For example, Figure 6 shows the
before and after pictures of a burning candle. The ‘after’ photo was very telling in revealing the
individual colors that were present. When one looks at the flame of a candle, it’s assumed that it
only emits yellow light, but here it can be seen that much of its light was in the orange-red
wavelength (600-700 nm).
Another example of a photographed light source was a bunch of Christmas tree lights (Figure 7). As seen from the photo, most individual bulbs from this photo did not produce a full spectrum of colors.

Figure 8 illustrated the before and after photos of a Cool White LED light source. The color spectrum for this light source was provided as an example in Figure 4. These Cool White LED lights clearly showed that they favored the 400 nm to 550 nm wavelengths by the heavy presence of the blues and greens in this picture.
Figure 8. Before (left) and after (right) pictures of a Cool White LED light source.

A final example of photos taken before and after using the diffraction grating slide is shown in Figure 9. These photos were taken of fish within a fish tank at a depth of 45 centimeters. In this example, not all the colors of the visible spectrum were present (Figure 9, right photo).

Figure 9. Before (left) and after (right) photos taken of a 75 gallon fish tank at a depth of 45 cm.

Discussion

Students were given one week to complete their task and as a result provided a wide scope of images. They seemed to enjoy this activity to the point where a photo competition was put into place. Any student could submit their photos into this competition, where they were posted for their classmates to view. The students could vote for the best photos (before and after shots), the top five vote getters were determined. A committee of several faculty members determined the top three photos. Finally, the students were given the same three questions they were given prior to the start of this activity: 1. What is the range in nanometers of visible light? 2. What light source (besides sunlight) provides a full spectrum of color? 3. What wavelengths are the best for
photosynthesis? Overall, the students had great improvement with their answers; I guess they did ‘see the light’.

References


Critical thinking is really an art. It is the art of analyzing and evaluating. It involves Bloom’s (1966) highest levels and it is something we all strive for in our student populations. Bloom provides a hierarchical taxonomy of learning objectives from the accumulation of knowledge, to comprehension, application, analysis, synthesis and evaluation. Critical thinking demands clarity, accuracy, relevance, depth, breadth and significance. These are the intellectual standards and they really need to be taught in every classroom.

There is a lot of evidence that active, collaborative activities engage students and have a positive impact on learning. A list of the characteristics of the best course designs include: clear and challenging goals, a hands-on approach, real-world application, focus on important and interesting ideas, feedback systems, personalized approach, clear modeling, reflection, variety of methods, safe environment for taking risks, teacher as facilitator, immersion experience, big picture and flow from parts to whole (Angelo and Cross, 1993).

With this in mind, the writers of this submission designed and taught an online course using Steven Johnson’s book, *The Ghost Map: The Story of London’s Most Terrifying Epidemic and How It changed Science, Cities, and the Modern World* (Johnson, 2006). The book is a page turner, a detective chronicle and a tribute to life in a city, then and now. The primary goal for the course was to prepare students to answer the essential question, “What is it that changed science, cities and the modern world.” Johnson writes a most compelling account of London’s cholera epidemic of 1854. His ability to develop a line of reasoning and explanation is a slate for his intellectual integrity. He is a writer’s writer.

It was a challenge to see how these submission writers could maximize the impact of this trade book and allow students to be responsible for their own learning. The following information tells our story as it is woven into the tapestry of Johnson’s story. This monograph is dedicated to innovation. The word is used to highlight the course components.

