JOURNAL OF CHEMICAL EDUCATION

Article

pubs.acs.org/jchemeduc

Coordinated Implementation and Evaluation of Flipped Classes and Peer-Led Team Learning in General Chemistry

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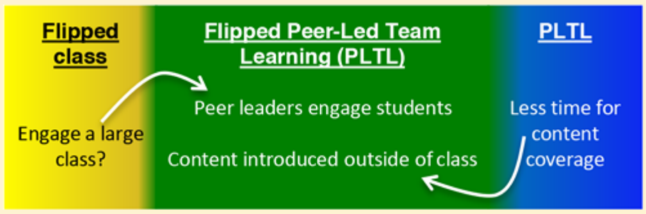
Supporting Information

ABSTRACT: The research-based pedagogical strategy of flipped classes has been shown to be effective for increasing student achievement and retention in postsecondary chemistry classes. The purpose of flipped classes is to move content delivery (e.g., lecture) outside of the classroom, freeing more face-to-face time for active learning strategies. The opportunity to engage in active learning with students can be a challenge for instructors of large classes (more than 100 students). Furthermore, there has been little discussion in the chemical education literature to provide instructors with detailed descriptions of successful implementations of flipped classes combined with active learning in large classes. To this end, this report provides a comprehensive description and evaluation of a coordinated implementation of flipped classes with peer-led team learning (PLTL) for second-semester general chemistry with class sizes greater than 200 students. This approach is described as "Flipped PLTL". This report includes details about creation of videos for flipped instruction, class structure, and the recruiting and training of peer leaders. The purpose of this paper is to provide an example of flipped classes with PLTL that can guide other instructors who wish to implement these pedagogies in large classes.



KEYWORDS: *First-Year Undergraduate/General, Collaborative/Cooperative Learning, Multimedia-Based Learning, Acids/Bases, Equilibrium*

INTRODUCTION

Flipped classes as a teaching approach have received growing interest in both the popular media and the chemistry education literature. The central premise of a flipped teaching approach is to move the presentation of content outside of the assigned class time. One common way to accomplish this is to create or identify online instructional videos for students to access. By presenting content outside of class, the assigned class time becomes available to actively engage students in the content. Thus, the class is flipped from the traditional setup that relies on class time for presentation of content and expects students to actively engage the content outside of class. In chemistry, the flipped class approach has been initially discussed at the secondary level, where smaller class sizes (fewer than 30 students) are amenable to managing active learning approaches. At the postsecondary level, class sizes can range up to several hundred, posing a substantial challenge to adopting active learning. This article details a potential solution to this challenge by describing a combination of pedagogies: flipped classes and peer-led team learning (PLTL).

BACKGROUND

Flipped Classes in Chemistry

As mentioned, flipped classes allow instructors to move transmission-oriented content delivery (i.e., lecture) outside of the classroom, freeing face-to-face class time for instructors to engage in active learning with their students. Beyond such practical considerations, flipped learning also might provide some cognitive benefits grounded in learning theories.[1] For example, Abeysekera and Dawson[2] hypothesize that the flipped learning might reduce students' cognitive load by allowing them to review direct instruction content at their own pace by pausing or rewatching the instructional videos. Furthermore, they propose that the flipped classroom environment might support students' needs for competence, autonomy, and relatedness—three elements that contribute to motivation according to self-determination theory.[3] Flynn proposes that flipped classrooms support student learning within a radical constructivist model, facilitating the construction of new knowledge upon prior constructs.[4]

The first step in implementing a flipped classroom approach is to move all or part of the presentation of content outside of class, often through the creation or identification of online instructional videos. Videos can be generated by instructors and delivered to students via the university's existing learning management system, or instructors can take advantage of free resources such as videos available through YouTube or the Khan Academy. Instructors who generate their own video content either videotape the delivery of an ordinary lecture (e.g., standing in front of a white board and speaking to the camera) or create voice-over slides with screen recording

Received: May 27, 2016
Revised: September 13, 2016

DOI: 10.1021/acs.jchemed.6b00395
J. Chem. Educ. XXXX, XXX, XXX−XXX

software such as Camtasia. Alternatively, out-of-class content can be offered via textbook or similar resources rather than video. Researchers speculate that the mode of content delivery is less important than the fact that this component takes place outside of class and frees class time for active learning activities.[5] Thus, flipped classes can be implemented in a variety of ways, allowing instructors to utilize the approach even with limited financial or technological resources. An additional consideration in flipped classes is to provide an incentive for students to engage with the instructional videos (or other content) outside of class.[1] Options for incentivizing engagement include pairing online quizzes with the videos or incorporating classroom activities that directly rely on video content to reinforce the importance of the videos.

