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A Service-Learning Chemistry Course as a Model To Improve Undergraduate Scientific Communication Skills

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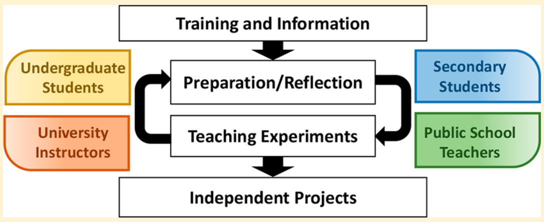
Supporting Information

ABSTRACT: Improving communication between people in science, technology, engineering, and mathematics (STEM) fields and the public is critical to the future of STEM. Partnerships between institutions of higher education with K−12 schools are identified as one effective strategy to support community engagement. We have employed a service-learning model to develop a chemistry course (Chemistry 010) that engages undergraduate students in developing and teaching chemistry experiments for a secondary school audience. This service-learning course design provided us with the consistency and flexibility to sustain substantive learning experiences for both the undergraduates and secondary students. In addition to describing the model of this course in detail, we evaluate this course's impact on undergraduate scientific communication skills. Analysis of reflections written by the undergraduates reveals that Chemistry 010 is an effective course structure for them to explore and assess their competencies to teach and communicate scientific concepts. The course's influence on the secondary students, teacher partners, and university instructors will be the focus of future studies to ensure the mutual benefit of all involved parties.



KEYWORDS: *Communication/Writing, First-Year Undergraduate/General, Learning Theories, Public Understanding/Outreach, Second-Year Undergraduate*

INTRODUCTION

Effective communication between scientists and the public is critical to public understanding and acceptance of science, and precollege education is a critical time for this acceptance to develop. Traditional attempts to engage the public have focused on a "deficit model", which is predicated on the belief that providing the public with knowledge improves their trust in science.[1] However, recent studies indicate that individuals' perceptions of science are only weakly correlated to their level of knowledge;[2] culture, economic status, social and political values, ideology, and media portrayals of scientists play larger roles.[1,3] Interestingly, research has also suggested that individuals' views are most often changed through activities that emphasize in-person, two-way dialogue,[4] and "serendipitous" encounters with scientists,[5] rather than through conventional informational methods, such as Internet articles.

The communication of scientific information to the public has increasingly come to be regarded as the responsibility of scientists,[4,6] but undergraduate science, technology, engineering, and mathematics (STEM) programs most often provide no formal training in science communication. Scientific training of undergraduate students in STEM fields focuses on high levels of specialization, content knowledge, and research skills. Most students receive many opportunities to improve their communication skills with other scientists through grant proposals, conference posters, and talks but have very few formal opportunities to communicate with audiences off-campus.

Several examples of undergraduate elective courses that directly target scientific communication have been reported recently.[7−11] This includes a biology course designed around oral communication of evolutionary concepts to the public[7] and a neuroimmunology course focused on written communication of recent scientific advances to a general audience.[8] Communication can also be a key component of the course's structure, as seen in models such as flipped classrooms[10] and peer-led team learning.[9,11] Analyses of these courses have found benefits to undergraduates, who demonstrated more sophisticated understanding of scientific concepts and refined oral and written communication skills.[7−11] Another study indicated that graduate students who served as teaching assistants were able to generate more effective hypotheses and experimental designs than graduate students who only engaged in research.[12]

With this research in mind, the Department of Chemistry and the Netter Center for Community Partnerships at the University of Pennsylvania collaborated to develop a course, Chemistry 010, through which undergraduates design and facilitate chemistry experiments for secondary school students from public schools in West Philadelphia. Service-learning

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courses emphasize the experiential aspect of learning,[13−16] and reinforcing this with the interactive nature of general chemistry laboratories creates an impactful STEM experience for both K−12 and undergraduate students.[17] Community partnerships have been a proposed mechanism for integrating service-learning into chemistry curricula,[18−20] and our model does this through established partnerships with middle and high schools.[21−23]

Herein, we provide the framework of Chemistry 010 as it was carried out in Fall 2015 and Spring 2016. We then explore Chemistry 010's impact on undergraduate communication. Analyzing the undergraduates' reflections written over the duration of the course supports that it was effective in improving communication skills. We believe this course model could be extended to other universities, and we offer suggestions to instructors looking to provide a chemistry-based service-learning course in their STEM curricula.

