
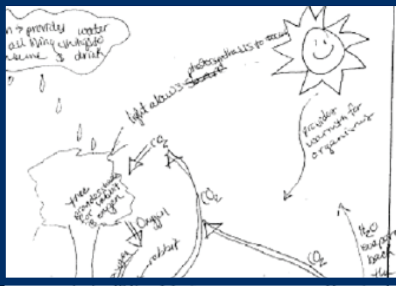

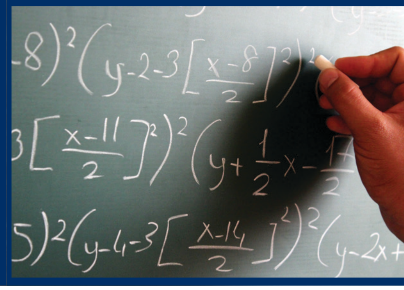

SCIENCE EDUCATION & CIVIC ENGAGEMENT

AN INTERNATIONAL JOURNAL

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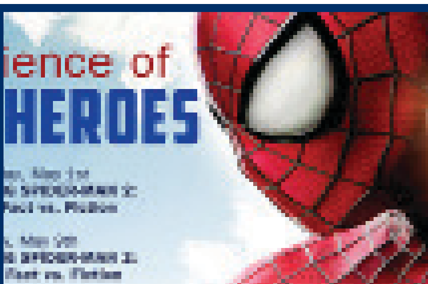



About the Journal

Science Education and Civic Engagement: An International Journal is an online, peer-reviewed journal. It publishes articles that examine how to use important civic issues as a context to engage students, stimulate their interest, and promote their success in mathematics and science. By exploring civic questions, we seek to empower students to become active participants in their learning, as well as engaged members of their communities. The journal publishes the following types of articles:

- *Book & Media Reports*
- *Point of View*
- *Project Reports*
- *Research*
- *Review*
- *Science Education & Public Policy*
- *Teaching & Learning*

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Contents

From the Editors

We are pleased to announce the Winter 2017 issue of *Science Education and Civic Engagement: An International Journal*. This issue provides a variety of articles that describe successful strategies for engaging students.

L. Jay Deiner (NYC College of Technology, City University of New York), **Gregory Galford** (Chatham University), and **Nancy Trun** (Duquesne University) describe an innovative strategy to assist students to understand complex, multidisciplinary community issues. A partnership between students studying chemistry and those studying interior architecture created a mutually beneficial learning environment in which all students could approach a brownfield redevelopment project from multiple perspectives.

Steve Cohen and **Melanie Pivarski** (Roosevelt University) partnered with **Barbara Gonzáles-Arévalo** (Hofstra University) to examine how the integration of projects into a Calculus II course impacted students who were designing the projects and those who were serving as embedded tutors. The authors evaluated the project using surveys, interviews, and classroom observations. Based on these data, they conclude that tutors reported greater confidence in the knowledge and teaching of calculus, whereas project designers gained educational benefits that were similar to those obtained from an undergraduate research experience.

Dan Mushalko (National Public Radio), **Johnny DiLoretto** (a performer), and **Robert E. Pyatt** (Nationwide Children's Hospital and Ohio State University) created a program for informal science education that invites moviegoers to participate in hands-on science activities prior to seeing a newly released film at a not-for-profit movie theater. Their approach has been successful at providing engaging enjoyable science experiences in an unexpected setting.

The water crisis in Flint, Michigan, was widely publicized in the news media. **Stephen G. Prilliman** (Oklahoma City University) used this incident as the foundation for his upper-level inorganic chemistry course. Students performed literature-based research projects that examined topics ranging from the aqueous chemistry of lead to therapies for treating lead poisoning. The instructor noted that the project was particularly effective at enabling students to make connections among various inorganic chemistry topics, while also prompting them to appreciate the connection between chemistry and an important civic issue.

What type of assessment strategies can be used to gain insight into students' understanding of a complex scientific concept like an ecosystem? **Rob Sanford** (University of Maine) has developed an assessment tool that asks students to draw an ecosystem and score the results using a rubric. Comparing students' ecosystem drawings at the beginning and end of the semester revealed a statistically significant improvement in their understanding of ecosystems processes and interactions.

We wish to thank all the authors for sharing their insightful work with the readers of this journal.

— *Trace Jordan*
Eliza Reilly
Co-Editors-in-Chief

PROJECT REPORT

Interdisciplinary Course Collaborations in Community-Based Learning

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Nancy Trun
Duquesne University

L. Jay Deiner
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Abstract

Teaching undergraduate science courses through the lens of local community issues has the potential to help students connect more strongly to the sciences and to the communities near the university. In considering the construction of such courses, it is clear that even community issues that have strong science cores—water quality, viral and bacterial disease vectors—are inherently multidisciplinary, with scientific and technological considerations in balance with the economic and social factors that inform public policy. The fundamental challenge is, then, to develop ways to teach complex and multidisciplinary community issues within the context of science courses. Here, we report on a pilot study of a course structure designed to address this challenge. Cohorts of students from different disciplines were paired, and a strategy was developed that required the students to work together to teach one another about a community issue from their discipline's perspective. This model was applied to cohorts of chemistry and interior architecture students studying local brownfield redevelopment efforts.

Introduction

Context of the Project

Application-based service learning (ABSL, www.ABSLnews.net) is a recently developed pedagogy that infuses laboratory science courses with five of the high-impact educational strategies endorsed by the Association of American Colleges and Universities: learning communities, writing intensive courses, collaborative assignments and projects, undergraduate research, and service-learning (Kuh 2008). A unique aspect of ABSL is that the undergraduate research and service-learning activities are both linked to a shared local community issue (Wei and Woodin 2011). Thus, a strength of this teaching method is that it shows students the application of science to community problems. As a result, it provides the opportunity to teach community awareness and engagement in the science disciplines, where such perspectives are not traditionally emphasized (Dostilio et al. 2013). The National Science Foundation (NSF) funded initial development of ABSL (CCLI Grant #0717685) and subsequent expansion and refinement of the pedagogy (TUES Phase II Grant #1226175). As part of the effort to expand ABSL, a team consisting of a chemistry professor at the NYC College of Technology of the City University of New York (City Tech, CUNY) and an interior architecture professor at Chatham University (Pittsburgh, PA) began creation of ABSL versions of chemistry laboratory courses and partnered interior architecture courses, both focused on the issue of brownfield redevelopment.

A brownfield is "a property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant" (United States Environmental Protection Agency 2015). As brownfield redevelopment is at the nexus of environmental chemistry, architecture, economics, politics, and social justice, development of an ABSL chemistry course focused on brownfield redevelopment should include perspectives from non-science disciplines. This made the choice of partnering with the Green and Sustainable Design course from the Interior Architecture program at Chatham a logical one. On the other hand, the Chatham Interior Architecture program's interest in teaching students about brownfields derives from its long-standing focus on sustainability. This program has won awards from the American Society of Interior Designers for its work in sustainability education, and Chatham has made sustainability a university-wide educational focus.

While the utility of interdisciplinary collaboration in ABSL course development is clear, a critical question must be answered: What strategies can be used to foster meaningful interdisciplinary collaborations when science and non-science courses partner to study a community issue?

Results and Discussion

Interdisciplinary Collaborations through a Shared Slide Presentation Project

At the beginning of the spring 2015 semester, a General Chemistry II laboratory course and a Green and Sustainable Design course were chosen as paired cohorts to develop and enact strategies for interdisciplinary collaboration in community-based teaching. Wherever possible, the core concepts of both courses would be taught through the lens of understanding a shared brownfield redevelopment site, the Gowanus neighborhood in Brooklyn. Chemistry students would perform in-class water quality laboratory experiments and out-of-class community service relating to the canal. Design students would use the canal as a case study. For the chemistry students, an in-class lecture and discussion about brownfields would provide an initial introduction to the issue. Then the class would take a walking tour of the canal, seeing brownfield development in action as sites previously occupied by chemical processing and heavy industry are transformed into residential neighborhoods and retail spaces. For the architecture students, brownfield issues would be introduced through an overview of environmentalism, then through specific investigations into environmental history. Students would also study seminal texts related to sustainability and building, tour local "green" buildings, and view presentations on green building certification programs.

To provide a chemistry perspective to the design students, and a design perspective to the chemistry students, the paired cohorts would co-produce a narrated slide presentation about sustainable development in the Gowanus neighborhood. For the chemistry students, this co-produced slide presentation relates to the learning outcome that students be able to communicate about science in written, oral, and visual forms to a range of different audiences. For the interior architecture students, the slide presentation connects to the learning outcome that students demonstrate an understanding of the concepts, principles, and theories of sustainability as they pertain to the built environment and its inhabitants. The presentation gives students an opportunity to construct a product that illustrates this gained knowledge.

Because the cohorts were located in different cities, met at different times, and followed semester schedules that included only seven overlapping weeks, the students' co-production was structured so that it could be achieved through virtual interactions. Figure 1 shows how the Spring 2015 cycle of slide presentation production, feedback, and response formed the basis of a second round of slide presentation production, feedback, and response to be performed by the next semester's cohorts of General Chemistry II and Green and Sustainable Design (Fall 2015).

Thus, through time, paired cohorts of different disciplines worked together to create increasingly refined versions of the slide presentation. Even though this model of presentation production, peer response, and feedback was developed for courses running in the same semester, the cyclical nature of the interactions means that even cohorts operating during different semesters could engage in such a collaboration model. The current presentation draft is uploaded to the ABSL website (Trun 2015).

We note that the structure of using feedback from one cohort's presentation to inform the next cohort's work was critical to pairing courses at Chatham and NYC College of Technology because the universities have such different semester schedules. Chatham begins the spring semester in early January and ends by the third week in April while NYC College of Technology begins the spring semester at the end of January, recesses for two weeks in April, and then ends the spring semester in late May. However, for universities with more compatible schedules, it would be useful to test a different interaction model, one that would ensure that students receive and act upon feedback from their partner discipline before the end of the course.

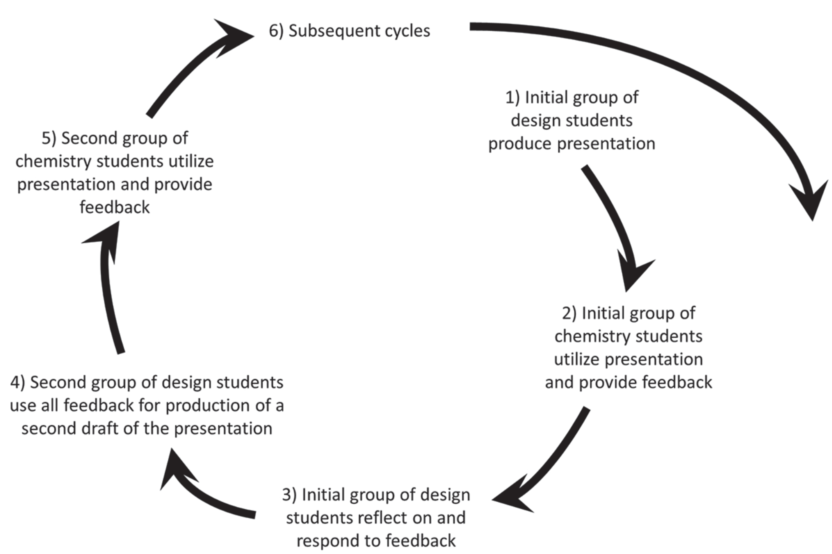

FIGURE 1. Cycle of presentation preparation, feedback, and response, as enacted by paired chemistry and design cohorts.