Most of the articles that describe flipping of postsecondary chemistry classes involve small class sizes of 35 or fewer students.[6−11] With these small class sizes, the active learning component is described as students asking questions from the videos,[6,8,10,11] working on problem sets typically in groups,[6−11] taking quizzes[6,10,11] or participating in class-wide discussions.[8−10] Additionally, the articles describe the need for the instructor to present mini-lectures[8,9] or work problems out step-by-step.[6,10] Three additional articles involve midsize classes of approximately 50 students, and each describes using group work without additional information.[12−14]

For large classes (more than 100 students), the active learning component focused on problem solving.[4,15−18] To gain feedback on student problem solving, instructors used classroom response systems such as clickers or TopHat.[4,16] Additionally, to facilitate student problem solving with large classes, instructors relied on graduate or undergraduate teaching assistants.[15,16,18] Eichler and Peeples[16] and Ryan and Reid[15] report student to teaching assistant ratios greater than 50:1, while Rein and Brookes[18] used undergraduate learning assistants to achieve a ratio of approximately 15:1. There is no specific mention of training the teaching assistants, except for the statement by Eichler and Peeples that the assistants "were given the worksheet and answer key to prepare them in answering student questions".

In summary, the chemical education literature provides few examples of implementing flipped classes with large class sizes. The particular challenge with large classes is in enacting the active learning component. Unless this challenge is met, the flipped class approach has the danger of freeing up class time only to have it be devoted to additional lecture. Furthermore, when flipped classes with large class sizes are reported, the description of student engagement seems constrained to answering student questions only when help is requested by the student or verifying student answers through the use of classroom response systems. However, research has shown that students can arrive at the correct answers using incorrect rationales.[19] Alternatively, students with correct answers may misunderstand the limits of the model enacted.[20] Both of these concerns call for meaningful elicitation of student explanations for their problem-solving process. Eliciting explanations from students in a large class environment is particularly difficult, but employing trained peer leaders in the setting provides a potential path toward doing so.

Peer-Led Team Learning

Peer-led team learning relies on peer leaders, i.e., students who have successfully completed a target course and then return to work with students enrolled in the target course while they engage with content in the course. Peer leaders are typically trained in both pedagogical knowledge regarding cooperative learning and the content knowledge associated with the target course.[21] PLTL is an attractive method for several reasons: (1) social constructivism suggests that peer instruction is effective in allowing students to learn with sufficient scaffolding;[22−24] (2) research supports the notion that in addition to the benefits students receive from peer instruction, peer leaders also experience benefits such as learning gains and the development of leadership skills;[25,26] and (3) in most institutions, peer leaders are more readily available than other instructional staff, making peer instruction more easily implementable and scalable than some other approaches.

The efficacy of PLTL for postsecondary general chemistry courses, particularly with respect to student retention and achievement, has been studied in a variety of contexts. PLTL effectiveness has been investigated as either an optional supplement to the assigned class time or as a replacement of assigned class time. For PLTL as an optional supplement, Hockings found that PLTL students performed better than their counterparts by a partial letter grade (B compared to B−).[27] In a similar study, Baez-Galib and colleagues reported that PLTL participants had a pass rate of 69% compared with 54% for students who did not participate in the intervention.[28] Alternatively, PLTL as a replacement for assigned class time has been compared with courses that rely on traditional lecture. Through the replacement of one-third of the assigned class time with PLTL, students enrolled in PLTL either progressively improved their performance on tests or maintained performance with a higher retention rate of students in comparison with students in traditional lecture.[29−31]

The replacement of assigned class time with PLTL sessions has mixed outcomes in terms of instructional preferences. Replacing assigned class time with PLTL has the benefit that the sessions can be made compulsory for all students enrolled in the course. If PLTL sessions are offered outside of class, it is not typically possible to make the sessions accessible to all students, particularly the lowest-achieving students. A logical alternative to optional out-of-class sessions is to create mandatory in-class sessions. However, the replacement of assigned class time reduces the time available for presenting content, which may hinder adoption. The flipped class approach describes an alternative means for presenting content outside of class, thereby providing an opening for incorporation of PLTL during the assigned class time, an approach herein called "Flipped PLTL".