■ SERVICE-LEARNING COURSE DESCRIPTION

Chemistry 010 was offered in Fall 2015 and Spring 2016 as a 3-credit-hour course. Over the course of an academic year, 26 teaching associates (TAs) consisting of sophomores, juniors, seniors, and postbaccalaureate students designed 20 experiments for 96 secondary students ranging from grades 6 to 12. The secondary students traveled to Penn's campus, and each secondary student spent a total of 12 h at Penn's teaching laboratories over the course of 4 visits. The TAs also prepared 10 experiments through their independent projects and implemented each experiment twice at our partnered secondary schools.

Enrollment Statistics

As can be seen in the enrollment distribution by year shown in Table 1, this course primarily appealed to junior and senior students. We rostered the course at a low number to encourage participation from first- and second-year undergraduates who may not have had extensive prior experience in chemistry. However, no first-year students enrolled in either semester of Chemistry 010, which may suggest the appeal of service-learning opportunities and scientific communication training to upper-level STEM students.

Table 1. Class Years of Enrolled Students for the 2015−2016 Academic Year as Listed in the Course Registrar

Student Classification	Number of Students (n = 26)
Sophomore	4
Junior	7
Senior	12
Postbaccalaureate	3

Conversely, our aim for this course to appeal to a breadth of majors was met, as shown in Table 2. 81% of the class was pursuing non-Chemistry majors. Of the declared majors, 82% were in STEM fields, including prehealth postbaccalaureate programs. Due to the broad representation of STEM majors, in-class discussions of chemistry communication were expanded to generally focus on scientific communication and how university−community partnerships can support STEM learning.

Schedule

The course was offered as a once per week, in a 3 h morning block to ensure that TAs would be available for the duration of the secondary students' visits. As outlined in Figure 1, the semester was divided into four sections: Training and Information, Preparation/Reflection, Teaching Experiments, and Independent Projects. The first 2 weeks of both semesters were devoted to training TAs in effective communication techniques and best teaching practices. Then, TAs developed two proposals for a chemistry activity suitable for a secondary student audience. Chemistry 010 instructors evaluated and selected proposals to be developed into a full-length activity, and the TAs spent a week writing, testing, and revising their activities. The next week, the secondary students visited to conduct the hands-on chemistry activities. This was followed by a week in which the TAs independently completed reflection forms about the visit, collectively discussed common challenges to effective communication with the secondary student audience, and revised the experiment in preparation for teaching it to a new group of secondary students. After facilitating the experiment across two visits, each TA group prepared a new hands-on experiment, and the process would repeat. According to prior studies, this iterative model shifts the teachers' perspective on lesson plans from standardized teaching strategies to more creative methods for communicating the material.[24]

Table 2. Majors of Enrolled Students for the 2015−2016 Academic year

Major	Number of Students (n = 26)
Biochemistry	2
Biological Basis of Behavior	2
Biology	5
Chemistry	5
Computer Engineering	1
Health and Societies	1
Political Science	1
Wharton Business	2
Undeclared	4
Postbaccalaureate	3

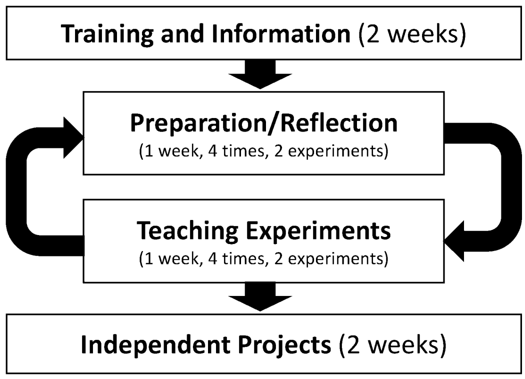

Figure 1. Chemistry 010's schedule for the 10 week semester, based on an iterative planning, teaching, and reflection model.