**INNOVATION:** We use the I for interdisciplinary. Research indicates that students really prefer self-directed and collaborative environments with a teacher presence. Our module structures needed to be: task oriented, participation driven and collaborative (Park & Mills, 2014). The online course had 15 modules with foci on the 9 chapters of Johnson’s book. Mahoney and Brown (2013) support positive results from using an interdisciplinary approach such as thoughtful consideration of each discipline, the transferring of concepts and methodologies between disciplines and improving student enthusiasm. The course addressed the following disciplines: biology, microbiology, mathematics, technology, engineering, history,
sociology, public health, cartography, forensics, English language arts and geo-mapping. There was a strong emphasis on interactions of the disciplines (Park & Son, 2010) highlighting topics with which to solve problems. In retrospect, the students showed higher levels of intrinsic motivation, engagement and task values (Stolk & Martello, 2015). Students actually reported higher use of critical thinking skills. Drake (2012) suggests that multidisciplinary, interdisciplinary and transdisciplinary approaches assist students in connecting essential questions to broad and enduring understandings in a wide range of academic fields. The objectives for the interdisciplinary modules are seen in table 1.

Table 1. Module Objectives

<table>
<thead>
<tr>
<th>Students will:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• reflect on the health problems encountered by city residents as London grew in order to assist them in their ability to perceive why London was chosen as a protagonist.</td>
</tr>
<tr>
<td>• analyze the development of scientific understanding to evaluate the data used in recognition of cholera's mode of transmission and point of origin in the 1850's epidemic.</td>
</tr>
<tr>
<td>• assess the 'human characters' to develop an interpretation of cholera's control.</td>
</tr>
<tr>
<td>• explore the relationship between evidence and models of disease used in the 1850's and 2014, in order to experience the progression of ideas in science.</td>
</tr>
<tr>
<td>• answer the question, “Why is it useful to identify a mechanism for the transmission of a disease such as cholera?” This will assist in identifying Johnson's use of cholera as a protagonist.</td>
</tr>
<tr>
<td>• apply epidemiological concepts to demonstrate that both biological and social determinants of illness are important, and an epidemiological study focusing exclusively on biological aspects of disease transmission is incomplete.</td>
</tr>
<tr>
<td>• annotate a bibliography for their final project.</td>
</tr>
<tr>
<td>• indicate how criticism shaped and improved Snow's work on cholera to support the role that criticism has in science.</td>
</tr>
<tr>
<td>• analyze evidence to de-bunk the miasma theory.</td>
</tr>
<tr>
<td>• investigate the variables that contribute to disease outbreaks to illustrate the interrelationships among biological, social and environmental variables contributing to such.</td>
</tr>
<tr>
<td>• *describe the anatomy and life cycle of a bacteriophage.</td>
</tr>
<tr>
<td>• investigate implications of using live agents as a form of treatment.</td>
</tr>
<tr>
<td>• weigh the personal/public concerns in selecting treatments that impact health of a population. *These objectives will allow for students to experience the ethical issues of the protagonist, cholera.</td>
</tr>
<tr>
<td>• discuss Snow and Whitehead's relationship to interpret Johnson's reasoning in choosing them as protagonists for his 'story.'</td>
</tr>
<tr>
<td>• investigate the cellular physiology of cholera as it relates to the 2010 earthquake in Haiti.</td>
</tr>
<tr>
<td>• analyze the importance of the actual Ghost Map.</td>
</tr>
<tr>
<td>• participate in solving an epidemiological mystery relevant to their surroundings.</td>
</tr>
<tr>
<td>• reflect on the overall experience afforded by the course.</td>
</tr>
<tr>
<td>• complete a final project relevant to course objectives.</td>
</tr>
</tbody>
</table>

INNOVATION: Here, the N stands for novel. The term novel is reflective in words such as fresh, unusual and of course, innovative. The course’s authors felt very strongly that students should have an opportunity to solve a present day epidemiological mystery. Graphic Information System (GIS) is a valuable tool for teaching and comprehending place and space in academic disciplines such as sociology, anthropology, medicine, geology, practical science and economics.
(Azzari et al., 2013). Several of these disciplines are part of the online course. GIS is a most important technical revolution in understanding the world in which we live and it supports active learning scenarios for students (Azzari et al., 2013). Kim and Bednarz (2013) concluded in their research that student experiences with GIS correlate to evaluating data reliability, sound spacial reasoning and assessing problem solving validity. Liu et al. (2010) concluded in their research that combining problem based learning and GIS technology results in higher ordered learning outcomes, especially analytical and evaluative skills. More fodder for developing critical thinking…