Structuring the First Round of Student Slide Presentation Production

For the first round of presentation production in Spring 2015, the instructor of Green and Sustainable Design introduced students to the issue of the Gowanus neighborhood redevelopment and discussed the nature of the peer-to-peer collaboration with the chemistry students. The instructor used principles of problem-based learning (PBL) to facilitate the design students' structuring of their first presentation draft (Duch et al. 2001). In accord with PBL, the instructor stated the problem (creating an informational slide presentation), provided access to relevant information, and acted as a facilitator for the student-driven conversations. Using categories of goals, ideas, information, and learning needs, students identified the content and organized the structure of the presentation. Using the structure they devised, students determined their own learning outcomes, established individual and team responsibilities, and defined areas where they needed to expand their knowledge. The students spent a total of two weeks planning and creating the presentation and providing feedback to one another. For the design students, this strategy mimics the project management skills they will use in their professional careers.

Details of Student Interactions to Refine Presentation

The Spring 2015 design students produced the first draft of the slide presentation approximately one week before the chemistry students were to begin water sample collection for their in-class research. The chemistry students watched the slide presentation at home, prior to the sample collection field trip. As an ungraded assignment, the chemistry students provided written feedback about the slide presentation to the design students. In the feedback, chemistry students answered the following prompts:

- Describe three things you learned from this video.
- What subject(s) presented in the video was (were) most interesting to you?

- If you were making a video about Gowanus Canal development, what aspect(s) do you think needs (need) additional investigation?
- Do you have any additional comments for the student videographers at Chatham University?

The chemistry students were surprisingly engaged in this feedback exercise. Despite that fact that watching the presentation and providing feedback were ungraded activities, eighteen out of twenty-one students provided feedback. All students who provided feedback gave detailed responses, most in the range of 120 to 205 words.

In their feedback, many of the chemistry students reported learning about or becoming interested in the land use concept of zoning, the design concepts of reverse engineering, and Leadership in Energy and Environmental Design (LEED) building practices. Students further reported learning about and becoming interested in specific buildings that are part of the Gowanus neighborhood redevelopment. Finally, students reported becoming particularly interested in the technologies of remediation and sustainable engineering such as combined heat and power systems. While all of the above-described concepts, from brownfields to zoning to environmental remediation, would require entire courses to cover in detail, the slide presentation provided an initial exposure for the chemistry students.

In addition to reporting that they had gained exposure to ideas of neighborhood development and sustainable design, the chemistry students commented on aspects of development that they had not previously understood. For example, students commented that they had learned about the level of detail that goes into planning a building. Another student commented that while he or she was familiar with the concept of reverse engineering in the field of computer science, it was a surprise to find that the same concept could be applicable to environmental issues.

After the chemistry students completed their feedback forms, names were redacted, and the forms were sent to the design students. By the time chemistry students had completed the feedback forms, the design students' semester had ended, so the design students received the feedback forms via email. In the email, the design students were asked to review the forms and provide written responses in consideration of the chemistry students' feedback and in consideration of the experience of making a slide presentation for a partner class. The design students were asked to respond to six prompts, including

- What responses were most similar to what you anticipated?
- What responses did you find most unexpected?

Despite receiving the chemistry students' feedback after the completion of the course, six out of the nine design students provided written feedback. Responses to the above prompts provided insight into the way design students view the learning style and knowledge background of science students. For example, some of the Green and Sustainable Design students said they expected that the science students would report being interested in the factual aspects of design (LEED, brownfields, and sustainable design technologies), but were surprised that chemistry students requested more information about the types and origins of pollution in the Gowanus neighborhood. In essence, the design students had expected that chemistry students would already have a full chemical understanding of the canal, even though such an understanding would require quite extensive and advanced laboratory work. In addition, the design students expressed surprise that the chemistry students commented on the design aspects of the presentation in particular, suggesting more visuals and less text in future versions of the presentation. Providing design students with insights into scientists' knowledge and communication styles was an unexpected outcome of the peer-to-peer collaboration activity, and it may be helpful as designers and environmental scientists frequently work together during a building project.

Conclusions and Path Forward

Incorporation of peer-to-peer interdisciplinary activities into an ABSL course provided a means to expose students to a complex community issue from a different perspective. A serial collaboration between separate cohorts of chemistry and design students was developed, but other disciplinary pairings are also possible, as are other work structures like simultaneous virtual or in-person collaboration or mixed discipline teams. Students' level of engagement in the peer-to-peer activities, as evidenced by their willingness to participate in ungraded exercises, was high. It is hypothesized that two factors contribute to the observed student engagement: the increased ownership students feel when participating in projects they have structured through problem-based learning; and the greater authenticity of generating work to be used by peers as opposed to work that is simply viewed by an instructor. These hypotheses will be investigated through continued use of interdisciplinary peer-to-peer learning projects in future ABSL courses.

Acknowledgements

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Gregory Galford is an assistant professor of interior architecture at Chatham University in Pittsburgh, PA. He is currently a doctoral student at the University of Missouri. His master's degree is from the Architectural Association in London. His research focuses on alternative forms of housing.

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L. Jay Deiner is an associate professor of chemistry at the NYC College of Technology of the City University of New York. Jay earned his Ph.D. in chemistry from Harvard University. His research focuses on electrocatalytic materials and on chemistry laboratory pedagogy.

References

Dostilio, L.D., N. Conti, R. Kronk, Y.L. Weideman, S.K. Woodley, and N. Trun. 2013. "Civic Learning through Public Scholarship: Coherence among Diverse Disciplines." Journal of Public Scholarship in Higher Education 3: 43–65.

Duch, B.J., S.E. Groh, and D.E. Allen, eds. 2001. The Power of Problem-Based Learning. Sterling, VA: Stylus Publishing.

Kuh, G.D. 2008. High-Impact Educational Practices: What They Are, Who Has Access to Them, and Why They Matter. Washington, D.C.: Association of American Colleges and Universities.

Trun, N. 2015. ABSL Cross-Discipline Collaboration: Architecture & Chemistry. http://www.abslnews.net/greg-galford.html (accessed November 24, 2016).

United States Environmental Protection Agency. 2015. Brownfield Overview and Definition. http://www.epa.gov/brownfields/brownfield-overview-and-definition (accessed November 24, 2016).

Wei, C.A., and T. Woodin. 2011. "Undergraduate Research Experiences in Biology: Alternatives to the Apprenticeship Model." CBE-Life Sciences Education 10: 123–131.

RESEARCH ARTICLE

Students as Partners in Curricular Design: Creation of Student-Generated Calculus Projects

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Hofstra University

Abstract

In recent years advanced undergraduate students have developed projects for our redesigned Calculus II classes. Our student designers create new mathematics projects and present their work at conferences and in local talks. They are often mathematically early in their college careers, and so we can involve students of all levels in research projects.

Our course redesign affected three groups of students: those taking the class, those designing projects for the course, and embedded tutors. This qualitative study examines how the second and third groups of students benefited from their experiences and how we can modify our program to improve it. Evidence was gathered from interviews, surveys, and observation of student research work and its implementation in the classroom. Tutors reported more confidence in their knowledge of calculus and insights into teaching it, and project designers experienced benefits similar to that of a traditional undergraduate research experience.

Introduction

The extensive use of undergraduate research in mathematics is fairly recent, dating back to the 1980s with the widespread introduction of the NSF-funded Research Experience for Undergraduates programs (Lopatto 2010). Most of these experiences are designed for advanced undergraduates who are in their junior or senior years, and they are often used to help prepare these students for graduate study. By using undergraduate students to develop projects for use in a Calculus II classroom, we can give freshmen and sophomores the opportunity to work on research. The purpose of their research is clear; our students are motivated by helping their peers learn. Developing the calculus projects as well as using them to teach calculus helps to contextualize the mathematics curriculum, which is seen as "a promising direction for accelerating the progress of academically underprepared college students" (Perin 2011).

The use of undergraduates as embedded peer tutors is common; see e.g. Evans et al. (2001) and Goff and Lahme (2003). Tutors attend most classes, and depending on the instructor, sometimes work with students during the class sessions. Tutors can connect more deeply with the material, increasing their calculus skills as well as their ability to communicate and collaborate effectively.

In order to avoid ambiguity, we use "embedded tutors" or simply "tutors" to refer to the embedded peer tutors and "project designers" or "student researchers" to refer to students who, after completing Calculus II themselves, worked on researching a project for use in a future Calculus II course. We refer to students who were currently taking the course simply as calculus students.

In the section Connecting Students to the Course, we briefly describe our Calculus II course and the overall role of the tutors and project designers. As this varied by semester, we elaborate with more details and context in the Experiences and Results section. In the section Curricular Design as Student Research, we discuss definitions of student research that occur in the literature and how these connect to our curricular design. In the Methodology section we describe the methodology used in our study. In the Experiences and Results section, we delve into the results of the study, providing and elaborating on themes found in the student responses. In the Conclusions section, we summarize our results with a list of best practices.

Connecting Students to the Course

At Roosevelt University, semester-long projects with a civic engagement component became a regular part of all sections of Calculus II in Spring 2010 (González-Arévalo and Pivarski 2013). Calculus projects help students explore STEM applications, acquire library research skills, and develop communication skills. Beginning in Fall 2010 each class was assigned an embedded undergraduate tutor who attended class at least once a week and helped students in and out of class. Starting in Summer 2011, undergraduate research students had the opportunity to work on designing materials for class projects. Their work involved picking a topic of civic importance, finding appropriate data sources, considering issues related to calculus, and linking these together. There are many possible outcomes for these projects: use in a Calculus II class, honors theses, research talks, and starter ideas for more advanced mathematical research. We consider all of these to be successful outcomes. We also had some unsuccessful outcomes where students failed to progress.

This course redesign originally developed as a result of our involvement with the Science Education for New Civic Engagements and Responsibilities (SENCER) project. Over the years, our continued involvement with SENCER helped us incorporate students as partners in our curricular design. At the end of 2013 we published a project report (González-Arévalo and Pivarski 2013) detailing the redesign of the course and what we then thought would be the benefits. The current paper provides a qualitative assessment of the newest components of this redesign, namely calculus project development by advanced undergraduate research students and the incorporation of embedded tutors. We provide a description of how we use the embedded tutors in class, as well as how students work on the design of calculus projects. Some of this is explained in our aforementioned project report but we have included it here also for the convenience of the reader.

Embedded Tutors

Each semester at Roosevelt University there are one or two Calculus II sections, each with between nine and thirty students. Because there are only one or two calculus tutors per semester, we do not have a formal tutor training process. Each section instructor informally trains their own tutor. Typically, an experienced instructor acts as a secondary faculty resource. The designers do not work directly with the tutors, except in the cases where an individual student acts in both roles. In that instance, the tutor has a deep knowledge of the goals of the calculus project; we elaborate on this in the section Theme A: Insight into better learning processes. We intend for tutors to

- attend all classes,
- hold regular office hours,
- test out the computer labs ahead of time, and
- work with groups both inside and outside of class.

In practice, we often are unable to find qualified students whose schedule allows them to attend all class meetings, and so we loosen the requirement to attendance at least once per week. Tutors are not needed as graders, as the homework is online. Instructors grade weekly quizzes by hand to gauge where the class is mathematically. Instructors also grade the project parts. Tutors are student

workers paid hourly; their salary is part of the institutional budget, often including Federal Work Study.
The use of the tutor varies by instructor. Some embedded tutors help students when they are working on problems during class, but others merely observe the class. When they are made available, some tutors try the class's computer assignments ahead of time. The tutors always help out during class periods involving computer use.

Project Designers

At Roosevelt University many students transfer in or take calculus their sophomore year, which means they are not ready for a traditional undergraduate research experience until their senior year. Therefore, students need to have research opportunities requiring less background knowledge. Project creation allows student researchers to choose an area for the calculus application.

In the initial course redesign process, research students compiled a literature review on calculus projects. This review and previous semesters' calculus projects provide a foundation for our project designers. Although they are mathematically constrained to construct a modeling project for a calculus class, designers independently explore an application of their own choosing. We ask that it involve actual data and ideally a social justice component. As they develop their plans, we meet weekly with the research students to discuss their ideas, progress, and challenges. During the week, they work independently, although we are always available either in person or by e-mail. At Roosevelt, students are funded through an NSF STEP grant (Science, Technology, Engineering, and Mathematics Talent Expansion Program) shared with the sciences, and through our university's honors program. At a school without funding, project design can act as an independent study project.