Training and Information

To prepare the TAs for the teaching experience, we spent the first 2 weeks of the course offering best practices for teaching chemistry laboratories and providing background information on the secondary school system of West Philadelphia. For best practices, we emphasized safety as the top priority, and then reviewed how teachers can act as both supervisors and mentors

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in the lab environment. In the background information, we provided an overview of the current socioeconomic circumstances in West Philadelphia that have shaped the secondary students' education. We also reviewed the differences between teaching in secondary school and higher education. Both components of the background information are intended to aid the TAs in tailoring their teaching style and content for their audience.

Preparation

The TAs worked in teams of two or three to design the experiments. In Spring 2016, Chemistry 010 instructors chose the themes for experiments such as thermodynamics and chemical reactions to help guide experimental design and directly support the chemistry curriculum. Through the proposal process, the instructors ensured that duplicate experiments were not selected. Afterward, the TAs tested their experiments in the lab during the class period. We asked the students to keep track of the amounts of materials and glassware used and to create a shopping list of materials that would scale-up to 100 students within a given budget.

The TAs also prepared an accompanying worksheet for their experiments. These worksheets were compiled into a workbook and distributed to each secondary student during their visit. A sample workbook is provided in the Supporting Information. We originally advised the TAs to format their worksheet with the following sections: Introduction, Procedure, Data, Observations, and Conclusions. At the suggestion of one of our teacher partners, we added a "Do Now" to the beginning of the worksheet and an "Exit Ticket" to the end. The "Do Now" and "Exit Ticket" are formative assessment strategies currently employed at our partner high schools. They consist of one or two content-based questions that probe understanding before and after a learning experience. Including these sections provided not only the TAs and teacher partners with assessment tools, but also the high school students with format continuity between their classroom experience and their visit to Penn. These workbooks were provided to the teacher partners prior to their visit to confirm that the experiments of the visit would align with their curriculum.

Finally, the TAs prepared instructor's guides as they optimized their experiments. These TA Notes provide preparation methods and suggestions on how to make the experiment successful. Such tips include troubleshooting techniques and additional experimental options should a teacher wish to extend the length of the experiment. The TA notes are offered to teacher partners alongside the workbook should they wish to implement the experiments in their classroom. The Supporting Information provides an example of the TA Notes.

Experiments

Every lab station lasted 20 min, during which the TAs guided their group of secondary students through an experiment. Each group of 2−3 TAs taught a maximum of 8 secondary students per 20 min block. Time management during the 20 min block was determined by the TAs. Teaching methods were also dictated by the TAs; many students opened with a general introduction, followed by opportunities for cooperative learning.[25] The secondary students would follow and complete their workbooks with the guidance of the TAs. After the 20 min, the secondary students would wrap up their experiments and rotate to the next section. A total of 6 rotations would be completed during the 3 h visit to Penn, as outlined in the generalized floor plan shown in Figure S1 of the Supporting Information. The secondary students would then provide their completed workbooks to their teacher partners for grading.

In the Fall 2015 semester, TAs planned experiments addressing these chemistry concepts:

- Physical properties
- Color and light
- Temperature
- Precision vs accuracy
- Mixtures and solutions
- Nature and states of matter
- Stoichiometry

These corresponding laboratory skills were also addressed:

- Safety
- Scientific method
- Measurements
- Using hot plates
- Spectroscopy
- Mass balance

In the Spring 2016 semester, the experiments the TAs planned experiments addressing these chemistry concepts:

- Acids and bases
- Kinetics
- Thermodynamics
- Redox reactions
- Catalysis
- Ideal gas law
- Colligative properties

These corresponding laboratory skills were also addressed:

- Safety
- Titrations
- Using micropipettes
- Indicators
- Data management
- Reproducibility

There are additional topics that were not covered by the TAs that could be pursued for future iterations of the course, such as polymer science[26] and green chemistry.[27] The majority of TAs opted to adapt classic teaching experiments for their workbooks, but this course model could also sustain an exploratory approach in which the TAs update previous experiment designs[28] or test new experiments for emerging topics in chemistry.