Here is what we designed. Google Maps was chosen as the application for the learning activity because it integrated with the campus email system and allowed the instructional designer to create one map of the region which could be duplicated with ease, saved, and shared with groups. First came the task of researching what disease would hit the area and the mathematics of epidemics in order to create a scenario in which a mystery illness was killing several local populations. Second, an Excel spreadsheet was created that contained clues for researchers of physical symptoms as well as GIS location points of fatalities as the epidemic scenario progressed. (The instructional designer created these GIS locators by randomly choosing spots in broad geographic areas, but never actual houses or buildings.) Leptospirosis was chosen as the infection; it was caused by a flash flood. Figure 1 gives a view of the spreadsheet which made it easy to send clues to students by copying and pasting into email groups that were created in their campus Gmail accounts.

<table>
<thead>
<tr>
<th>Student</th>
<th>Purple Balloon</th>
<th>April 8</th>
<th>April 22</th>
<th>Community members report that the Theater in town which had been closed for years, opened Sunday March 15 (total tickets sold 600 from 3/15 to 3/29 with four shows)</th>
<th>The epidemic fatality numbers show that most of those who become acutely ill are the very old and the very young</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>44 718750, -</td>
<td>44 718750, -</td>
<td>73 383197 44 718750, - 73 383197 44 699108, - 73 447806 44 707130, - 73 453213 44 698558, - 73 448878 44 701487, - 73 446647 44 704812, - 73 470765</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>44 949323, -</td>
<td>73 460590 44 952539, - 73 431980 44 707791, - 73 470027</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May 1</td>
<td>No reported fatalities</td>
<td>May 2</td>
<td>No reported fatalities</td>
<td>May 3</td>
<td>44 716494, - 73 401259</td>
</tr>
</tbody>
</table>

Figure 1. Student assignment components for GIS activity.

When the scenario was opened, there were resources about how to use the shared Google map as well as a practice map to try the tool out in a non-threatening environment. Each student was given an icon and color to mark fatalities and then asked to create a new layer on the group’s shared map. One of the bonuses of layers in Google maps is that you can turn them on and off and see how an epidemic progresses. The only snafu was we did not realize we were limited to ten layers per map and for mapping an epidemic that really means ten days. Figure 2 shows the
whole geographic area of the scenario and Figure 3 shows a more narrow view of the epidemic. Students reported that they understood the directions, were able to map with ease, zoomed in to see patterns, and found the scenario assisted in their understanding of epidemics. The words they used to describe the learning experience were: different, appropriate, stressful, fun, exciting, interesting, nerve-wracking, enlightening, and realistic.

![Figure 2. Map of epidemic region in upstate New York.](image)

![Figure 3. A more tightened view of the epidemic icons.](image)

**IN\textsc{Novation}:** The second \textbf{N} also represents the term novel. We embedded a librarian within the course and an entire module was devoted to demystifying the research process. The librarian provided students with some novel ways to present their projects, such as: Trello (good for organizing to do tasks individually or in a group), Easel.ly (allows creation of infographics), Go\textsc{Animate} (self-explanatory), Wix (for creating a website), Prezi (an alternative to traditional slide making programs such as PowerPoint), Haiku\textsc{Deck} (story telling software), Zines (do it yourself magazines) and Storify (allows one to create and curate Twitter and Tumblr conversations). An important component of the module was evaluating resources and using Currency, Reliability Authority of Author, Authority of Organization, Purpose /Point of View (C.R.A.P.) (\url{www.homercentral.org/tfiles/folder444/CRAP%20test}). Yes, Virginia, librarians do have a sense of humor. Table 2 gives a thumbnail sketch of the Librarian’s Module.
Table 2. Embedding a Librarian

