Active Learning Strategies in Undergraduate Physical Chemistry (CH441) at Oregon State University

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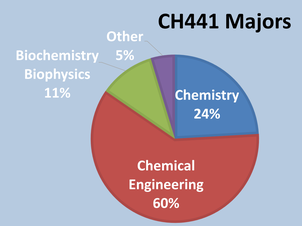
Abstract

CH441 is the second term of the year-long Physical Chemistry lecture sequence at Oregon State University. This large-enrollment course is generally regarded as one of the more challenging classes on campus largely because physical chemistry requires working knowledge of *both abstract concepts and advanced mathematics simultaneously,* often unlike what students have previously been exposed to (Derrick and Derrick, 2002). Our goal in this research study was to evaluate the impact of active learning strategies on student learning and to provide ways to improve instruction in future terms.

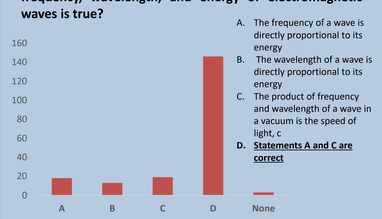
Context

CH441 focuses on **quantum chemistry** and **spectroscopy**. Students learn the fundamental postulates of quantum mechanics and how they are applied to the behavior of atoms and molecules. Seventy percent of students enrolled in Winter 2017 had Junior class standing. This course is required for Chemistry, Chemical Engineering, and Biochemistry Biophysics majors.

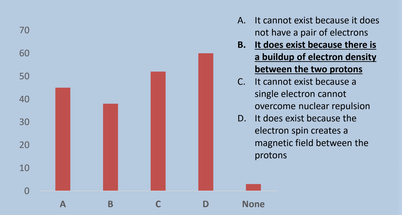
In our pre-survey, we found 65% of students had taken the General Chemistry for Science Majors series (CH23X), 32% had not taken general chemistry at OSU, and the remaining 3% took a different series. Using select questions from a Quantum Chemistry Concept Inventory (Dick-Perez et al., 2016), we see that some concepts introduced in Freshman level chemistry were retained through Junior year (Q1), but others were not (Q2).



Q1. Which of the following statements about the frequency, wavelength, and energy of electromagnetic waves is true?



Q2. Which statement about a chemical bond in H_2^+ is correct?



Students recall the equation $E = \frac{hc}{\lambda}$ to correctly answer Question 1. However, in Question 2 the class is evenly split on the existence of H_2^+. Linear combination of atomic orbitals (LCAO) theory is also taught in CH231 at OSU.

Research Questions

Active learning has been shown to increase student engagement and critical thinking. Students in CH441 need to combine abstract thought with advanced mathematics. We therefore asked:

1. Which of the following strategies can be adapted for active learning in Physical Chemistry:
   - Semi-flipped classroom days complemented by online video content;
   - Optional recitations with worksheets and group activities led by graduate and undergraduate teaching assistants;
   - "Muddiest Point" exercises after exams

2. How can we evaluate the impact of active learning lessons on student learning? Can we assess student learning in terms of exam scores and sophistication of responses?

Background and Frameworks

Active learning engages students and promotes critical thinking by asking students to make connections between different ideas and concepts (Ueckert and Gess-Newsome, 2008). To improve student understanding and draw connections between lecture material and applications we implemented a series of active learning strategies like group work, peer mentoring, and studio-style recitations. Such efforts have previously been successful in higher-level mathematics courses (Rosenthal, 1995).

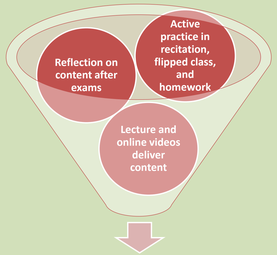
Activities chosen to study:

Semi-flipped classroom with online content. In this approach, students use lecture time for problem solving. The professor and teaching assistants help student groups. Online content supplements lecture material. We chose to do flip class activities during exam weeks. Online content was added throughout the term.