Reflection

After hosting the secondary students, TAs were given a week to write reflections on the success of their experiments, improvements for the next visit, and interactions with the secondary students. Beyond being a useful gauge of TA progression through the course, writing reflections about student interactions allows the TAs to think critically about their own teaching style and build interpretive inferences about secondary student understanding.[29] Reflections were graded solely on completion. While thoroughness was not incentivized and there was no required word limit, students were still eager to describe their experiences. The average word count per reflection question was 67, but as the binned histogram in Figure S2 shows, several of the TAs' answers extended beyond 200 words. Sample reflection questions and answers are offered in the Supporting Information.

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Independent Project

For the last 2 weeks of the course, the TAs completed an independent project, which entailed writing a new hands-on experiment to bring to two school-day classrooms in West Philadelphia public schools. The goal of this portion of the course was to give the TAs an experience teaching chemistry experiments in a public school environment. This presented the TAs with two major experimental considerations: safety and limited equipment availability. To address safety, we required that the TAs build their experiments around activities that would guarantee minimal safety risk and utilize materials that could be transported to and from the school safely. Waste streams and personal protective equipment (PPE) were available at the schools. Along with PPE, plasticware, benchtop space, and some prep equipment like hot plates were available at the schools. Any additional equipment would have to be brought or foregone by the TAs. The TAs found that developing experiments using commodity materials, such as food items and nonhazardous consumer products, effectively addressed both considerations. The TAs also prepared a fresh worksheet using the same template as the workbooks to accompany their activity.

Evaluation

As this was a course taken for credits, the TAs were offered a grade at the end of each semester. Table 3 indicates the grade breakdown we used for this course in both semesters. The majority of the grade (60%) was dedicated to performance on out-of-class activities (discussions, reflections, and assignments), but the completion of this work was contingent on classroom participation. The out-of-class activities were mainly graded on the basis of completion, and there is room to make these graded activities. Attendance was graded every day, including training and preparation periods. Lab leadership was determined by observation of the TAs during the course by the instructor and their actions in leading their group.

Table 3. Grade Breakdown for Evaluation of TA Performance

Item	Percentage
Attendance and Participation	25
Lab Leadership	15
Workbook and TA Notes	30
Discussions and Reflections	30

■ RESULTS

Methodology

We evaluated the TA-written reflections periodically through the semester to gauge TA development over the semester in terms of teaching, communication, and self-improvement. In Fall 2015, TAs wrote four guided reflections that each had 15 questions. Response rates for the first and second reflections were 100% (12 out of 12). For the third and fourth reflections, response rates were 91.67% (11 out of 12) and 83.33% (10 out of 12), respectively. In Spring 2016, TAs wrote three guided reflections to the same 15 questions asked from Fall 2015. The response rate for the first reflection was 100% (14 out of 14). The second and third reflections had the same response rate of 85.71% (12 out of 14).

Feedback on the Service-Learning Course Structure

Among the learning goals listed for their activities, TAs mentioned not only chemistry concepts such as colligative properties and solubility rules, but also laboratory skills such as how to use hot plates and Bunsen burners. TAs would not have been able to teach these skills at the school sites due to lack of equipment and resources. Therefore, the TAs had a broader range of activities that they could facilitate because they were able to use Penn's general chemistry lab facilities.

The course's schedule required TAs to reteach their experiments, to which TAs responded favorably. One TA noted, "I think we made a lot of progress from week 1 to week 2, and I am really looking forward to getting started with our next activity!" To improve, TAs most frequently cited the need to shorten their introductory lectures to give more time for the secondary students to complete their experiments. TAs also revised their handouts and laboratory procedures for better comprehension within the allotted time. One student noted, "The shortening of the handout and lecture time primarily led the way for more time for the carrying out of the experiment itself. The students liked this because that put the ball more in their court and allowed them to be more hands-on than before." Some students also added demonstrations to increase secondary student interest. Hence, the repetition allowed for TAs to improve upon their lab procedures and instructional tools.