■ SETTING

The Flipped PLTL approach is being developed and implemented at a large research institution in the southeastern United States in second-semester general chemistry (GC2) and first-semester organic chemistry as part of a larger evaluation project. This article describes only the GC2 implementation. At this setting, multiple classes of GC2 are offered each semester with class sizes ranging from 196 to 262 students. Classes meet in a large lecture hall with fixed seating. In the past academic year, eight classes of GC2 have been offered, with the Flipped PLTL approach implemented in four of them (two each in the fall and spring terms) and the remaining four relying on traditional lecture. Classes that utilized the Flipped PLTL class did so for the entirety of the 16-week semester. Each term the GC2 classes were coordinated using a common syllabus and schedule for content coverage, exams, and homework assign-

DOI: 10.1021/acs.jchemed.6b00395
J. Chem. Educ. XXXX, XXX, XXX−XXX

ments. All of the classes took identical exams concurrently and had identical homework assignments with a common due date. Thus, the Flipped PLTL approach was designed to match the content coverage and pace of a traditional lecture-based instructional approach. Both the traditional lecture and Flipped PLTL classes met twice weekly in 75 min sessions, used in-class clickers regularly, and had eight online homework assignments.

The course content for GC2 at the setting covers intermolecular forces; properties of solutions; chemical kinetics; equilibrium; acids, bases, and buffers; thermodynamics (entropy and spontaneity); electrochemistry; and a brief introduction to nuclear chemistry. The content covers nine chapters of a typical general chemistry textbook.[32] The instructors agreed to a set of learning objectives, listing seven to 17 objectives per chapter, prior to the start of the term. Each instructor contributed questions related to the relevant learning objectives for the creation of the midterm exams. The final exam was the most recent iteration of the American Chemical Society (ACS) second-term general chemistry exam.[33] The grading system for all sections as delineated by the shared syllabus was 45% midterm exams, 25% final exam, 10% online homework, and 20% at the instructor's discretion.

■ FLIPPED PLTL

Creation of Videos

In preparation for the first implementation of Flipped PLTL, a series of short instructional videos to present content were created. Two instructors and two undergraduate students who had successfully completed GC2 began creating videos during the summer preceding the first fall implementation. The team of videographers first met and reviewed the learning objectives for a particular chapter to determine which videos would be made. Approximately half of the learning objectives were selected for videos, matching the intent to replace half of the assigned class time with the PLTL approach discussed later. It was found preferable to identify math-based learning objectives for videos, as there was an abundance of math-based topics in the GC2 content covered and presenting the math in class can be time-consuming. Additionally, math problems seemed more prone to pacing issues during lecture, where different students may report the presentation as too fast and too slow.

Once learning objectives for the videos were identified, each member of the video team created one or two videos related to the chapter. To make the videos, a slide show was developed and then a screen cast was recorded. Camtasia software was used to record and edit each video. During the early creation of the videos, the video team reviewed each video as a group and provided constructive feedback on the audio and video clarity, accuracy of statements, and logical flow. The meeting as a video team not only provided learned lessons for each member of the group but also promoted commonality across the videos. The target time for each video was 5 min, with a goal that no video should be longer than 10 min. After four chapters, where each videographer made approximately eight videos, the ensuing video-making was more independent, with the undergraduate students submitting scripts and the slide show for feedback and approval prior to recording. Each video also began with a statement of the learning objective to show students the relationship between the video content and the course expectations. Approximately six chapters of videos were made over the summer, and the final three chapters were made during the fall semester implementation. This process resulted in 47 videos with an average length of 5 min, 33 s. Representative videos (one on solubility product constants and one on pH of weak acids) are available in the Supporting Information.