Some students had their own ideas for projects, and others modified existing projects. For example, one student found a project that involved studying population growth through a series of biology experiments. She wanted the project to be compelling to the many science majors taking the class. The original project involved studying population growth in simple life forms and in humans. Since growing cell cultures involved more lab time than was realistic for a calculus class, she arranged to use some existing yeast data from one of our biologists' research labs. She investigated curve fitting with MAPLE, split the problem into discrete assignments, and structured the investigation to fit the topic schedule of the calculus course. We helped her with this process over the summer and made adjustments during the semester that we used her project.

Design typically happened over the summer, but it sometimes occurred during the semester. At any given time there are at most two students working on design. Although they had access to them, the designers did not formally review past projects, and they did not have formal discussions with tutors. They instead drew informally from their own experiences and anecdotes from their friends. The designers whose projects were used in courses saw the results of the students' work through a STEM poster session.

Curricular Design as Student Research

The work that our students do creating calculus projects is a distinctive research experience that has much in common with a traditional undergraduate research experience. In the report "Mathematics Research by Undergraduates: Costs and Benefits to Faculty and the Institution" (MAA CUPM 2006), the Committee on the Undergraduate Program in Mathematics of the Mathematical Association of America lists four characteristics of undergraduate mathematics research:

- The student is engaged in original work in pure or applied mathematics.
- The student understands and works on a problem of current research interest.
- The activity simulates publishable mathematical work even if the outcome is not publishable.
- The topic addressed is significantly beyond the standard undergraduate curriculum.

Although these guidelines were originally designed to describe a traditional mathematics research project, they apply in many ways to the work that our research students do. Our research students create projects for use in a Calculus II classroom, and so theirs is more of an applied curricular design research project than a traditional mathematics research project. Because of this, the first item is only partly true; the work is often adapted for a Calculus II classroom from another source. The second item holds, and it was a significant motivator for our research students when they chose the topic of their project. The third holds in the sense that their work, when completed, is made public through use in our classrooms. This is similar to an applied project being used by a company. For our students, two of six projects reached this point. Others either lacked time or good data sets or transitioned from a Calculus II project into applied math research for an honors thesis. The final point applies in the sense that it takes them outside the traditional curriculum. While the mathematics might be found in an undergraduate math modeling course, the act of designing mathematics activities that relate to a social justice theme provides a deeper challenge. At the same time, this allows our student project designers the chance to work on research very early in their undergraduate studies.

> **Dietz (2013, 839) defines three levels of student research activities:**
>
> **Guided discovery:** In these classroom activities, students make step-by-step progress toward a standard (but unknown to them) mathematical formula, or other result, via open-ended, but guided questions.
>
> **Independent investigation:** In these multi-day activities, the instructor asks open-ended questions that require independent exploration by the students. Results may not be surprising to professionals, but they cannot be easily found in the literature.
>
> **Scholarly inquiry:** In these intense activities, students engage in scholarly work that is typical of a given field of inquiry.

Our research students engage in curriculum design, researching applied areas and educational theories in order to develop a guided discovery project for the Calculus II class. The process of creating a new calculus project is an independent investigation; for one of the students it moved beyond this into the area of scholarly inquiry where she analyzed the efficacy of her project. For another, her work extended beyond that of a typical Calculus II project and became scholarly inquiry in the area of actuarial science.

There are multiple layers of learning, where advanced students progress beyond Calculus II while helping students currently taking Calculus II. When surveying the literature, we have found a few instances where advanced students created mathematics materials for introductory students. In Duah and Croft (2012), four mathematics students worked with lecturers to create materials for a module in vector spaces and complex variables. The authors noted the call for student-led curricular design in the UK (Kay et al. 2007; Porter 2008), which other fields have responded to. The authors also noted that there was a paucity of literature on student-created mathematics curricula. At least two papers were written in response to Duah and Croft (2012). In Hernandez-Martinez (2013), two students at an English university worked to create mathematical modeling teaching and assessment tasks for a second-year mathematics for engineers course. In Swinburne University of Technology in Australia (Loch and Lamborn 2015), a team of engineering and multimedia students created videos for engineering students to demonstrate how mathematics is used in engineering. In Pinter-Lucke (1993), the program of Academic Excellence Workshops (AEW) at Cal Poly Pomona involved STEM upperclassmen as leaders of cooperative learning-based workshops for underclassmen in courses ranging from college algebra through calculus. Student facilitators selected materials and led weekly problem sessions. The facilitators met weekly with faculty who were teaching the course, and they went to an intensive two-day training session. Although the paper does not mention whether the problems are student-created or student-selected, the process of choosing appropriate course materials is an advanced one, and so this is a notable example of students contributing to the enhancement of mathematics curricula.

Some institutions involved with the SENCER project are also working with students to create curricular materials, notably in biology (Goldey et al. 2012), where students are used to create and update labs. At Guilford College students are creating a new course as a part of their independent study, and at New England College a proposal is being piloted. At the United States Military Academy students are doing in-depth assessment research of the university's curricular design across the STEM disciplines (United States Military Academy 2014).

In many of these cases, a small number of students were selected to participate in this work, but without a particular common experience to draw upon. In our project we bring students into the experience systematically and intentionally, which leads to the following multi-level learning experience: students have the initial experience of working on a Calculus II project as students in the class, then are given the opportunity to work as a peer tutor or project designer (or both). Their subsequent work then impacts the next set of potential tutors and designers. The depth and detail of the work done by our project designers appears to go beyond that of the AEW leaders, and so the combination of multi-level learning with the depth of experience appears to be unique to our endeavor.

Methodology

In this qualitative study, which received IRB approval, we interviewed each student with several open-ended questions (Appendix A) to get them to reflect on how they were affected by the experience.

We created a survey after we interviewed a few of the students, and it included questions that were based on the interviews. The survey itself was anonymous, and it was used to corroborate the interviews. This qualitative study involves a relatively small number of potential subjects: six project designers, one of whom was also a tutor, and eight additional students who were embedded tutors. Eight students, four of whom were project designers, agreed to be interviewed; four of these also completed a follow up survey. Two individuals, including one project designer, completed the survey, but not an interview. Four did not respond to our contact request. Due to the small sample size it was not possible to conduct a quantitative study of these results, and we have therefore avoided all numerical data throughout the paper (since it would not be statistically valid). Instead, we present the results of the qualitative study of the interviews. The survey was only used to triangulate the results of the interviews.

To categorize the responses, the three authors independently reviewed the interview transcripts and labeled responses according to a variety of categories (Appendix B). The labels were compared and discussed until consensus was reached. The results are organized into three main themes as follows:

Theme A: Insight into better learning processes.

Theme B: Insight into applying mathematics/calculus.

Theme C: Feedback on improving the experience of embedded tutors and researchers.

Experiences and Results

In the first part of this section we will describe some of our observations made as course instructors and research advisors. In the second part of the section we will concentrate on the actual results of our interviews.

Experiences

Overall, our experiences have been positive. While some of our embedded tutors merely benefited from a review of calculus, others developed into expert teachers. All students surveyed confirmed that they gained in some way in varying amounts.

At the beginning, we hoped that the use of tutors would contribute to a sense of community among the students in the class and in our major. We also hoped that the class's mathematical skill level would increase along with the tutor's mathematical skills. We hoped for smoother computer labs, smoother group dynamics during the project, and a source of peer advice. Two of the tutors explicitly commented on the increased sense of community; we observed this as well, both in the classroom and among the tutors. Due to the small number of class sections observed it was difficult to discern whether embedded tutors consistently improved the mathematical skill level of the class and to assess their group dynamics. But tutors had a noticeable effect on the computer labs; these benefited greatly from the extra support. The amount of peer advice given varied by tutor; some of them commented on this in the interviews. Students in sections where the embedded tutors helped during the class period appeared to be more likely to work with the tutors outside of class.

There has not been a good mechanism for class feedback on the tutors; an online survey had a low response rate, but informally they praised tutors who were actively involved.

Our experiences with student researchers have also been mixed. They have definitely learned the difficulty of finding data, since much of what is found online is processed data that give only means, medians, and standard deviations rather than raw data. They found that government sites are usually a good data source. As a result of their work, we used two student-created projects in our course; these are on modeling population and modeling air pollution. Those student researchers gave talks on their projects, both internally and externally. Two students developed more involved research projects on actuarial and head injury models that were not used in class because they were too advanced for a Calculus II class but which resulted in internal and external talks. Two projects (population, actuarial modeling) developed into honors theses, with the first thesis also studying the impact of the population project on the class using it. Two projects were not finished. One of the student researchers, working on temperatures, was stalled in the data collection stage, and did not relate the topic to calculus. The other, working on planetary motion, had planned activities but lost the plans in a move. After this, we started making students type up their results part-way through their research project to prevent the loss of work. In our experience, project designers have the best results when they fill out weekly timesheets rather than being paid in a lump sum for their summer research. Timesheets appear to help with their pacing and accountability. In a situation where a designer is working in an independent study, the structure of the independent study course can be used to aid in pacing.

Results

The student interviews indicate that the students benefited from their experience as tutors and designers as well as from working on the Calculus II projects. They also provide valuable feedback on the curricular design. Note that we have removed words such as "Uh, um, like" as well as repeated phrases from the transcription quotes without explicitly labeling each occurrence.

Theme A: Insight into Better Learning Processes

This theme encompasses the students' sense of themselves as learners and tutors, how math instruction is enhanced by students working on open-ended problems, and the components of effective project design. All of the tutors and designers report gains in their understanding of calculus and in becoming better students themselves. All appreciate the value of a required Calculus II project.

Tutors and designers put considerable thought into what students need to be successful. All of the tutors helped with the technology. One noted that they wanted students to see that the computer is doing something you can do by hand but just much faster. Tutors noted the value of learning to work in teams and that talking about a project is a good way to communicate to outside people what you learned in the class. Tutors noted the value of sitting through the class a second time. They were able to work on their problem areas and to look for connections among the topics and applications. Having experienced the challenge of working on a project that is more open-ended than a typical homework problem, they are in a position to coach students through the process. One tutor spoke at length about the psychology of a student facing a difficult subject. Knowing that their tutor struggled with calculus when they first took the class can reduce the student's own stress and self-doubt.

Project designers tried to include elements that connected naturally to particular calculus concepts. For example, population growth naturally associates with differential equations. But more importantly they tried to make the project connect to students' own majors such as biology. The project designers discussed how they had to think about what calculus topics students needed to know and how the project could help them with difficult concepts. One project designer explained that conceptually, integration is difficult for students, and so he wanted the project to connect integration to a real life problem. They are interested in making the topics current such as using calculus to study greenhouse gasses. By putting more emphasis on a meaningful situation, students would naturally move away from a more mechanical view of calculus.

Several tutors viewed the project as motivating interest in math. Previously their math classes involved memorization and refinement of processes. As embedded tutors they appreciated a mathematically relevant context.

One said, "I think that it was really interesting getting to do lots of different things, but I also think that it is something that students talk about especially within the same degree program. So if we did something that was more biological, population based... one semester when I had a classmate who did something that was more ecological, like the oil spill one, we could have those conversations about how we're applying the same skills in a very sort of different context."

It is evident that tutors and creators think a lot about the students. They care about whether the project is feasible and relevant to student interests. The majority of the students in Calculus II are science majors, so project designers looked for projects that related to biology and chemistry, as we do not offer a physics major at our institution. Typically, projects are related to an important social issue (e.g. climate change and overpopulation). Several tutors expressed empathy for the students and were motivated to help students practice, find related problems in the homework, and discover new ways to explain things.

Tutors took advantage of their unique relationship with the students. Tutors know what the students are hearing from the instructor; they can fill in gaps from the instructor to the students and can also give some of the students' perspective back to the instructor. This advocacy for the students helps the instructor better understand the needs of the students. The tutor's view is different from the instructor's; their recent mastery of the material helps them to understand the students' thought processes. Students often felt more comfortable talking to a peer.