- Library Research Help Forum
- Make an Appointment with a Librarian URL
- Alternative Presentation Technology- be better than PowerPoint
- Evaluating Resources: Is it C R A P file
- When you already have a citation: How to Use Google Scholar URL
- Picking Your Topic IS Research URL
- Introduction to Topic Exploration with CredoReference Topic Pages URL
- Ask a question of the Librarian Forum
- Cholera Topic Page URL [This and the next three give information on the four protagonists.]
- London Topic Page URL
- John Snow Biography from PLoS One URL
- Reverend Henry Whitehead’s biograph from UCLA School of Public Health
- Worksheet to assist in creating an Annotated Bibliography File
- Evaluating Sources Forum: Cholera Outbreak in Chicago

INNOVATION: The O in the word denotes ownership. Students were provided with a list of 17 options for their final project. They had a choice; they had ownership. Fourteen of the 17 choices were selected. A few choices were selected by more than one student. See table 3. for student selections.

Table 3. Options for Student Final Projects and Number of Students’ Choices

- Document ways in which the Arts have expressed humanity’s frustration with epidemics. Reflect on the Mayan and Incan art, paintings from medieval Europe, the AIDS quilt, annual AIDS benefit concerts, etc. [N=2]
- Explain the Centers for Disease Control’s rule of thumb for travelers preparing food or drink in Latin American countries: “Boil it, cook it, peel it, or forget it.” Now, what type of advice would you give to persons traveling to Africa;To Bangledesh; Haitii; India [N=2]
- Create a Board Game that “brings home the message” that the miasma theory had nothing to do with the cholera epidemic. Color is important. [N-1]
- Create a comic book that tells the story of The Ghost Map. Color is important. [N=1]
- Write an illustrated book of poetry based on content in The Ghost Map. [N=1]
- Create a song about The Ghost Map. Put the lyrics to music [yours or other music], sing it to yourself or find a willing vocalist. Audio tape the music/lyrics to be played in class during the final week. [N=1]
- Write a research paper about garbage [recycling efforts, re-using efforts, etc.]. [N=2]
- Write a diary of one of the Night Soil men from the perspective of a member of the "scavengers' in 1850's London. [N=4]
- Using graphic arts, create a series of advertisements for products that would help 'cure' cholera in the 1850's and then in the 2050's. [N=1]
• Create a series of photo collages that show the story of acquiring, suffering through, and surviving cholera. [N=1]
• Create a series of video Public Service Announcements [each must be a minimum of :30 seconds in length] that depict steps taken to avoid a cholera epidemic. These videos must show the history of how the 1850's population learned about the transmission of cholera. [N=1]
• Draw or Paint...your product must be accompanied by an annotated bibliography of literature that supports your reasoning behind the drawing or painting. You must also submit a reflection piece that tells us what you were thinking during the artistic process. [N=2]
• Write a science fiction story about *Vibrio cholerae* or the phage that can infect it. [N=1]
• Create a webpage that addresses the four Protagonists, London, *Vibrio cholerae*, John Snow and Henry Whitehead. [N=1]

The next pages show the project results from two students including Figure 4.
Figure 4. Student generated Board Game by K. Hopper.

Figure 5 indicates one of the messages from the board game.

You are a parishioner that said the new sewers caused the outbreak and blamed miasma due to disturbed corpses from the 1665 Plague. You live 1 block from the suspected plague cemetery and yet no one in your neighborhood is sick. Move ahead 2 spaces. Do not go to Hospital. Do not roll.

Figure 5. A representation of directions from a board landing resulting from rolling the dice.