Recitation. Twice-weekly recitations were optional but we awarded bonus points if students attended and participated. Different activities were used each week including group worksheets (3 problem sets), white board activities, and stations.

"Muddiest point". After each exam, we asked students to revisit the question they found most difficult (i.e., the "muddiest point") and solve the question again with explanation at each step.

The rationale of our course design is shown schematically on the **right**. Teaching assistants discuss integrating course content with video recordings and recitation activities (**below**).



Conceptual and Mathematical Understanding of Quantum Chemistry

Methods

To guide the development of activities, we examined the Student Learning Outcomes and reviewed exam responses from previous years that track with a given learning outcome in order to determine where improvement is needed.

Data Collection:

The data we collected included student surveys, recitation attendance, exam scores, and post-exam reflections.

Students completed both a pre- and post-survey. In the post-survey, students were asked to reflect on what they had learned over the quarter.

Data Analysis:

Midterm scores, final exam scores, homework scores and overall course scores were compared to previous years.

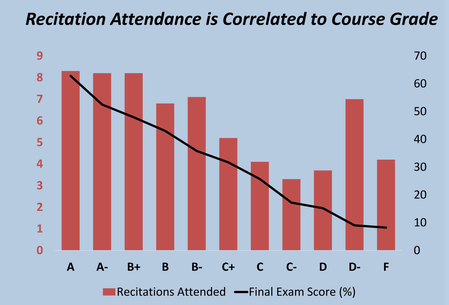
Composite scores and student responses were compared to previous years to evaluate if our interventions were successful. Student success is defined not just as higher composite scores, but also in terms of increased correct responses related to learning outcomes. Recitation worksheets, flip class worksheets, and final exams were analyzed for evidence of student learning.

Results

Of the active learning strategies we pursued, we found that recitation attendance was strongly correlated with course performance. 145 students of 215 total (67%) attended the twice weekly sessions on average.

Students who made an A, A-, and B+ grades attended an average of 8.3 of 9 recitation sessions. Students who made a D or less attended recitation half as often on average.

In the post-survey, students reported that recitation was helpful.



"Muddiest point" exercises after Midterms 1 and 2 had been implemented in CH441 as early as 2015. While less strongly correlated to success, students who participated after both midterms were more likely to end the course with a B- or better.

Flipped class exercises were difficult to assess because students reported that they did not have enough time to complete the tasks. Only half of a 50 minute lecture period was allotted for each flipped class activity that included up to three demonstrations and/or example problems.

Discussion

Of the strategies we investigated, the focused recitation seemed to impact course performance the most. However, recitation participation was also highest. On average 67% of the class attended recitation each week. Approximately 57% of students attended class on flipped days, and roughly a quarter (27%) of students completed both muddiest point exercises. In 2015 and 2016, muddiest point exercises had higher participation (40%).

Student effort seems to be a larger predictor of success, which was seen when we analyzed homework assignments (Table 1).

	A	A-	B+	B	B-	C+	C	C-	D	D-	F
2017	88 (0.2)	87 (0.3)	82 (0.4)	76 (0.5)	77 (0.5)	71 (0.6)	56 (1.3)	50 (1.7)	45 (1.3)	45 (1)	22 (3.4)
2016	90 (0.1)	83 (0.4)	80 (0.5)	75 (0.6)	66 (1)	69 (0.9)	58 (1.3)	70 (0.9)	35 (2.5)	--	40 (2.2)
2015	80 (0.1)	90 (0.1)	81 (0.4)	76 (0.5)	77 (0.4)	70 (0.7)	65 (0.9)	45 (1.7)	--	--	46 (2.2)

Table 1. Homework scores and average number of homework zeros (in parenthesis) from 2015 to 2017.

Participation is required for successful active learning. In future years, we will also explore strategies to increase student engagement. We will also revisit the idea of flipped classes during exam weeks and instead flip the classroom earlier, when students are first learning the material.

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