Flipped PLTL Class Structure

The Flipped PLTL approach targeted replacing half of the assigned class time with PLTL sessions. The replacement of only half of the class time is sometimes called a hybrid-flipped or semiflipped approach. As the normal class structure met twice weekly for 75 min, this meant replacing one class session each week with PLTL. During these sessions, students engaged in small-group work facilitated by peer leaders and the instructor. Each peer leader was assigned a location in the classroom (usually a row of seats) and approximately 12 students to work with. Smaller groups of two to four students formed within the groups of 12 students, and though this limited the interactions between the groups, it was a logistical necessity because of the stadium-style fixed seating available. During the first week of classes, students were informed of their assigned location, and the assigned location did not change over the semester. This was done to promote long-standing familiarity between the students and the peer leader and among the students. Student attendance at the PLTL sessions was mandatory; leaders took attendance at these sessions by passing sign-in sheets to their assigned students.

Each week then incorporated one lecture followed by one PLTL session. At the start of each week, three to five videos related to the content covered that week were posted on the classroom management system. The relationship between the lecture content and video content each week was variable. When a new topic was introduced (e.g., at the start of a chapter) videos addressed foundational concepts and the definition of key terms. With much of the GC2 content (kinetics, equilibrium, acid−base, thermodynamics, and electrochemistry), the majority of the videos focused on additional problem-solving examples and the interpretation of the resulting answers.

Additionally, each week a quiz was posted on the management system with questions related to the video content. Each quiz featured three to five questions related to the posted videos for the week. To promote watching of the videos by the students, the related videos were also ported into the quiz. Each week the quiz was due by 11:30 p.m. the night before the PLTL session. This schedule was designed to increase the likelihood that students would engage with the material and be more prepared for the problems in the sessions. Performance on the quizzes counted for 5% of each student's final grade.

During the PLTL sessions, students worked in groups on worksheets, which consisted of a set of problems that were generated collaboratively by all of the instructors teaching with the Flipped PLTL approach. Problem sets were based on content recently covered in lecture and the videos that were assigned. The length of the problem sets varied from 12 to 17 problems. Some problem sets were designed to scaffold the introduction of complicated content, progressing from more accessible to more complicated. For example, students could be asked to first identify and describe a buffer solution, then to solve for the pH of an example buffer solution, and finally solve for the pH after an acid or base has been added to the solution. Other problem sets deliberately incorporated open-ended problems, such as Creative Exercises,[34] to promote group

DOI: 10.1021/acs.jchemed.6b00395
J. Chem. Educ. XXXX, XXX, XXX−XXX

work by allowing each member to contribute and to show the linking of content throughout the course. Representative worksheets are available in the Supporting Information.

In addition to the worksheets, clicker questions were designed by the instructors of the reformed pedagogy to periodically test the students' understanding of the worksheet problems and serve as formative assessments for instruction. That is, if students did not perform well on a clicker question, the instructor might engage in a short (1−3 min) period of "just in time" teaching during the PLTL session. For these periods of teaching, the instructor might refer to an earlier conceptual explanation, describe a common misconception associated with a problem, or on rare occasions work through a problem on the document camera. To promote student focus on the process and not the answer, these worksheets were not graded; students received credit only for attendance and clicker responses. Similarly, answer keys to the worksheets were not posted. However, at the end of each session, clickers were used to hold a student vote to determine one question from the worksheet that would have a worked solution posted online after class.

Recruiting and Training Peer Leaders

Peer leaders were recruited from students who were successful (earning a B or higher) in previous semesters of GC2. Recruiting for the first implementation involved identifying students from university records and using e-mail solicitations. After the first implementation, the majority of peer leaders were recruited from previous students enrolled in the GC2 classes that used Flipped PLTL. With the goal of a 12:1 student to peer leader ratio, 21 peer leaders were needed. Because of concern that one or two peer leaders may occasionally be absent, 23 peer leaders were recruited. The two extra peer leaders were floaters whose responsibilities included filling in for absent peer leaders, relaying to instructors student progress or common misconceptions in the problem set, and otherwise helping students when available.