The following is a one page reflection generated by the student writing the illustrated book of poetry.
"One Page Reflection: When choosing which project I would like to do, it was difficult. There were so many great ideas, but the one that stood out to me the most was the illustrated book of poetry. I have been writing poetry since I was in elementary school because it was my way to escape everything and just be in my thoughts. Whatever I was going through, I would make sure I not only write an essay, but that I put my heart and emotion into it and make it a poem. I haven’t written poems since I got into college, so I used this opportunity to go back and do what I used to do best. I’ve never drawn my thoughts into paper though, so that was new to me. Writing poetry for a deadly disease was very different, so the approach I took to ensure that emotion is shown is to put myself in the victims of the cholera outbreak in London. The first poem titled “Cholera” was set up so that cholera is spelled going down and for each line, it had to start with the next letter in the word. The approach I took in this one is to make sure the lines right after one another rhymed. That was very difficult and I am aware that poems do not have to rhyme, but it was just the approach I wanted to take. The first poem is very general. It was sort of like a timeline. First describing the big issue in 1854 in Victorian London, and then how the Londoners believed the miasma theory until Dr. John Snow intervened. Epidemiology being the breakthrough and how many Londoners fled their home country because of the deadly disease. The second poem is titled “Give Me My Vaccine” because in this the Londoner does not care whether it was an airborne disease or waterborne disease; he just wants a cure so that he does not get infected. It starts off by describing Soho: Hot, filthy, bloody, smelly, and humid. These descriptions indeed do describe the air possibly being the cause of so many deaths. Symptoms of cholera include: Upset Stomach, odd sense of unease, muscle spasms, vomiting, abdominal pains, and crushing thirst. These symptoms sound like something that would occur if an individual consumes food or water. The protagonist in the poem does not care if it was airborne or waterborne; he simply just wants a cure. He questions who Dr. John Snow is, but knows he does not have a choice but to trust him because at the end of the day, people are still dying. The third poem is very interesting because it is the first time I thought about whether or not someone is to be blamed for the number of deaths due to the cholera outbreak. It is titled “Who To Blame?” It was short and to the point. Fillipo Pacini, Dr. John Snow, The miasmist, and the Londoners. The poem points out the fact that Pacini and Dr. Snow are complete opposites. If Pacini had tried to disprove the miasmist further, would there be so many deaths? Was it the miasmist fault for instilling in the minds of the Londoners that it was the air? Was it Dr. John Snow’s fault because in order for him to continue his investigation, he needed more Londoners to die from the disease to develop a pattern? Or was it the Londoners fault for not taking precautions? The fourth poem titled “A Quiet Storm” was a response to Walter Benjamin in the beginning of the book. I remember the “Through Your Lens” assignment we had to do in the beginning of the semester and at that time, I did not view the storm to be the outbreak of cholera. After reading the book and reading the passage again, I saw the storm to be referring to the neighborhood that found it hard to believe that it was not an airborne disease; to those who could not believe in the physical evidence, but believed in church more and how they let a stranger try to figure everything out still leaving some questions unanswered.”

- Abdourahamane Barry
Research confirms that Project Based Learning (PBL) is a valuable and enjoyable way to learn, allowing one to develop deeper learning competencies necessary for success in college, career and civic life (Buck Institute for Education (BIE)). The hallmarks of PBL follow:

- students learn knowledge allowing them to tackle realistic problems
- students control their own learning
- teachers facilitate inquiry and reflection (Barron & Darling-Hammond, 2008; Thomas, 2000)

Students regularly indicate that they really like to have choices in what they do rather than having one set assignment. In a survey of studies about student choice in assignments, however, von Mizener and Williams (2009) uncovered the fact that student choice or lack of choice in their assignments did not lead to differences in performance, though they did have better attitudes about their learning. In 22% of the studies, student choice as part of an assignment did lead to superior performance rather than if there was no choice (von Mizener & Williams, 2009).

INNOVATION: V is for vocabulary, and there was a plethora of interesting words in the Johnson book. Each student was responsible for a given number of terms and a glossary component was a part of each module. Students created their own glossary of terms. See Figure 6.

<table>
<thead>
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<th>B</th>
</tr>
</thead>
</table>

*Bildungsroman* - A story of a person coming to age, or their education.

*Bone-pickers* - Bone-pickers are men that search for not only bones, but rags, metals, and various other wastes from the cities they live in. They are known for carrying a greasy bag on their back and carrying a stick as well in the hand with a hook that makes it easier to collect items while searching. A bone-picker is out searching all day and at the very end of the day, he sits and sorts out everything that he has found.