One tutor had designed the project that was being used that semester. This experience was especially fruitful, as they had thought very deeply about what they wanted to include in the project, how students learn, and where they were lacking in skills. They reported that this greatly increased their effectiveness as a tutor for the course; this self-reporting is consistent with our observation.

Theme B: Insight into Applying Mathematics/Calculus

Our main motivation for incorporating projects in Calculus II is to give all students the ability to talk about calculus and its uses. The project challenges students to think about the mathematical concepts in a contextualized situation that requires imagination and technological assistance. Our tutors and designers reflected about their time as calculus students, both here and elsewhere, in their interviews. Calculus II students must communicate among themselves about mathematical modeling in order to successfully complete the project. Many cited this communication as crucial.

One described group work in their previous calculus class at a different school: "It was never actually going out into the world and presenting your findings and being knowledgeable of what you were talking about, so I liked that as a component." One said their experience as a Calculus II student here helped them talk to professionals at a job fair.

The project designers' reflections deepened when discussing the thinking that went into designing a project. Project designers looked for ideas that were feasible for Calculus II students to complete in a semester. Designers wanted their projects to be socially relevant and therefore searched for an interesting area and then had to deconstruct it; one chose to study head injuries and came across the head injury index. That led to a new kind of analysis for her, working backwards from a formula to work out its derivation. The designers intended for students to experience how a model may be limited, but they still wanted students to make valid inferences about what formulas would be reasonable to try. One designer noted his own growth as a student through understanding why concepts are true rather than simply accepting them as an established principle.

The project designers applied knowledge acquired since having had Calculus II. One, an actuarial science major, designed a project using mortality tables. Reflecting on the project done and the project design led to the problem of data. The projects needed some publicly available data to analyze. They could see that the data used when doing the project as a Calculus II student had problems. Most of the designers expressed awareness of the difficulty of doing a project with real data, in particular, finding a good source and dealing with flaws in the data themselves.

There is consensus among the designers that the project brings value to the class. It gives insight into how calculus can be applied in the real world, and the learning that is needed to navigate the project provides an incentive for students to learn more about calculus itself.

Theme C: Feedback on Improving the Experience of Embedded Tutors and Researchers

Tutors and researchers gave feedback on how to run the different activities. The tutors felt strongly that more preparation and better coordination between instructors and tutors was needed. They gave suggestions about the structure of the class and insights on the value they should bring to it. Tellingly, the project designers did not express concerns about what was expected of them. Their biggest concern regarded the difficulties of finding good projects, particularly those with usable data sets. Because the designers met regularly with their research mentor, they remained informed of the goals and expectations of the project.

Most tutors saw the value and importance of integrating technology into the class, but most did not feel that their skill level improved while tutoring. Many pointed out the need for more training for students, tutors, and instructors. The tutors believe that students in the class need more formal instruction on using the software, noting that much class time is spent troubleshooting the difficulties students are having or getting them started. The tutors felt that more training for them would improve their effectiveness, as they were unable to answer some questions students had. Finally, there are indications that the instructors also need additional training, both on the software being used and on the way to utilize the tutors effectively. In some cases the instructor relied on the tutor to troubleshoot any problems arising with the software. Most tutors felt instructors only explicitly engaged them when technology was being used in that day's class. In fact, many of the tutors were not active during class unless there was an activity involving computers.

It is not surprising then that communication was the most cited concern among tutors. Several of them said they wished they knew more about the instructor's goals. The true value of the embedded tutor is to act as a partner of the instructor, and for this he/she needs to be aware of what the instructor is trying to accomplish. Some tutors tended to hold back and not be proactive about helping, in part because they had no direction and in part because of their own inexperience and lack of training.

Many noted the value of having the time structured so that tutors are available to students both in and outside of class. Opportunities to be active in the class were important to the tutors, though some needed more prompting from the instructor. This suggests that some changes in the structure would help facilitate the tutor's activities. Possibilities include more training involving all members of the team, regular meetings between tutor and instructor where plans for the class are discussed, and a set of prompts for the instructor to help guide the tutor.

Conclusions

Our experiences with student researchers mirrored those of others, even though our student research had a curricular focus instead of a mathematical one. In Seymour et al. (2004), a survey of seventy-six student science researchers at four different liberal arts institutions was compared with literature from fifty-four different papers on hypothesized benefits of being a student researcher.

They found that students reported gains in many areas, including confidence in their ability to do research, finding connections between and within science, their organizational and computer skills, their enthusiasm, enhanced resumes, and their attitudes towards learning and working as a researcher. In our study, we also found these gains, giving evidence that this type of student research project has many of the benefits of a traditional research project.

The main advantage of research with a curricular focus is the possibility for students to work when they are just beyond the calculus level. In our study, designers and tutors gained a deeper knowledge of how to apply mathematics and use technology. Both reflected on what makes a good teacher, indicating this type of experience could greatly benefit undergraduates who are interested in teaching. They also provided thoughtful comments on how to improve the program, most notably the need for consistent communication between tutors and instructors.

4.1 Best Practices for Incorporating Students in Curricular Design

Given the extensive amount of research on embedded tutors, we will concentrate primarily on best practices for student researchers.

- Meet student researchers and tutors at least weekly.
- Be available for tech support, orienting all students to new software.
- Pay students using timesheets rather than lump sums.
- Encourage researchers to become embedded tutors for the course (both before and after creating a project).
- Have a set of background literature, including previously used projects, available for new student researchers.
- Don't be too prescriptive. Let them brainstorm ideas and act as a sounding board for them.
- Have at least two students working at the same time; they can give feedback to each other, and bounce ideas off each other.
- Communicate your expectations to help them steadily progress.
- Use file sharing (Dropbox, iCloud, etc.) to prevent the loss of student work.
- Proofread and give feedback on projects and talks. Be supportive and encouraging.
- Make students aware of speaking opportunities (with enough time to write an abstract, to plan a trip, etc.).
- Provide internal venues where they can present their work.
- If the topic gets too deep for calculus allow it to become a more traditional research project.

Recommendations for Further Study

We would love to see a quantitative study on our style of design process. For this, a large university or community college would have to undertake these activities in Calculus II or a similar course. We are also interested in more studies on the impact of doing research early on in college. In our specific work, it would be interesting to increase interactions between the embedded tutors and the project designers. It would also be interesting to have new project designers formally review old projects. This would structure their introduction to the design process and help them to think critically about issues involved in the design. Similarly, when possible, one could have the tutors formally review the current semester's project in the week prior to the semester as a form of tutor training.

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References

Dietz, J. 2013. "Creating a Culture of Inquiry in Mathematics Programs." PRIMUS 23 (9): 837–859.

Duah, F., and T. Croft. 2012. "Students as Partners in Mathematics Course Design." In CETL-MSOR Conference Proceedings 2011, D. Waller, ed. 49–55. York, UK: The Maths, Stats & OR Network.

Evans, W., J. Flower, and D. Holton. 2001. "Peer Tutoring in First-Year Undergraduate Mathematics." International Journal of Mathematical Education in Science and Technology 32 (2): 161–173.

Goff, G., and B. Lahme. 2003. "Benefits of a Comprehensive Undergraduate Teaching Assistant Program." PRIMUS 13 (1): 75–84.

Goldey, E., C. Abercrombie, T. Ivy, D. Kusher, J. Moeller, D. Rayner, C. Smith, and N. Spivey. 2012. "Biological Inquiry: A New Course and Assessment Plan in Response to the Call to Transform Undergraduate Biology." CBE Life Sci Educ 2012 11 (4): 353–363. doi:10.1187/cbe.11-02-0017.

González-Arévalo, B., and M. Pivarski. 2013. "The Real-World Connection: Incorporating Semester-Long Projects into Calculus II." Science Education and Civic Engagement: An International Journal (Winter 2013). http://seceij.net/seceij/winter13/real_world_conn.html (accessed December 19, 2016).

Handelsman, J., C. Pfund, S.M. Lauffer, and C.M. Pribbenow. 2005. "Entering Mentoring." The Wisconsin Program for Scientific Teaching. http://www.hhmi.org/sites/default/files/Educational Materials/Lab Management/entering_mentoring.pdf (accessed December 19, 2016).

Hernandez-Martinez, P. 2013. "Teaching Mathematics to Engineers: Modelling, Collaborative Learning, Engagement and Accountability in a Third Space." Mathematics Education and Contemporary Theory 2 Conference (MECT2), June 2013. http://www.esri.mmu.ac.uk/mect2/papers_13/hernandez.pdf (accessed December 19, 2016).

Kay, J., P.M. Marshall, and T. Norton. 2007. "Enhancing the Student Experience." London: 1994 Group of Universities. http://old.1994group.ac.uk/documents/public/SEPolicyReport.pdf (accessed December 16, 2016).

Loch, B., and J. Lamborn. 2015. "How to Make Mathematics Relevant to First-Year Engineering Students: Perceptions of Students on Student-Produced Resources." International Journal of Mathematical Education in Science and Technology 47: 29–44.

Lopatto, D. 2010. "Science in Solution: The Impact of Undergraduate Research on Student Learning." Tuscon, AZ: The Research Corporation.

MAA CUMP (Mathematical Association of America Committee on the Undergraduate Program in Mathematics). 2006. "Mathematics Research by Undergraduates: Costs and Benefits to Faculty and the Institution." http://www.maa.org/sites/default/files/pdf/CUPM/CUPM-UG-research.pdf (accessed December 16, 2016).

Perin, D. 2011. "Facilitating Student Learning through Contextualization." Community College Research Center Working Paper No. 29, Teachers College, Columbia University. http://ccrc.tc.columbia.edu/media/k2/attachments/facilitating-learning-contextualization-working-paper.pdf (accessed December 16, 2016).

Pinter-Lucke, C. 1993. "Academic Excellence Workshops." PRIMUS 3 (4): 389–400.

Porter, A. 2008. "The Importance of the Learner Voice." The Brookes eJournal of Learning and Teaching 2 (3). http://bejlt.brookes.ac.uk/paper/the_importance_of_the_learner_voice-2/ (accessed December 16, 2016).

Seymour, E., A. Hunter, S. Laursen, and T. DeAntoni. 2004. "Establishing the Benefits of Research Experiences for Undergraduates in the Sciences: First Findings from a Three-Year Study." Science Education 88 (4): 493–534.

United States Military Academy. Core Interdisciplinary Team. "Interdisciplinary Learning, Assessment, Accreditation, and SENCER Courses: How Do They All Fit Together?" Presentation at the SENCER Summer Institute, Asheville, NC, July 31–August 4, 2014.

Appendix A: Interview Questions

- Describe your experiences as a student in Calculus II.
- (Designer only) How did you go about creating the Calculus II project?
- (Designer only) What did you learn while creating a Calculus II project?
- (Tutor only) What did you do as an embedded tutor?
- (Tutor only) What did you learn as an embedded tutor for Calculus II?
- What do you think an embedded tutor should do?
- If you could travel back in time, what advice would you give to yourself?
- What resources would be useful for you to have?

Appendix B: Coding Categories

- Teaching style of instructors: (1) How it influenced you when you took calculus, (2) Learning in class you were taking, (3) Teaching style of instructor in the class you were taking, (4) Teaching style of instructor in the class you were tutoring.
- Teaching style of self: (1) Your learning due to your acting as a tutor, (2) Student learning due to your tutoring, (3) Communicating with students you were tutoring, (4) Project creation: reflecting about how to help other students.
- Resources: (1) Communicating with faculty, (2) Resources (computer-based), (3) Resources (other), (4) "People creating/tutoring should have property X," (5) "I needed knowledge about X," (6) "I used X to do Y."
- Uses of calculus: (1) Uses of calculus (class you were taking), (2) Uses of calculus (class you were tutoring), (3) Uses of calculus (project you created).
- Self-reported changes: (1) In how you think about calculus "I created a project, and now I am awesome at calculus," (2) Interest in mathematics/applications/teaching, (3) Communicating with an outside audience, (4) "I can do X."