With 20 min to teach per secondary student group, TAs cited time as the biggest problem in their first reflections (15 out of 26). In later reflections, lack of time was cited as less of a problem. Instead, finishing the activity within the given amount of time was what TAs liked about their activities. One TA wrote, "Before, our first experiment had seemed simple to us, but turned out to be confusing and difficult to explain. Keeping that in mind this past week, we chose an activity that we could complete very quickly, and could explain with relative clarity to younger students." With subsequent visits, TAs were able to simplify their activities and manage time more wisely. TAs indicated that the 20 min experiment block was long enough to teach valuable chemistry concepts and short enough to hold the secondary students' attention.

TAs as Instructors

Many TAs reflected on their roles as teachers, indicating that teaching was both more challenging and rewarding than they had expected. Initial reflections focused on the difficulties of managing secondary student interactions, including non-participation and teaching complex scientific concepts to young students with little to no chemistry background. One TA wrote, "I think one of our main problems was assuming that the students knew more information than they did. This could be due to the fact that they were in middle school as opposed to high school." In later reflections, TAs wrote much more frequently about breaking secondary students into small groups to ensure that each student completed a portion of the experiment. To gauge comprehension, TAs became adept at asking questions to the secondary students. One student noted, "We routinely asked [the secondary students] questions and tried our best to guide them to the correct answers."

Almost universally, TAs stated that they preferred teaching high school students to middle school students as high school students had much greater chemistry knowledge and the ability to complete experiments independently. For example, one TA wrote, "This group of students had more background

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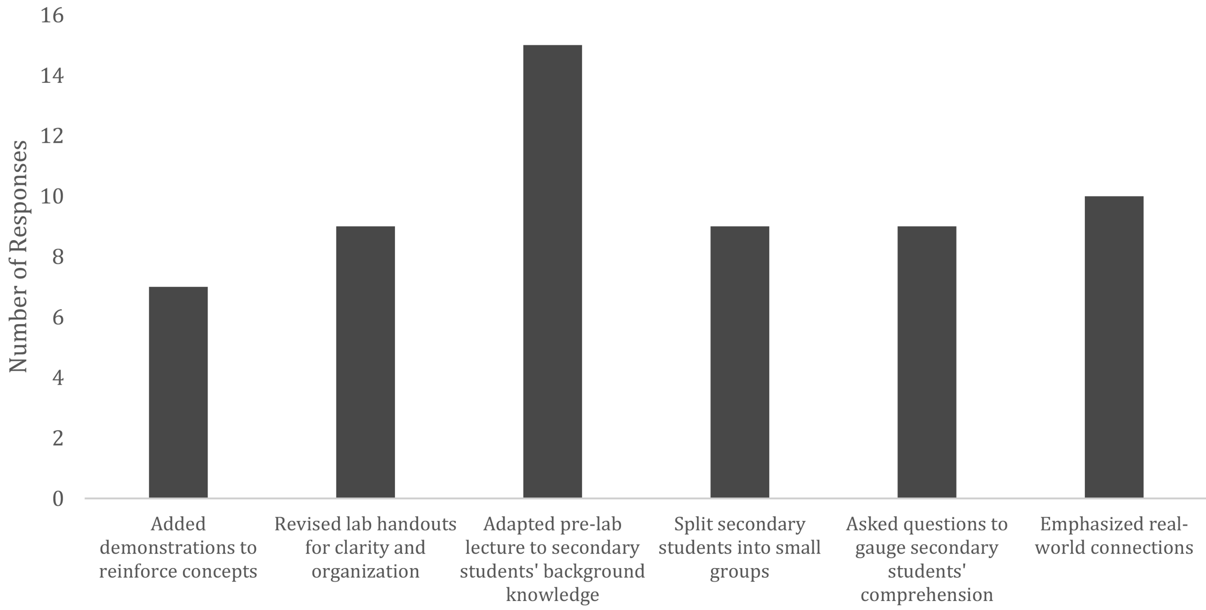

Figure 2. Coded open-ended responses from TAs regarding methods of improving communication with secondary students.

knowledge about chemical reactions, so the introductory discussions were more productive than in the previous visit." Five TAs from Spring 2016 mentioned that high school students had few to no misconceptions about the chemistry concepts that they were teaching.