*Bunters* - Bunters are...low class women who are typically prostitutes that do not pay their rent.

Figure 6. A sampling of the B words and student definitions found in the glossary.

Certainly reading enhances direct vocabulary knowledge, but engaging the student in the construction of word meaning using the context of the work and their prior knowledge is useful for acquiring explicit vocabulary and cultivating comprehension (Nelson-Herber, 1986). Certain questions should guide a teacher's decisions regarding which vocabulary should be taught.
How important is the word likely to be to the student? As an example, is it important to giving the student a grasp of the text?

Is it a term that may be recognized with a different meaning in a different context? Is it a word a student is likely to come across again?

How likely will the student get the meaning of the word from its context? Is it defined well in context or does the author assume the reader will recognize meaning?

Is it likely the student already knows the word? Is it totally known, partially known, or totally unknown (Stahl, 1986)?

These questions were considered in picking out vocabulary terms from Johnson’s trade book.

Thornbury (2002), by quoting David Wilkins, says that “Without grammar very little can be conveyed, without vocabulary nothing can be conveyed.” Vocabulary comprehension is dependent on many exposures to the word, exposures in context, a variety of rich information about the word and ties between the word and student’s experience and prior knowledge. Students must also have an operative role in the word learning process (Nagy & Herman, 1987; Beck et al., 2002). Hence, the glossary was an active learning component.

INNOVATION: This A is reflected in active learning. Active Learning combines theory and concepts with student involvement in the learning process (Auster & Wylie, 2006). In a broad sense this is anything a student does in a class which is not passively listening to a lecture given by the instructor. Active Learning Strategies have been supported to be better than lecture-based (Burns, Pierson, & Reddy, 2014). Because this learning is student-focused, it creates room for individual differences in learning preferences (Strage, 2008). These activities give students a break from regular class activities, varying the pace and making the learning more enjoyable (Lumpkin, Achen & Dodd, 2015). Active Learning increases students’ knowledge and ability to comprehend course material (Pinder, 2013). Examples of Active Learning include: writing, reading, discussion, problem-solving exercises, simulations, and case studies that engage the higher-ordered learning that comes with analysis, synthesis, and evaluation (Limbach & Waugh, 2010; Heriot, Cook, Jones & Simpson, 2008).

As students learned foundational content, the activities were largely reading, writing, discussion, and the class-constructed glossary. After their knowledge was firmly solidified they delved into actual case studies about bacteriophages and cholera after the Haiti earthquake. Analyzing case studies is shown to increase critical thinking competencies (Pariseau & Kezim, 2007). The geomapping simulation was a problem that needed to be solved. Students use higher-level thinking skills when they work with simulations (Springer & Borthick, 2004). Active student engagement facilitates the comprehension of how problems unfold in various stages, as they are resolved (Douglas, 2012). Cavanagh (2011) found that active learning assisted learners in maintaining attention and interest in what was being studied; Matherly and Burney (2013) observed these activities improve student participation and attitude toward course topics. This was mirrored in the exit surveys of students in the course who found the learning activities useful, interesting and “something totally new.”
INNOVATION: This is for taxonomy, Bloom’s, of course (Bloom, 1956; Bloom et al. 1966). Every two weeks, students were responsible for answering some assessment questions. The design of the questions was such that the pinnacle of the Bloom’s triangle was the objective. As you may be aware, the Bloom’s triangle has seen some changes since 1956, as seen in Figure 7 (Anderson et al., 2001).

![Changes to Bloom’s](https://search.yahoo.com/yhs/search?p=bloom%27s+taxonomy+1956+citation&ei=UTF-8&hspart=mozilla&hst=ysl001)

Figure 7. Comparison of the old and the new Bloom’s Taxonomy.

An example of an assessment question follows: “Steven Johnson describes his book as having four protagonists: Dr. John Snow, Reverend Henry Whitehead, the *Vibrio cholerae* bacteria and the city of London. What does he mean by including London as a “character” in the book? How does he achieve that? And is it effective? Provide supporting evidence for your answers and do not forget to cite and reference, using APA style. Here, students had to analyze, evaluate and create a substantial answer about effectiveness.