Appendix C: Survey Questions

When did you master calculus? (Select all that apply.)

- As a student in calculus class.
- As a tutor.
- While creating a new project (as my research).
- In Calculus III.
- In more advanced math or actuarial science courses.
- In my job.
- Other:

What background should a student have before working on designing a new project? (Select all that apply.)

- Calculus II.
- Calculus III.
- More advanced mathematics courses.
- A mathematical computing course.
- A programming course.
- Other:

What software have you used? (Select all that apply from Maple or Mathematica, Wolfram Alpha, Excel, PowerPoint, Statistical software [specify type], Other.)

- At Roosevelt University outside of Calculus II?
- At Roosevelt University while taking or tutoring Calculus II?
- At your job, if you are employed outside of Roosevelt University?
- What software do you think is useful for Calculus II students to learn?

Ignoring exam days, about how frequently should a Calculus II class involve the following? (For each option below, select from Never, Once or twice, Monthly, Weekly, Every day.)

- A lecture.
- Group work.
- Project work.
- Computer work.
- Problem sessions.

How do projects benefit Calculus II students? (For each option below, select from Essential for the students, Helpful for the students, Somewhat helpful for the students, They'd learn this without the projects.)

- Increased computational skills (taking integrals, etc.).
- Increased conceptual skills (what does an integral represent, etc.).
- Finding out that calculus is actually useful.
- Increased skills working with data.
- Increased skills working with people.
- Increased skills with computers.
- Learning about connections to other fields.
- Greater ability to communicate mathematics.

If you created a project, how did constructing a project benefit you? (For each option below, select from Essential for the students, Helpful for me, Somewhat helpful for me, Did not help me/does not apply.)

- Increased computational skills (taking integrals, etc).
- Increased conceptual skills (what does an integral represent, etc).
- Finding out that calculus is actually useful.
- Working with data.
- Working with people.
- Working with computers.
- Learning about a field you are interested in.
- Increased patience.
- Understanding how people think and learn.
- Understanding how you think and learn.
- Better research habits.
- More experience doing literature searches.
- More responsibility.

What skills should an ideal embedded tutor have? (For each option below, select from Essential, Good to have, Not needed.)

- Strong mathematical content knowledge.
- Knowledge of computer software.
- Love of mathematics.
- Desire to teach.
- Enthusiasm.

What should an ideal embedded tutor do? (For each option below, select from Essential, Good to have, Not needed.)

- Act as a bridge between faculty and students.
- Help with project during class.
- Help with calculus examples during class.
- Help outside of class.
- Make connections between the project and the class.
- Help build student confidence.
- Meet regularly with faculty outside of class.

Which skills increased for you due to your work as an embedded tutor or project designer? (Select all that apply.)

- Presenting posters.
- Giving talks.
- Writing papers/projects.
- Tutoring.
- Confidence in my ability to do math.
- Confidence in my ability to explain math.
- Other:

What resources are needed for embedded tutors? (For each option below, select from Essential to have, Helpful to have, Somewhat helpful to have, Not needed/not applicable.)

- MyMathLab Course Access.
- Tutoring time in 401/Math and Science Resource Center.
- A room dedicated to only tutoring (not classes).
- Regular communication with faculty teaching the course.
- Tutor orientation and training prior to the start of the semester.
- Computer orientation and training.
- Written sample solutions for homework assignments.
- Written sample solutions to project parts.
- Ability to schedule office hours each week at times that are convenient for both you and students (not necessarily fixed).
- Feedback on performance.

If you would like to clarify or expand on any of your answers, please do so below.

PROJECT REPORT

A Research Project in Inorganic Chemistry on the Flint Water Crisis

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Abstract

Students in an introductory inorganic chemistry course conducted a semester-long literature-based research project on the then-ongoing drinking water crisis in Flint, Michigan, USA. Students presented their findings at a poster session that was open to the public. The implications of choosing an ongoing news story as a focus and the ability for such a project to shape the curriculum in a broad introductory course is discussed.

Introduction

If organic chemistry is the study of carbon, inorganic chemistry is the study of all the other elements on the periodic table. The breadth of possible topics in an undergraduate introductory inorganic chemistry course can thus present a challenge for the instructor. In fact, the topics actually taught in inorganic chemistry vary substantially from one institution to another (Raker et al. 2015). At Oklahoma City University, Inorganic Chemistry is a one-semester, lecture-only course for upper-level chemistry and biochemistry majors. The course covers orbitals, periodic trends, bonding, symmetry, transition metal complexes, acid-base chemistry, redox chemistry, and solid state chemistry.

The addition of a research project with societal implications to this course came about because of the demise of another course. For several years students in our college were required to take a senior seminar in which they would investigate and write policy proposals for problems facing humanity in the 21st century, e.g., pollution or climate change. The course proved difficult to staff, and departments were instead asked to offer upper-level courses with a strong research component. However, this research project, initially an "add-on," became central to the course experience.

A number of factors made the Flint crisis a good choice for an inorganic chemistry research project, including

- A sense of immediacy due to the ongoing nature of the crisis
- Strong curricular overlap
- Availability of information from journalistic sources
- Availability of independent data from the Flint Water Study (2016)
- Strong social justice aspect
- A story impacting a diverse urban area not unlike our own

Several other recent chemistry-related events were considered, including the explosion at a fertilizer plant in West, Texas (Chemical Safety Board 2015) and the Gold King Mine contaminated water release impacting the Navajo reservation (Environmental Protection Agency 2015), but neither had all of the advantages listed above. Local cases were also considered. The abandoned Tar Creek mine in far northwest Oklahoma (Barringer 2004) lacked the timeliness of Flint, while the recent earthquakes in Oklahoma stemming from wastewater injection at well sites required knowledge deemed to be beyond the scope of the course.

Overview of the Flint Water Crisis

In 2012, the city of Flint began investigating cheaper alternatives to its water purchasing agreement with Detroit. At the time, Flint was under the administration of a state-appointed emergency manager due to ongoing fiscal difficulties. Flint officials decided to join a regional effort to construct a treatment plant on Lake Huron by 2016 with an anticipated savings of $200 million over 25 years (Kennedy 2016). In the interim, the city would treat its own water from the Flint River beginning in April, 2014. Residents quickly complained of yellow and brown water. The city had trouble regulating, alternately, E. coli bacteria and chlorination by-products. Corrosion found on newly made parts prompted the General Motors engine plant in Flint to discontinue use of city water in October 2014. In January 2015, the first elevated lead levels in drinking water were found. Michigan state officials dismissed independent results showing elevated lead levels until October 2015, when residents were told to stop using Flint city water for drinking, cooking, or bathing. A more thorough overview of the crisis can be found elsewhere (Flint Water Advisory Task Force 2016; Kennedy 2016; Wisely and Erb 2015).

Mechanics of the Project

Students in the inorganic chemistry course were assigned to research and present a poster on some aspect of the Flint water crisis. Learning objectives for the project are listed in Table 1. Posters were chosen as the final research product so that students could present their research in a forum that encouraged community engagement and discussion. A poster session would also give students an authentic experience in explaining their findings to both scientists and non-scientists who might be in attendance.

TABLE 1: LEARNING OBJECTIVES

Students completing this project will be able to

1. Independently research a topic of current interest
2. Locate, assess the quality of, and synthesize information from various information sources, including the scientific literature, news reports, government reports, and independent research sites
3. Present information about a chemistry-related topic at a level that is accessible to both scientists and non-scientists
4. Appropriately choose graphs, photos, computer simulations, and props that help convey the chemistry in a meaningful way

In the second week of the semester the students read a newspaper article (Wisely and Erb 2015) and a trade journal article (Torrice 2016) in class. Students were given two additional days in class for research and consultation but were mostly expected to complete their research on their own. Halfway through the semester students were required to turn in a summary of their research up to that point.

Results

Students' topics fell into two broad categories that we referred to as "people" and "pipes." Most students in the "people" group focused on the mechanism of lead toxicity. Two students examined biological pathways in which lead ions displace calcium ions. Another looked at using the common ligand molecule EDTA as a treatment for acute lead exposure. Those focusing on "pipes" looked at the chlorination byproducts acting as oxidizing agents that converted lead metal to soluble lead ions. Several others focused on whether treating water with phosphates might have prevented pipe corrosion by creating and maintaining a solid layer of iron/lead phosphate on the interior of city and residential pipes.

Each of the thirteen students in the class presented a poster at the end-of-semester poster session (Figure 1). In addition to students, faculty, and staff who attended, a reporter from the local independent weekly newspaper, the Oklahoma Gazette, also attended, resulting in an article in her newspaper (Estes, 2016) and providing students an authentic experience in explaining science to the public.

Discussion

There were two unplanned benefits of this project. First, many of the students addressed the social justice aspect of the crisis. While students had been instructed to be sensitive to the fact that real people were affected, many decided that it was important to discuss the injustice of the situation. One student's poster prominently displayed a quote by Mayor Dayne Walling declaring the Flint River "good, pure drinking water, and it's right in our backyard." Another student expressed to the Oklahoma Gazette reporter her incredulousness upon realizing that city and state officials "were really letting this happen to people."

Another unplanned benefit was how the project motivated study and reinforced course material. Student research projects discussed redox chemistry, electrochemistry, chelation, and periodicity. This made it easier to motivate students to study these subjects and gave the course a sense of coherence. In this way, the project, which was originally an addition, became a focal point for the entire course. As one student put it, "Once we found the water reports and the results had shown a high chlorine residue, I felt like the chemistry became real for me."

We missed one opportunity when we failed to reach out to Oklahoma City community members with specialized knowledge in water treatment and water quality to add a local dimension to the project. Although the students showed a remarkable capacity to empathize with the citizens of Flint, a local connection would have added greater relevancy to their research. Providing students a rubric for the poster at the beginning of the semester and additional checkpoints throughout the semester would have ensured that expectations were better understood. A formal method of assessing students' perception of learning during the project (rather than an assessment for the entire course) should have been established also.

FIGURE 1: Students discuss their findings at the end-of-semester poster session. Water was served as a reminder to attendees of the importance of clean, potable water.

Conclusion

The project, which focused on a current news topic and culminated in a public poster session, presented students with a unique opportunity to experience the need for expert analysis on an ongoing news event. The chemistry was neither simple to understand nor to explain. Students needed to integrate their scientific knowledge with information gleaned from news reports to explain the salient chemistry to both scientists and non-scientists. Students were thus provided with an experience that lies outside the norm of most undergraduate programs and which might not have been possible with a more traditional case study or research project.

Acknowledgements

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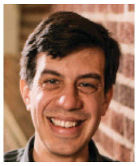

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References

Barringer, F. 2004. "Despite Cleanup at Mine, Dust and Fear Linger." http://www.nytimes.com/2004/04/12/us/despite-cleanup-at-mine-dust-and-fear-linger.html (accessed December 20, 2016).

Chemical Safety Board. 2015. "West Fertilizer Explosion and Fire." http://www.csb.gov/west-fertilizer-explosion-and-fire-/ (accessed December 20, 2016).

Environmental Protection Agency. 2015. "Emergency Response to August 2015 Release from Gold King Mine." https://www.epa.gov/goldkingmine (accessed December 20, 2016).

Estes, L. 2016. "Oklahoma City University Students Research Facets of Water Crisis." Oklahoma Gazette, May 5, 2016, 4–5.

Flint Water Advisory Task Force. 2016. "Final Report." http://www.michigan.gov/documents/snyder/FWATF_FINAL_REPORT_21March2016_517805_7.pdf (accessed December 20, 2016).

Flint Water Study. 2016. "Updates." http://flintwaterstudy.org (accessed December 20, 2016).

Kennedy, M. 2016. "Lead-Laced Water In Flint: A Step-By-Step Look At The Makings Of A Crisis." http://www.npr.org/sections/thetwo-way/2016/04/20/465545378/lead-laced-water-in-flint-a-step-by-step-look-at-the-makings-of-a-crisis (accessed December 20, 2016).