Peer leaders enrolled in a semester-long training course that ran concurrently to GC2, for which they received upper-level elective credit; they were not monetarily compensated for their time. The training course met once per week, before the PLTL session, and was conducted as a mock PLTL session. Peer leaders were placed in groups of four and worked on the same worksheets students would be given that week. One of the instructors of the Flipped PLTL GC2 class taught the training course and modeled desired peer leader behavior during these classes. Targeted peer leader behavior was based on the collaborative learning literature. For example, the instructor encouraged leaders to talk to each other about problems, probed their understanding of the concepts needed to complete the worksheets, and guided them through points of difficulty rather than providing answers to questions. Additionally, peer leaders were asked to explain the process needed to reach a particular answer, with a particular emphasis on having explanations for both answers that were initially correct and those that were incorrect. Peer leaders were also asked to brainstorm likely student misconceptions related to the problem set and how they would identify those during the PLTL sessions. As the instructor engaged in these practices, the decision-making process for engaging in particular discussions was made explicit, alerting the peer leaders to the intention that they should also engage in such practices during their PLTL sessions.

Peer leaders were graded on mandatory attendance at the training classes and PLTL sessions, biweekly reflection journal assignments, random observation of their practice in PLTL sessions, and timely submission of attendance records. For their journal assignments, leaders were asked to reflect on recent PLTL sessions and describe goals for improvement of their future practice as facilitators. Each journal had a theme that was based on areas of improvement recognized in the sessions. Example themes include having the peer leaders describe their efforts in the sessions to promote students working in groups, challenge students to explain their process particularly when students have a correct answer, model a productive start to the sessions, and proactively engage all students instead of reactively working with those requesting help. The instructor of the training course reviewed these journal entries and provided the leaders with written feedback including ideas for improving trouble areas or topics of concern.

Random observations were primarily conducted by the instructors of the reformed pedagogy and occasionally by other members of the instructional team (e.g., postdoctoral scholars and graduate teaching assistants trained in collaborative learning techniques). During these observations, the evaluator passively observed a leader engaging in a portion of a PLTL session; immediately after the session, the evaluator met privately with the leader and provided both positive and constructive verbal feedback. At this time, leaders were also encouraged to express their own opinions about their experiences as leaders (both positive and constructive reflection) so that the feedback was more conversational than directive-based.

■ EVALUATION OF FLIPPED PLTL

To determine the effectiveness of Flipped PLTL to achieve educational outcomes, the evaluation focused on the common exams at the research setting. Within each semester, the instructors teaching the course created common exams that used multiple-choice questions and one measure of linked concepts (MLC).[35] The MLC provides students a single prompt related to recent content and a series of true/false statements for students to evaluate. The true/false statements include content from past topics throughout first- and second-semester general chemistry to show the links of content throughout the course sequence. Students took each exam at a common time.

The analysis guiding the evaluation was conducted on the class level, with each class representing a single data point. Two considerations drove the decision to use class-level data instead of student-level data. First, inferential statistics rely on an assumption of independence of observations. At the student level, there are concerns that this assumption is violated, as students may impact the academic performance of other students within a class. At the class level, it is less likely that one class influences the academic performance of another class. Second, instructors' decision to adopt a pedagogical reform occurs at the class level, and class-level statistics are more informative regarding the expected outcomes of adoption. The drawback to the class-level approach is a limit on statistical power due to the small sample size, which will be discussed in interpreting the results.

During the two semesters of implementation, each semester used a different topic sequence and created new exams. To combine exam scores from the two academic terms, each student's exam score was converted to a z score. The z score

DOI: 10.1021/acs.jchemed.6b00395
J. Chem. Educ. XXXX, XXX, XXX−XXX

used the overall average across all classes within one semester. The z-score conversion adjusts for the difficulty and topic coverage of a particular exam, as the two semesters' exams were not equivalent. After the z-score conversion, the class average for each exam was determined, and these class averages represented the data points used. The performances of the Flipped PLTL and traditional classes are presented in Table 1 along with demographic information and SAT subscores obtained from university records. (A review of class averages within each semester found similar results as in Table 1, with every flipped class outperforming every traditional class.)

Table 1. Impact of Flipped PLTL Pedagogy on Class Performance

Measure	Average (SD) for Four Classes of Flipped PLTL Instruction	Average (SD) for Four Classes of Traditional Instruction
Class size	254 (12)	245 (33)
Female students, %	60.9 (4.0)	62.0 (4.2)
URM,[a] %	35.5 (4.1)	38.1 (3.1)
SAT math subscore	579.9 (31.4)	573.4 (5.5)
SAT verbal subscore	570.5 (28.8)	558.9 (6.1)
Exam 1 score	0.289 (0.198)	−0.310 (0.159)
Exam 2 score	0.299 (0.175)	−0.333 (0.173)
Exam 3 score	0.237 (0.171)	−0.261 (0.077)
Final exam	0.165 (0.172)	−0.180 (0.046)
Pass rate, %	93.3 (3.8)	84.3 (5.6)

[a]URM indicates the percentage of students who identified as an under-represented minority (Hispanic, African American, or Native American).

The data in Table 1 indicate that the classes employing the Flipped PLTL implementation outperformed the classes with traditional instruction on each exam. Independent sample t tests were conducted on each exam, and the results are shown in Table 2. The effect size for each was also determined using Cohen's **d**, as shown in Table 2.

Table 2. Results of Independent Sample t Tests Comparing Flipped PLTL and Traditional Instructional Approaches

Exam	t Statistic	p Value[a]	Cohen's **d**
1	4.71	0.003	3.33
2	5.15	0.002	3.64
3	5.31	0.002	3.75
Final	3.85	0.008	2.72

[a]$\alpha = 0.01$.

The t tests were evaluated at an α level of 0.01 to manage groupwise error, and each exam had a significant difference with this threshold. The interpretation of Cohen's **d** warrants caution, as effect sizes at the class level are not comparable to those at the student level.[35] That said, past class-level analysis of the use of PLTL to replace lecture time had an effect size of **d** = 1.49−1.78 on an ACS Exam.[31,36] The effect sizes in Table 2 for the ACS Exam exceed these figures, providing an indication of a stronger impact, though replication is needed to verify this claim.

From Table 1, it can be seen that the class-average SAT subscores for the classes with the Flipped PLTL approach are higher than those for the classes with traditional instruction. Univariate analysis of covariance (ANCOVA) can determine the effect of pedagogy on each test score while controlling for a covariate such as SAT Math or SAT Verbal. Since SAT Math and SAT Verbal are highly correlated in the data, the decision was made to conduct an ANCOVA to determine the impact of Flipped PLTL for each test while controlling for SAT Math. The analysis was then repeated while controlling for SAT Verbal. Each test was conducted with an α level of 0.01. The results showed that the Flipped PLTL pedagogy has a positive and significant impact on class performance while controlling for each SAT subscore for each exam.

The classes adopting the Flipped PLTL pedagogy consistently outperformed the classes with traditional instruction. The consistent improvement was also maintained when controlling for either SAT subscore. It is also noteworthy from Table 1 that the pass rate for the classes with the Flipped PLTL approach exceeded the pass rate in the traditional course. The difference in pass rate was not significant, likely because of the aforementioned limit on the statistical power. However, the higher pass rate with the Flipped PLTL approach rules out concern that the improved performance was a result of greater student attrition in the course.

■ CONCLUSIONS AND FUTURE DIRECTIONS

The Flipped PLTL approach has been offered in four classes of GC2 at a large research-intensive university. This approach offers a means for students to engage in purposeful discussion of course content, including being challenged to explain their understanding and processes beyond arriving at a correct answer. The Flipped PLTL approach is able to match the depth and breadth of content covered in a traditional lecture format, as in this setting both approaches employed a common content sequence and exams. After the first year of implementation, assessment of the reformed pedagogy indicates that students in Flipped PLTL classes experienced both higher achievement and higher retention. Future work will further evaluate the effectiveness of the approach as well as investigate the impact of a multicourse adoption through first-semester organic chemistry to investigate the impact on curricular-wide student retention.

The intent of this article was to provide sufficient detail for would-be adopters to implement a similar approach in their courses. Those implementing flipped pedagogies, particularly with large class sizes, are cautioned against relying on flipped classes as a vehicle for additional lecture. The Flipped PLTL approach can serve to mitigate this risk by facilitating student engagement in active learning. Additionally, the model is scalable to any class size by modifying the number of peer leaders enrolled.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.6b00395.

Sample worksheets (PDF, DOCX)

Example video on K_{sp} (MOV)

Example video on pH of weak acids (MOV)

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DOI: 10.1021/acs.jchemed.6b00395
J. Chem. Educ. XXXX, XXX, XXX−XXX

Notes

Disclaimer: Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

Partial support for this work was provided by the National Science Foundation's Improving Undergraduate STEM Education (IUSE) Program under DUE-1432085.

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DOI: 10.1021/acs.jchemed.6b00395
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