Weekly forums were also a part of the online design. Here, students were asked to weigh in on specific questions and then peer review each other’s work by using warm and cool comments. Cool comments needed to be in question format. Here are examples: The forum questions were—What do you think is the next cholera-like disease, and what are we doing about it? What is the likelihood that a widespread event like the cholera outbreak could happen in North America today? Where might it start, and what conditions would need to exist? Student Answers: The next Cholera-like disease might as well be Campylobacteriosis, caused by *Campylobacter*, because it is the most common foodborne disease. It is found in poultry, red
meat, unpasteurized milk, and untreated water (Accepta, 2015). I feel that this bacterium could be the next threat because it is found in food items necessary for daily life; if these foods are handled improperly, the bacterium could easily infect people. This foodborne disease is similar to Cholera because it causes bad diarrhea, though Campylobacter diarrhea is bloody (Accepta, 2015). It only takes a few of the bacterium to make a person sick; with this being said, prevention of contracting the associated disease includes: cooking meat thoroughly, washing hands before preparing food, washing hands after handling raw foods that came from an animal, and not drinking unpasteurized milk or untreated water (CDC, 2014). If the disease is contracted, treatments include: drinking a lot of fluids, and antibiotics (CDC, 2014).

I think that an event such as the Cholera outbreak to happen in North America is quite unlikely; national disease prevention agencies keep track of occurrences of diseases, and help prevent them from becoming outbreaks (CDC, 2014). However, if something did occur it would start in areas of poor standing, because they generally have the least clean housing developments, poorest hygiene, and least sanitary food preparation.


Peer Review:
Warm:
I like your disease choice of campylobacteriosis. It was something I didn't think about when answering this question.
I like how you went in depth with what the disease consisted of.

Cool:
Do you think medical advances could help with lessening the chance of an outbreak?
Could you have stated some of the main differences the bacteria has compared to cholera?

INNOVATION: In this section, the I is reflected in illustrations. Each course module had a painting, photograph, diagram or map representing content. For example, Module I had the ‘Angelus Novus’ painting done by Paul Klee. Students were asked to do the following:

Activity for Ghost Map:

Choose Walter Benjamin’s (1940) (Pertinent to Klee painting) comments on the page after contents or Steven Johnson’s comments on the page after the map at the beginning of the book. Interpret the passage through your own lens. At the end of the course, you will be asked to re-interpret said passage.

Further illustrations are found in Table 4.

Table 4. Illustrations Used in Online Course

<table>
<thead>
<tr>
<th>Module</th>
<th>Illustration</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module I</td>
<td>‘Angelus Novus’</td>
<td><a href="http://epc.buffalo.edu/authors/bernstein/shadow-time/wb-thesis.html">http://epc.buffalo.edu/authors/bernstein/shadow-time/wb-thesis.html</a></td>
</tr>
<tr>
<td>Module</td>
<td>Content</td>
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<tr>
<td>--------</td>
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<td></td>
</tr>
<tr>
<td>III</td>
<td>Photo of John Snow</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>Photo of Prehistoric Googling</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Photo of William Farr</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>Miasma Theory Depiction</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>Rendering of Variables in Disease Outbreak</td>
<td></td>
</tr>
<tr>
<td>VIII</td>
<td>Cholera Bacterium Photo</td>
<td></td>
</tr>
<tr>
<td>IX</td>
<td>Illustration of John Snow Breaking the Pump</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>Photo of Aftermath of Haiti Earthquake</td>
<td></td>
</tr>
<tr>
<td>XI</td>
<td>Voronoi Diagram (Mathematical)</td>
<td></td>
</tr>
<tr>
<td>XII</td>
<td>John Snow’s Map</td>
<td></td>
</tr>
<tr>
<td>XIII</td>
<td>Modern Photo Hackers in London’s Underground</td>
<td></td>
</tr>
</tbody>
</table>
Many of our students are visual learners and enjoy images, pictures, colors and maps. They look for visual depictions of knowledge. Visual learners remember more efficiently when they can see representations (Felder and Brent, 2005). After all, *a picture is worth a thousand words*.