Additionally, TAs frequently cited the importance of making real-world connections to their lab activities. They noted that the secondary students seemed to learn more and show more enthusiasm when the experiment touched on concepts or materials relevant to their daily lives. One TA noted, "I always had to bring up a real-life example comparison for [the secondary students] to finally be a little more engaged in what the experiment will be about."

To formally assess the TAs' perceptions of their scientific communication abilities with the secondary students, reflections were analyzed for explanations of perceived improvement in communication. All TAs (26 out of 26) noted at least one improvement that they felt made their communication with the secondary students more successful. The most commonly cited improvements are included in Figure 2. While each of the 26 TAs recognized at least one mode of improvement, some offered multiple in their responses, leading to a sum of responses greater than 26. Of these improvements, adapting the introduction to suit the secondary students' background knowledge was deemed one of the most successful tactics by the TAs for improving the learning experience for the secondary students.

TAs as Mentors

A few TAs mentioned they had conversations with the secondary students about pursuing science in their future careers. One TA noted, "I think having high school students gave us an opportunity to encourage them about their choices regarding the future, even though this topic was outside that of the activity." Some students mentioned that, with more time, they would have liked to make a personal connection with the secondary students about their postsecondary goals. The setup of the course lends itself to opportunities for TAs to mentor and increase positive attitudes of science and college among secondary students. Another TA noted, "I enjoyed being able to meet so many [secondary] students in such a short period of time." Mentorship opportunities have been shown to leave a sustained, impactful commitment between the students and a course's content.[30,31]

■ OUTLOOK

After establishing the course model in the Fall 2015 and Spring 2016 semesters, we offered Chemistry 010 again in Spring 2017. We did not offer the course in Fall 2016 because the teacher partners wished to introduce more of the scientific curriculum to the students prior to the Chemistry 010 experience. We agree that doing so created a more substantive experience for both the secondary students and TAs.

For the Spring 2017 iteration of the course, we primarily focused on refining the logistical elements of the course. For example, we changed the independent project portion so that multiple groups would visit the same classroom in West Philadelphia together. This reduced logistical considerations that had to be made by both the TAs and teacher partners, effectively streamlining this component of the course without diminishing the opportunity for the TAs to experience teaching outside of Penn.

We have rostered the class for Spring 2018. We will use this semester to begin evaluating the course's impact on several measures. For example, TA surveys employing closed- and open-ended questions on competencies in communication will be employed. Beyond the benefits for the TAs, Figure S3 highlights the perceived benefits to the secondary students, public school teachers, and university instructors that led to Chemistry 010's development. In order for this course model to be sustainable, every party involved must benefit, so future work will focus on verifying perceived benefits. For example, pre- and postlab surveys provided to the secondary students could evaluate if Chemistry 010 improves their science content understanding, scientific aptitude, and appreciation for STEM experiences.

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■ CONCLUSIONS

We have described a chemistry service-learning course that provides undergraduates with opportunities to improve their scientific communication abilities. By teaching, revising, and reteaching chemistry experiments, the TAs explored different techniques to improve upon their written and oral science communication skills. An analysis of written reflections from the TAs of this course indicates that the mentorship opportunities were valued, while instructional time constraints and secondary content knowledge led to challenges for the TAs. While additional evaluation tools are needed to quantify the extent to which TAs improved upon their content knowledge, the reflections revealed that Chemistry 010 had an effective course structure for TAs to explore and assess their competencies to teach and communicate scientific concepts.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00679.

School visit floor plan, histogram of written reflections, and overview of course benefits (PDF, DOCX)
Sample workbook (PDF)
Sample TA Notes (PDF)
Raw TA reflection data (XLSX)

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Notes

The authors declare no competing financial interest.

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