Raker, J.R., B.A. Reisner, S.R. Smith, J.L. Stewart, J.L. Crane, L.Pesterfield, and S.G. Sobel. 2015. "Foundation Coursework in Undergraduate Inorganic Chemistry: Results from a National Survey of Inorganic Chemistry Faculty." Journal of Chemical Education 92: 973–979.

Torrice, M. 2016. "How Lead Ended Up in Flint's Tap Water." Chemical and Engineering News 94 (7): 26–29.

Wisely, J., and R. Erb. 2015. "Chemical Testing Could Have Predicted Flint's Water Crisis." Detroit Free Press, October 11, 2015. http://www.freep.com/story/news/local/michigan/2015/10/10/missed-opportunities-flint-water-crisis/73688428/ (accessed December 20, 2016).

PROJECT REPORT

Geek Sneaks: Incorporating Science Education into the Moviegoing Experience

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Abstract
There are many published examples of strategies for using movies in science education, ranging from individual activities within a class to complete courses like "The Biology of Jurassic Park" at Hood College or "The Physics of Film" at the University of Central Florida (Borgwald and Schreiner 1994; Dubeck et al. 1988; Dubeck et al. 1995; Firooznia 2006). However, all of these strategies employ the use of the film within a formal classroom setting. This paper describes a collaborative program connecting hands-on science activities and new release motion pictures for informal science education in the innovative setting of a movie theater.

Initial Development
The Gateway Film Center (GFC) is a not-for-profit theater which includes eight screens, an art gallery, an upper level bar/ lounge area, a large lobby, and a lower level nautical-themed restaurant. In 2015, the theater was recognized by the Sundance Art House Project as an independent theater of excellence based on "high standards including: quality programming, deep involvement with their local communities, strong financial standing, and recognition from their peers and their communities"(Madden 2015)

The GFC initially began experimenting with science-related supplemental programming through discussions following showings of the film Gravity and the TV series Cosmos in 2013. Based on the success of those events and a love of science by the GFC staff, the theater was interested in broadening that concept to a wider range of new release films. Beginning in 2014, we formed a collaboration with the GFC to develop supplemental science programming related to and in support of films shown at the theater. The mission of the Gateway Film Center includes an educational component, but this traditionally had referred to cultivating film appreciation, movie criticism, and production skills (http://gatewayfilmcenter.org/films-cool/). However, they also promoted their facility as a "learning lab" to promote curiosity and the seeking of new knowledge (http://gatewayfilmcenter.org/films-cool/). We felt that this inspiring philosophy could also apply to science education and the use of the theater as an informal learning environment. This initiative was founded on the goals of (1) integrating science engagement into a unique part of popular culture, (2) exposing moviegoers to real scientists and real science questions, (3) facilitating learning in an informal environment.

During the 2014 summer blockbuster season, we spearheaded a series of panel discussions hosted by ourselves and other scientists from our immediate area in conjunction with three new films. As one journalist noted in a piece to promote these events, "You can't spell 'science fiction' without 'science'" (Madden 2014). Discussions were held after the 7 p.m. show on consecutive Fridays during the month of May and included topics such as "The Monstrosity of Science in Film" for the movie Godzilla and "The Science of Mutation" for X-Men: Days of Future Past (Figure 1). The series concluded with a discussion on the relative importance of scientific fact or narrative development in motion pictures. All panel discussions were held in the upper level lounge area of the theater and announced at the end of the film screening to encourage people to stay afterwards and attend. Most seats in the lounge area were usually filled for each panel and attendees were typically adults. Discussions were lively and included both expert commentary and audience questions to allow individuals the opportunity to directly interact with scientists around topics they were familiar with (e.g., comic books, superheroes, and monsters). When possible, we also supplemented panels with interactive displays such as a collection of insects for "The Hero: Fact vs. Fiction" discussion for the film The Amazing Spiderman 2.

FIGURE 1. Advertisement from the GFC promoting Science of Superheroes discussions.

Science and the Geek Sneaks

While the panel discussion format had proven successful, we wanted to develop science programming that was more interactive, broadly appealing to younger audiences/families, and would extend across a larger range of time/movie show times. We expanded the scope of our efforts and began developing science-related content for the Geek Sneak series at the GFC. Geek Sneaks are advertised as "the ultimate geeking-out atmosphere: parties, unique pre-show entertainment (think behind the scenes and rare footage) and themed drink and dining specials, with a group that loves the movie as much as you do!" (http://gatewayfilmcenter.org/featured_film_series/geek-sneaks/). Geek Sneaks are held the Thursday before a film opens nationwide and consist of multiple showings of that movie during the evening hours. As promotion for the Geek Sneaks highlighted special pre-show entertainment, this seemed like an excellent environment in which to incorporate an informal science education component.

Science activities related to each film are designed to be of short duration (completed in roughly ten minutes or less) and suitable for small groups of people (the typical sizes commonly attending movies). All activities are designed to be hands-on and focused around science content related to themes in the associated film. The GFC hosts multiple Geek Sneak programs throughout the year, but only those movies with science-related premises were deemed suitable for related science activities. In addition to our work, the GFC also arranged other science guests for some Geek Sneaks to further develop the educational message and promotion around some films.

The GFC has eight screens, and Geek Sneak science activities were typically hosted in the lobby area, which allowed them to be accessible to all moviegoers and not just those attending the Geek Sneak. For example, the Marvel Studios movie Ant-Man opened in June of 2015 and tells the story of a superhero who has the ability

FIGURE 2. Author D. Mushalko leads some theatergoers through an activity for the movie Ant-Man, using air pressure to increase or decrease the size of marshmallows.

FIGURE 3. 2 Participants use hand pumps to pressurize tubes containing marshmallows to shrink them in an activity for the movie Ant-Man.

to shrink in scale thanks to a super suit created by his scientist mentor. As a superhero fantasy, there are many components of the story that lack scientific accuracy, such as the suit's implausible ability to shrink a person to insect size, Ant-Man's superhuman strength, and the ability of a human to go sub-atomic and survive in the quantum realm at the film's conclusion. However with a plot and hero based at least in part on real science principles, we felt that this movie offered an excellent opportunity to couple some related science activities. Two such activities were set up in the theater lobby from 6 p.m. to 8 p.m. the evening of the Geek Sneak so that they were prominently visible to all theatergoers. The science activities for Ant-Man included one focused on air pressure as a mechanism to shrink or enlarge marshmallows using a hand pump or a vacuum chamber, as this most directly connects with the movie's plot and the hero's abilities (Figures 2 and 3). Each activity was accompanied by basic background information on the topic, which in this case included a brief definition of air pressure, a description of the composition of marshmallows, and a short discussion of how changing pressure makes them grow or shrink. Participants were also given markers and encouraged to create their own Ant-Man character with the marshmallow before experimentation. Additionally an entomologist and representatives from a local conservatory were also invited to present displays on ants and insects respectively.

For the film Jurassic World, we conducted DNA extractions from wheat germ so that moviegoers could take a sample of DNA they had processed themselves into the theater for the show, and a display of fossils was presented by the Ohio State University Orton Geological Museum including an impressive T-Rex skull. For the film Fantastic Four, science activities included light refraction experiments to mimic the powers of the Invisible Woman, and melting a small piece of the metal gallium (melting temperature 85.58°F) in the hand to mimic the heat of the Human Torch. For Star Wars: The Force Awakens, activities based around the Force focused on magnetism and static electricity (Figures 4 and 5). We have continued to develop film-related science activities with the GFC and have adopted a hybrid approach based on our experiences. For films with broader appeal that are more likely to pull in family audiences, we continue to develop hands-on, film-related science activities for Geek Sneaks associated with those movies. For the film X-Men Apocalypse we presented activities allowing theatergoers to search the human genome using a computer or test their own genetics of bitter taste [Figure 6]. For the film Star Trek Beyond, attendees could examine the warping of space or explore the International Space Station through a NASA computer simulation (Figure 7). Most recently, for the release of Shin Godzilla we showed the random nature of radioactive half-life using M&Ms and demonstrated the use of a Geiger counter with common household radioactive items.

For documentaries or other films aimed at more adult audiences, we have moved to hosting panel discussions in the theater's restaurant area to continue conversations about film-related topics after the film has ended. For example, recent screenings of the documentaries The Last Man on the Moon and Science, Sex and the Ladies were followed by lively discussions on the future of manned flight and female sexuality. While documentaries typically do not have the same appeal as Hollywood blockbusters, we find many adult audience members are more interested in digging into the respective topics in greater detail through discussion sessions following the showings.

Audience Reactions and Challenges

Moviegoers have been generally positive towards this unusual science programming, and we frequently receive comments like "That's really cool!" or "Why do you guys do this?" We see individuals coming to Geek Sneaks and checking in with us to see what new science activities we have planned for that film. For Batman v Superman: Dawn of Justice, we conducted "super" experiments to see how a person's grip strength and total lung capacity would compare to Superman's given some of the feats we've seen him demonstrate in movies. We also recorded both measures on a large board for all participants as a comparison across Geek Sneak attendees that evening. We found that not only did moviegoers enjoy these activities, but some came back repeatedly throughout the evening to check their scores compared to others. A few even asked to repeat the activities to try to improve their scores, allowing us to discuss ways they could do that long term. We would also see one individual from a group complete the activities and then go and bring their friends over to try it as well. Most encouraging, however, is seeing groups who have completed the activities walk away discussing their results, which serves as further reinforcement of those concepts. We love watching informal science learning happening in a movie theater.

Given that the reason people are at the GFC is to see a movie, we try to be respectful of their time as they interact with us. We don't want to make anyone late for a movie. If attendees decline to participate, we graciously thank them for looking and comment that we hope they enjoy their movie. When individuals do participate, we often will ask when their show time is and modify our presentation accordingly if their time is limited. The popularity of a given movie directly relates to the number of attendees we will see for a Geek Sneak. For a film with reasonable popularity like Batman v Superman: Dawn of Justice, we saw forty people participating in at least one of the activities during the roughly two hours we were present for the Geek Sneak.

FIGURE 4. An enthusiastic attendee demonstrates the non-contact force of magnetic attraction during activities for the film Star Wars: The Force Awakens.

FIGURE 5. Author R. Pyatt leads some movie attendees in experimenting with the force of magnetism in an activity for the film Star Wars: The Force Awakens.

The participation of moviegoers was observed during the American premiere of Shin Godzilla. Two activities were run simultaneously for 45 minutes, and 34 moviegoers participated in at least one of the activities; most people did both. Participation was measured if an individual spent at least one minute on an activity. Gender (male; female) and age (child; teenager; adult) were recorded, as perceived by the observer, and each participant was also asked what movie they came to see as part of the demonstrators being cognizant of movie start times. Participation was scored by counting the unique ways moviegoers participated, including if the participant asked a question, answered a question, participated in the hands-on activity, watched the Geiger counter demonstration, helped another participant with the hands-on activity, or shared a story with the demonstrators. Participation scores ranged from a 1 (for someone who, for example, just watched an activity) to a 5 (for someone who, for example, actively participated). An example of a high participation score is the first female participant. She saw another movie but was interested in the activity because her mother is a statistician. While at the table, participant 1 asked and answered questions, shared her mother's occupation, observed the Geiger counter and participated in the hands-on activity. The average level of participation for a participant was 2.5, indicating that they engaged in between two and three unique activity modalities.

FIGURE 6. Author D. Mushalko leads a theatergoer through an activity for the movie X-Men: Apocalypse, exploring the genetics of bitter taste.

Most participants were adults (82%), possibly due to the lateness of the show, as well as the movie being in Japanese with English subtitles, which skews viewership based on reading comprehension levels. Furthermore, most participants were men (70%); however, this seemed representative of the gender skew of moviegoers who came for the Godzilla movie. Of the 10 women who participated, three (30%) women came to Gateway to view another movie, while of the 24 men only four (16%) came to see a movie other than Godzilla. There was no statistical difference between how much men and women participated, though they participated in different ways. Men were more likely to be the first to start the hands-on activity, ask a question, or share a story, while women were more likely to answer a question or help with the hands-on activity.

Conclusions

A recent report by a committee convened through the National Research Council described the venues of informal learning as occurring in the context of three areas: everyday (life) experiences such as personal hobbies, designed settings like museums, and after-school and adult programs (Bell et al. 2009). Studies by Falk et al. have shown that the public has a broad interest in science, and a 2007 survey identified the "lifelong predominantly free choice nature of science learning" as the primary method of science education (Falk et al. 2001; Falk et al. 2007). Based on their results, the authors then recommend "a more holistic approach to science education" which "integrates school, work, and leisure time learning experiences" (Falk et al. 2007, 464). While extensive research has focused on designed settings such as museums or planetariums and informal programs such as out-of-school clubs and citizen science projects, there is considerably less information about informal science education in everyday settings.

A recent publication by Bultitude and Sardo described a new subclass of everyday settings they termed as "generic," which included locations designed primarily for leisure activities, where participants have chosen to be, but for reasons unrelated to science

FIGURE 7. With the help of author R. Pyatt, attendees explore the International Space Station using a NASA computer simulation.

or science learning (Bultitude and Sardo 2012). In their article, the authors describe three such everyday settings including a collective of science communicators called Guerilla Science presenting at a music festival, a physics demonstration set up at a garden festival, and a biological survey (Bioblitz) conducted at a large country park. Through interviews and structured observations, the authors found that attendees of these "generic" events valued "audience participation opportunities and hands-on nature of some activities." The authors subsequently concluded that "holding activities within a relaxed but not habitual environment, where participants are at their leisure, offers clear advantages in reaching non-standard audiences"(Bultitude and Sardo 2012, 32). Our experiences using the innovative setting of a movie theater as one such "generic" everyday setting for informal science education would confirm this. While we have only anecdotal responses from participants, we have observed that hands-on activities and discussions in the theater stoked curiosity and promoted science learning in theatergoers. Especially following panel discussions, we observed that participants seemed to connect to a movie's science content in more personal ways. Finally, these science activities and discussions were excellent material for the Gateway Film Center to use in advertising and promotions which solidified the collaborative nature of this program.

At a recent Geek Sneak during the summer of 2016, we were approached by an attendee who was excited to talk to us. He had attended a previous Geek Sneak for X-Men Apocalypse and had participated in the activity around bitter taste genetics and the TAS2R38 gene. He excitedly told us that since that film he'd read a couple of articles which mentioned the TAS2R38 gene; he had remembered the gene from our activity and had gone to look up additional information on it himself. While it is only a single piece of anecdotal evidence, this is exactly the impact we are aiming for.

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References

Bell, P.B., B. Lewenstein, A.W. Shouse, and M.A. Feder. 2009. Learning Science in Informal Environments: People, Places, and Pursuits. Washington, DC: National Academies Press.

Borgwald, J.M., and S. Schreiner. 1994. "Science and the Movies: The Good, the Bad, and the Ugly: A Novel Interdisciplinary Course for Teaching Science to Nonscience Majors." Journal of College Science Teaching 23 (6): 367–371.

Bultitude K., and A.M. Sardo. 2012. "Leisure and Pleasure: Science Events in Unusual Places." International Journal of Science Education 34: 2775–2795.

Dubeck, L.W., S.E. Moshier, and J.E. Boss. 1988. "Science in Cinema: Teaching Science Fact through Science Fiction Films." New York: Teachers College Press.

Dubeck, L.W., S.E. Moshier, and J.E. Boss. 1995. "Using Science Fiction Films to Teach Science at the College Level." Journal of College Science Teaching 25 (1): 46–50.

Falk, J.H., P. Brooks, and R. Amin. 2001. Free Choice Science Education: How We Learn Outside of School. New York: Teachers College Press.

Falk, J.H., M. Storksdieck, and L.D. Dirrking. 2007 "Investigating Public Science Interest and Understanding: Evidence for the Importance of Free-Choice Learning." Public Understanding of Science 16: 455–469.

Firooznia, F. 2006. "Giant Ants and Walking Plants: Using Science Fiction to Teach a Writing Intensive, Lab-Based Biology Class for Nonmajors." Journal of College Science Teaching 35 (5): 26–31.

Gateway Film Center. n.d. "Education." http://gatewayfilmcenter.org/films-cool/ (accessed December 17, 2016).

Gateway Film Center. n.d. "Geek Sneaks." http://gatewayfilmcenter.org/featured_film_series/geek-sneaks/ (accessed December 17, 2016).

Madden, H. 2014. "Discuss Science and Superheroes at Gateway Film Center." http://www.columbusunderground.com/discuss-science-and-superheroes-at-gateway-film-center-hm1 (accessed December 17, 2016).

Madden, H. 2015. "Gateway Film Center Wins Sundance Honor." http://www.columbusunderground.com/gateway-film-center-hm1 (accessed December 17, 2016).

PROJECT REPORT

The Draw-an-Ecosystem Task as an Assessment Tool in Environmental Science Education

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Introduction

Environmental science is a broad, interdisciplinary field integrating aspects of biology, chemistry, earth science, geology, and social sciences. Both holistic and reductionist, environmental science plays an increasing role in inquiry into the world around us and in efforts to manage society and promote sustainability. Mastery of basic science concepts and reasoning are therefore necessary for students to understand the interactions of different components in an environmental system.

How do we identify and assess the learning that occurs in introductory environmental science courses? How do we determine whether students understand the concept of biogeochemical cycling (or "nutrient cycling") and know how to analyze it scientifically? Assessment of environmental science learning can be achieved through the use of pre- and post-testing, but of what type and nature?

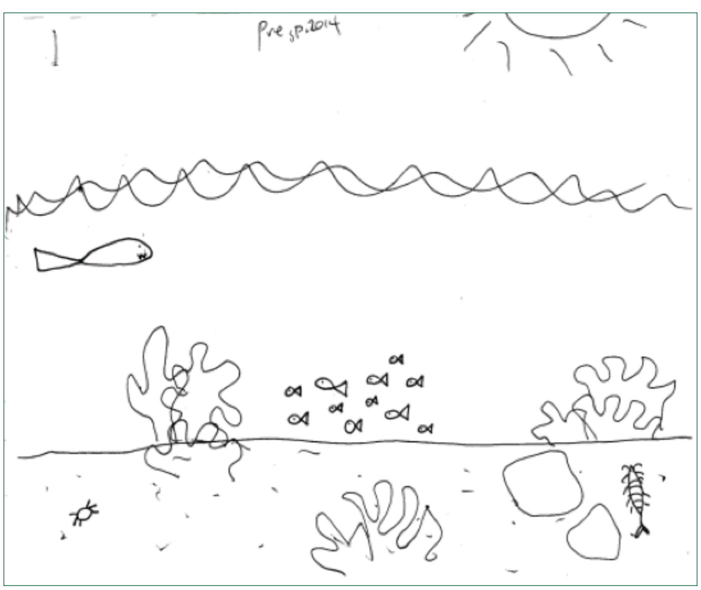
Physics, chemistry, biology, and other disciplines have standardized pre- and post-tests, for example Energy Concept Inventory, Energy Concept Surveys; Force Concept Inventory (Hestenes et al. 1992); the Geoscience Content Inventory (Libarkin and Anderson 2005); the Mechanics Baseline Test; Biology Attitudes, Skills, & Knowledge Survey (BASKS); and the Chemistry Concept Inventory (Banta et al. 1996; Walvoord and Anderson 1998). Broad science knowledge assessments also exist, notably the Views About Science Survey (Haloun and Hestenes 1998). Some academic institutions have developed their own general science literacy assessment tool for incoming freshmen (e.g., the University of Pennsylvania [Waldron et al. 2001]). The literature abounds with information on science literacy. The American Association for the Advancement of Science (AAAS) and the National Science Teachers Association (NSTA) are leaders in developing benchmarks for scientific literacy (AAAS 1993; www.NSTA.org).

Perhaps the closest standardized testing instrument for environmental science is the Student Ecology Assessment (SEA). Lisowski and Disinger (1991) use SEA to focus on ecology concepts. The SEA consists of 40 items in eight concept clusters; items progress from concrete to abstract, from familiar to unfamiliar, and from fact-based (simple recall) to higher-order thinking questions. Although developed principally for testing understanding of trophic ecology (plant-animal feeding relationships), this instrument can be used in most ecology or environmental science classes, even though it does not address all aspects of environmental science (for example, earth science, waste management, public policy).

The Environmental Literacy Council provides an online test bank that can be used for assessment (http://www.enviroliteracy.org/article.php/580.html). Results of this and other instruments suggest that the average person's environmental knowledge is not as strong as he or she thinks (Robinson and Crowther 2001). Environmental knowledge assessment may help us to determine what additional learning needs to be done in creating an environmentally literate citizenry—an important public policy task (Bowers 1996). However, a major reason for assessing environmental knowledge is to improve teaching. If we can assess how students conceptualize an ecosystem at the start of a course, then we can measure the difference at the end of the course. Additionally, understanding what knowledge they possess at the start of a course will help us expand their knowledge base in a manner tailored to their initial understandings and their needs.

The challenge lies in deriving a rapid assessment tool that will help determine abilities to conceptualize and that also has comparative and predictive value. It is quite common in environmental science courses to ask students to draw an ecosystem—it can be done as an exam question, as homework, or as an in-class project. Virtually all environmental science textbooks contain illustrations of ecosystems. An environmental laboratory manual we frequently use (Wagner and Sanford 2010) asks students to draw an ecosystem diagram as one of the assignments. But what about examining how the students' drawings illustrate growth in knowledge and understanding—their ability to use knowledge gained and to communicate ecological relationships in a model? We needed an instrument that provided immediate information, could be contained on one page, would not take a lot of class time, and that did not look like a test. The draw-an-ecosystem instrument meets those criteria, but there is a price: the difficulty of quantifying and comparing the drawings. It seemed a worthwhile challenge to work those bugs out, and even if that proved to be impossible, the students themselves could see the increased ecological sophistication of their drawings and would experience positive feedback from the change.

FIGURE 1. A representative ecosystem drawing from the first day of class.



The Draw-an-Ecosystem Approach

Our approach is to use a pre-test and post-test in which students draw and label an ecosystem, showing interactions, terms, and concepts (Figure 1 and Figure 2). The assignment is open-ended. We hand out a page with a blank square on it and the following directions:

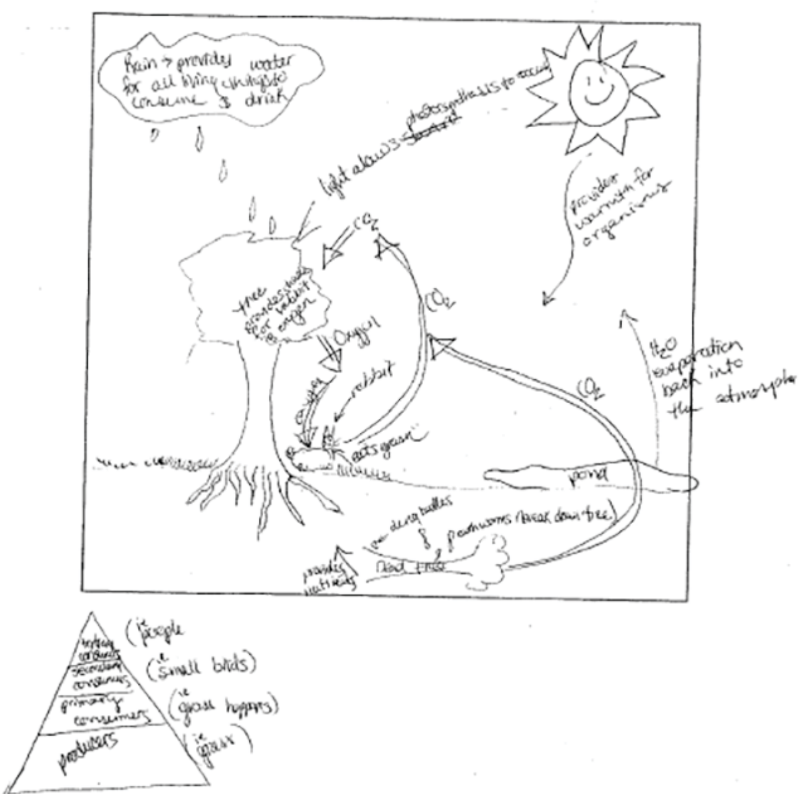
> *Date________. Course __________. Please draw an ecosystem in the space below. It can be any ecosystem. Label ecosystem processes and concepts in your diagram. Take about 15 or 20 minutes. This will not be graded, it isn't an art assignment, and the results will be kept anonymous.*

We tried out this assessment in our graduate summer course in environmental science for sixth–eighth grade teachers (even short-term courses can produce a change in environmental knowledge according to Bogner and Wiseman [2004]) and in our Introduction to Environmental Science course. We developed a rubric to evaluate and score the pre- and post-test ecosystem diagrams drawn by students. The rubric included eight categories, each with a 0–3 score, where 0 represented no display of that category and 3 represents a comprehensive response. The categories, labeled A-H, cover ecosystem aspects (listed below). Certainly, not all eight categories are equal, nor should they be equally rated or represented; however, since we are examining pre- and post-course conceptualization of ecosystems, the comparative value of the scoring remains, and we decided it was reasonable to sum the category scores for a final score. Accordingly, the maximum possible score was 24. The scores were then compiled and analyzed to determine whether there was a statistically significant difference in pre- and post-test scoring.

To interpret the student ecosystem diagrams, we examine the following factors:

1. Presentation of the different spheres (hydrosphere, atmosphere, biosphere, geosphere, and cultural sphere)
2. Proportional representation of species and communities
3. Recognition of multiple forms of habitat and niche
4. Biodiversity
5. Exotic/invasive species
6. Terminology
7. Food chain/web
8. Recognition of scale (micro through macro)
9. Biogeochemical (nutrient) cycles
10. Earth system processes
11. Energy input and throughput
12. Positive and negative feedback mechanisms
13. Biological and abiotic interactions and exchanges
14. Driving forces for change and stability (dynamics)

FIGURE 2. Typical drawing of an ecosystem at the end of a semester-long environmental science course.



Initially we used the above factors as a guide in interpreting the drawings and comparing the pre-test and post-test drawings for each student—we did not compare one student's work with another. However, if the ecosystem test can become a valid and reliable standardized assessment, then comparison makes sense and will inform how an entire course makes a difference in student learning rather than just the progress of an individual student. Accordingly, we developed a scoring rubric (Table 1).

In determining the categories and weights for each scoring rubric, we consulted three other environmental science faculty with experience in teaching an introductory environmental science course. We sought a scale for which both beginners and professionals would achieve measurably distinct scores. To ensure objectivity, we scored multiple examples before settling on the final rubric elements and weights. This is similar to the norming approach used by the College Board in scoring Advanced Placement (AP) Environmental Science exams. The final scores reflect a student's holistic understanding of ecosystems. The maximum score for the pre- and post-test is the same, 3 points x 8 categories = 24. Analysis of pre- and post-course test scores using a Student's t-test for independence, with separate variance estimates for pre-test and post-test groups, was conducted using Statistica v.10 (StatSoft, Tulsa, OK). Analysis revealed a significant enhancement of students' abilities to communicate their understanding of ecological concepts ($t = -10.77$, $df = 364$, $p < 0.001$) (Figure 3). We also tested the scoring system on a small group of workshop participants at the New England Environmental Education Alliance conference

TABLE 1. Scoring Rubric for Draw-an-Ecosystem Exercise

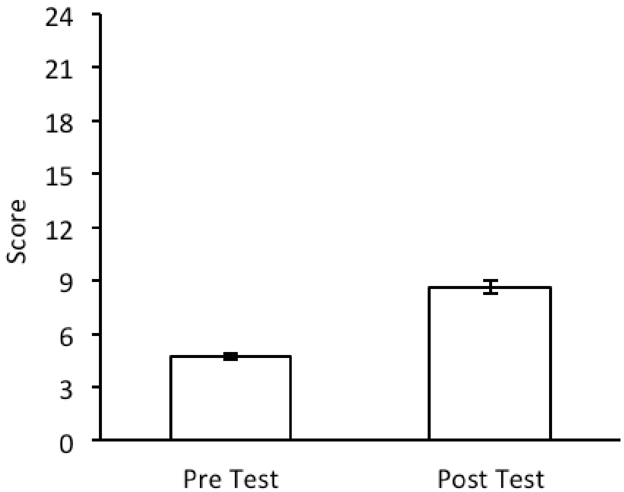
CATEGORY AND SCORE	3	2	1	0
Nutrient cycling. Water, carbon, nitrogen, phosphorus, sulfur, other. Abiotic and biotic mass transfer	Positive and negative feedback arrows that also suggest magnitude	Positive and negative feedback arrows	A positive or negative feedback arrow or mention of nutrients	none
External energy input	Quantitative/ qualitative aspect to labeling energy source, sink. Magnitude and direction of energy transfer	Sun and labeled energy. Magnitude or direction	Sun drawn or labeled	none
Geosphere	Complex interaction with cycling of matter and energy	Cycling of matter or energy	Rock or soil; labeled or shown in cross-section	No soils/rock layers
Trophic levels/organism interrelationships (biosphere)	More than two; arrows linking food web members (arrows distinct from feedback loops). Interspecific, intraspecific, saprophytic, autotrophic, heterotrophic (consumers)	Two: Consumer and producer	One: Predator or prey	none
Human activities				
(cultural sphere)	Explicit mention of humans incorporated into ecosystem, anthropogenic influences	Evidence of more than one type of human activity/product (buildings, smoke stacks, pavement)	Evidence of one human activity/product	No indications that human exist on planet
Hydrologic cycle (hydrosphere)	Evidence of transformation of water forms, storage, residence time	More than one example—surface, underground, atmospheric, biosphere	Labeled or shown in cross-section	No water present in figure
Atmosphere	Complex interaction of matter and energy	Habitat and/or multiple nutrient cycling	Water and O2 cycling	No labeling
Systems and environmental issues	Illustrated example (e.g., climate change and deforestation)	Stated example	Implied/inferred	none
SCORE				

(October 2014). Participants included members of their state's respective environmental education association, plus a mixture of grade school teachers and non-formal educators (with environmental education equivalent to or higher than that achieved by the post-course group of students). The scores by these educators averaged 13 and ranged between 10 and 15.

Discussion

The draw-an-ecosystem test provides an open-ended but structure-bounded means to gauge a person's understanding about ecosystems. We measured change between the first week of a semester-long environmental science course (four credits of lecture and lab) and the last week. The change showed an approximate doubling of scores. The drawings provide clues to where the students are for their starting points and provide a way to indicate possible misconceptions about science or the environment—misconceptions that may need to be cleared up for proper learning. Thus, the drawings can be a useful diagnostic tool for both the student and the teacher. They may also give insight into geographical, cultural, or social biases. For example, many ecosystem drawings were of ponds, not surprising given the water-rich environment of Maine. None of the over 300

FIGURE 3. Draw-an-Ecosystem Rubric Test Scores. Average test scores with SE (bars) for freshmen/transfer undergraduate students in first-semester Environmental Science. Pre-test (n =297, mean = 4.7) and Post-test (n =60, mean = 8.6).



drawings were of desert ecosystems, yet such might be conceptually more common for people from an arid region such as the Southwest. Another aspect of the sample ecosystem drawings is that they tend to be common rather than exotic, leading one to wonder whether we care for what we do not know, or if perhaps the opposite is true—a "familiarity breeds contempt" scenario in which the vernacular environment is seen as less important due to its commonality. A related question is whether or not the ecosystems selected for portrayal change as a result of education. Not only might students think more deeply about ecosystems, but perhaps they are more aware of and value the greater variety of them.

Another benefit of the ecosystem drawing is that it adds another dimension to the learning process. It provides a different way of assimilating and processing information, although according to our sample, artists tend to score about the same as those with fewer artistic skills, suggesting that perhaps a drawing assignment validates their supposedly lesser artistic abilities. Certainly, an exercise that incorporates multiple modes of representation, expression, and engagement—such as drawing and writing—fits better with a Universal Design for Learning (UDL) approach; these modes are the three principles of UDL (Burgstahler and Cory 2008; Rose et al. 2005).

In the future, we may seek a way to reduce the large number of categories in the scoring system, especially if the test is to be used with younger age groups. We should also attain a more comprehensive method of assessing inter-rater agreement for scoring the drawings. We may also explore use of the ecosystem drawings as discussion starters for peer evaluation and collaborative learning. Ecosystem concepts seem to be a powerful way of capturing and reflecting student thinking about environmental settings as dynamic systems.

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References

American Association for the Advancement of Science (AAAS). 1993. Benchmarks for Scientific Literacy. Oxford: Oxford University Press.

Banta, T.W., J.P. Lund, K.E. Black, and Frances W. Oblander, eds. 1996. Assessment in Practice. San Francisco: Jossey-Bass Publishers.

Bogner, F.X., and M. Wiseman. 2004. "Outdoor Ecology Education and Pupils' Environmental Perception in Preservation and Utilization." Science Education International 15 (1): 27–48.

Bowers, C.A. 1996. "The Cultural Dimensions of Ecological Literacy." Journal of Environmental Education 27 (2): 5–11.

Burgstahler, S.E., and R.C. Cory. 2008. Universal Design in Higher Education: From Principles to Practice. Cambridge, MA: Harvard Education Press.

Environmental Literacy Council. Environmental Science Testbank. http://www.enviroliteracy.org/article.php/580.html (accessed November 30, 2016).

Halloun, I., and D. Hestenes. 1998. "Interpreting VASS Dimensions and Profiles for Physics Students." Science and Education 7 (6): 553–577.

Hestenes, D., M. Wells, and G. Swackhamer. 1992. "Force Concept Inventory." The Physics Teacher 30: 141–158.

Libarkin, J.C., and S.W. Anderson. 2005. "Assessment of Learning in Entry-Level Geoscience Courses: Results from the Geoscience Concept Inventory." Journal of Geoscience Education 53: 394–201.

Lisowski, M., and J.F. Disinger. 1991. "The Effect of Field-Based Instruction on Student Understandings of Ecological Concepts." The Journal of Environmental Education 23 (1): 19–23.

Nuhfer, E.B., and D. Knipp. 2006. "The Use of a Knowledge Survey as an Indicator of Student Learning in an Introductory Biology Course." Life Science Education 5 (4): 313–314.

Robinson, M., and D. Crowther. 2001. "Environmental Science Literacy in Science Education, Biology & Chemistry Majors." The American Biology Teacher 63 (1):9–14.

Rose, D.H., A. Meyer, and C. Hitchcock, eds. 2005. The Universally Designed Classroom: Accessible Curriculum and Digital Technologies. Cambridge, MA: Harvard University Press.

Maine Mathematics and Science Teaching Excellence Collaborative (MMSTEC). http://mmstec.umemat.maine.edu/MMSTEC/

Sexton, J.M., M. Viney, N. Kellogg, and P. Kennedy. 2005. "Alternative Assessment Method to Evaluate Middle and High School Teachers' Understanding of Ecosystems." Poster presented at the international conference for the Association for Education of Teachers in Science, Colorado Springs, CO.

Wagner, T., and R. Sanford. 2010. Environmental Science: Active Learning Laboratories and Applied Problem Sets. 2nd ed. New York: Wiley & Sons.

Waldron, I., K. Peterman, and P. Allison. 2001. Science Survey for Evaluating Scientific Literacy at the University Level. University of Pennsylvania. (http://www.sas.upenn.edu/faculty/Teaching_Resources/home/sci_literacy_survey.html).

Walvoord, B.E., and V.J. Anderson. 1998. Effective Grading: A Tool for Learning and Assessment. San Francisco: Jossey-Bass Publishers.