**INNOVATION:** The **O** in innovation reflects organization. Course organization and design are critical in online learning as they create familiar structures to support student learning and naturally allow course designers to scaffold content delivery. For instructors, organization is not only about the content, but also goals and expectations, instructions, and clear deadlines for activities and assignments (Song, Singleton, Hill & Koh, 2004). For students, organization is about keeping a calendar that allows them to be successful in meeting those goals. With this in mind the topmost module in the course was developed to meet these needs see Figure 8.

![Figure 8. Course general instructions.](image)

Characteristics of good course design include: clear and challenging goals, a hands-on approach, real-world application, focus on important and interesting ideas, feedback systems, personalized approach, clear modeling, reflection, variety of methods, safe environment for taking risks, teacher as facilitator, immersion experience, big picture and flow from parts to whole (Angelo & Cross, 1993). The trade book
used for the course allowed designers to chunk content delivery, and after students mastered content, they worked through higher-ordered learning activities such as case studies and scenarios. Figure 9 illustrates a common weekly module.

![Figure 9. Course weekly module example.](image)

Evaluating the quality of the product of the design process before course roll-out assists in detecting things that might not be so evident during course construction. In advance of this course going live, the submission writers put it through an online course quality review using the Open SUNY COTE Quality Review (OSCQR) rubric which has a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International license ([http://commons.suny.edu/cote/course-supports/](http://commons.suny.edu/cote/course-supports/)). Based on a Community of Inquiry model, research, and best practices in online teaching and learning, this rubric was created by an internal panel of experts and vetted by stakeholders. The rubric is open, customizable, provides a gap analysis rather than a score, and focuses on continuous improvement.

**INNOVATION**: The last **N** in innovation is reserved for a non-fiction trade book. It reflects English Language Arts both in reading and in writing. And it certainly plays to information literacy. As one student stated, “I really enjoyed this course. It takes a lot to get me to read an entire novel and enjoy it, and this class allowed me to do that! I loved the story line of the book and it constantly kept me interested. I also loved how the book was able to educate me about the bacteria itself as well as the history of it. The assignments outside of the book readings were also very interesting to me. I like learning about epidemics, phages, and antibiotics. This field really interests me. The toughest part was the GIS case study. I loved the mystery but doing it with a group got a little confusing. Although I was unable to complete the final project I wanted to, I stepped out of my comfort zone and did a project I have never done before, which was actually really fun.”

One of the benefits of using a trade book is that it can make academic content more personal and significant (Chan, 1979). Trade books give teachers the autonomy in material selections (Chan, 1979).

Non-fiction trade books assist in building background knowledge, thus fostering comprehension. As adults, it is reckoned that eighty-six percent of reading comes from factual texts (Atkinson et al., 2009). It is not unexpected that cultivating skills that build comprehension from informational texts have been cited as an “urgent priority,” often not found in literacy curriculum and instruction (Gambrell et al., 2002). Using a non-fiction trade book is one method of differentiating content and offering new avenues of informational literacy, both for students and for faculty (Webster, 2009).

Lastly, the use of a non-fiction trade book supports the inquiry approach to content knowledge. It opens doors to an assortment of methodologies designed for ways that students can represent their knowledge. As one of the students taking the online course stated, “I believe this course should be taught again! It was very interesting, informative and allowed students to learn about an event in the history of science. It is very difficult to find time to educate ourselves throughout the semester through reading a novel and this course allowed me to do so. I found it hard at times to balance the course with my other work but I think critical thinking is an important task that aids in teaching. I also think it was appropriate as an online course because it helped us stay on task, while taking our time to read, write and understand the material! I had a great time reading, writing and painting my final project through this course. I believe I took a lot from it in regards to history, advancements and understanding of science in society.”

References:


