Abstract

Introductory Organic Chemistry (CHM242) has over 350 students each semester, representing a wide range of academic backgrounds and study habits. This project initially aimed to compare active learning strategies, such as Problem-Based Learning (PBL), with traditional passive methods through qualitative observations to determine which approach best supported student learning and engagement. However, midway through the study, the results became less conclusive, prompting a shift in the hypothesis.

The revised hypothesis proposed that active learning environments, like PBL, foster positive changes in study habits, ultimately enhancing student performance in CHM242. Rather than directly comparing learning methods, the objective was to determine whether active learning could motivate less engaged students by encouraging peer discussion and collaboration, thereby promoting self-improvement. The findings suggest that active learning can indeed improve study habits, and it is never too late to recognize what isn't working and make the necessary changes—something I also experienced working on this project.

Introduction

Organic chemistry is one of the most challenging STEM subjects and a key foundation for fields like biology and medicine. CHM242, a second-year introductory course with over 350 students per semester, introduces principles and mechanisms of alkanes and alkenes, essential for CHM243 and other upper year courses. The course emphasizes understanding and application over rote memorization, raising the question: how can educators better foster critical thinking and problem-solving skills to prepare students for advanced courses and interdisciplinary concepts?

While traditional lectures and tutorials focus on passive learning, Facilitated Study Groups (FSGs) offer interactive, personalized experiences in learning. As a facilitator for two years, I used the CHM242 sessions to test my initial hypothesis: that problem-based learning (PBL), an active learning approach, fosters better understanding and problem-solving skills in organic chemistry compared to traditional passive learning. Drawing from my experience with PBL in CPS401: Development in Scientific Education, I implemented a student-centered instructional approach where students are challenged to identify and define the problems themselves, encouraging active engagement and critical thinking.[1] PBL integrates peer instruction, fostering collaborative discussion where students evaluate and critique each other; flipped classrooms, where students prepare independently and use classroom time to solve problems; and systemic thinking, which involves applying what has been learned to solve a present problem, and then branching out to connect with other relative concepts.[2] My goal was to foster self-motivated learning, helping CHM242 students take ownership of their learning while building critical thinking, creativity, teamwork, and adaptability for real-world challenges.

I developed PBL-specific problems combining CHM242 test-style questions with chemical laboratory scenarios, requiring independent research from students. Student outcomes, including time spent and accuracy, were analyzed and compared to trends observed in passive learning environments like lectures.

Midway through the semester, I realized that my conclusion seemed self-evident: smaller class sizes, typically around 20 students, are significantly more effective for implementing active learning strategies. In these settings, students can get to know each other more easily, fostering better collaboration among peers. However, I noticed that many students remained disengaged, even in the active PBL environment, which led me to question their motivation for attending as I worked to promote engagement. This realization prompted me to refine my hypothesis: active learning environments like PBL encourage positive changes in study habits, ultimately enhancing student performance in CHM242.

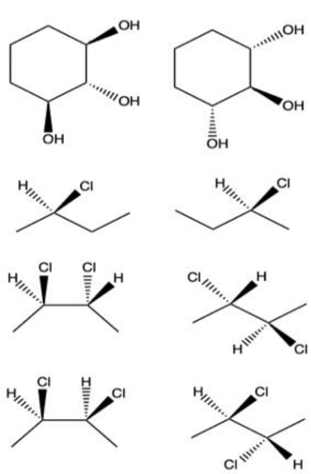
PBL allowed me to assess students' cumulative knowledge after midterms while helping them reinforce previous topics, build a foundation for future material, and track tangible progress. Notably, one initially unenthusiastic individual showed significant improvement by the end, encouraged by my guidance and peer support. This outcome supported my hypothesis that active learning environments foster healthier study habits through collaboration and a sense of constructive competition, driving self-improvement.

Experimental/methods

Initial observations in traditional settings, such as Monday lectures and Tuesday tutorials, revealed predominantly passive learning, with students listening to the lecturer which limited group interactions. In contrast, the professor's help sessions encouraged active participation, where students took the initiative to ask questions at the blackboard and problem-solve. Similarly, in the Facilitated Study Groups (FSGs) I led through UTM RGASC, I designed weekly plans with tailored questions and activities to promote engagement and collaboration in CHM242.

The first type of questions focused on theoretical concepts, aiming to explore foundational principles and straightforward explanations. Within this, topics included bonding, with questions such as: *What are three differences (among many) between sigma and pi bonds?* and *how does hybridization allow for the bonding of simple molecules like methane?* The next two topics covered stereochemistry identification and conformational analysis, with examples provided below.

Identify the following pairs as enantiomers, diastereomers, or meso compounds.



Draw an energy diagram for $CH_3CH_2CH(CH_3)_2$ *with all the Newman projections and plot their relative energies against the angular rotation (start with the highest energy).*

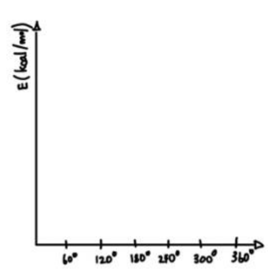


Figure 2. Sample questions in the session plan involved identifying stereoisomers, converting between Newman projections, and determining the difference in energies among configurations.

The second type of question focused on predicting reaction products and drawing corresponding mechanisms, including distinguishing between substitution and elimination reactions and identifying conditions favoring each. Students analyzed specific mechanisms (E1, E2, SN1, and SN2), selecting and accurately illustrating the appropriate mechanism using arrow-pushing to show electron movement. Questions were sourced and adapted from textbooks, past tests, and exams, with modifications to align with the course material.

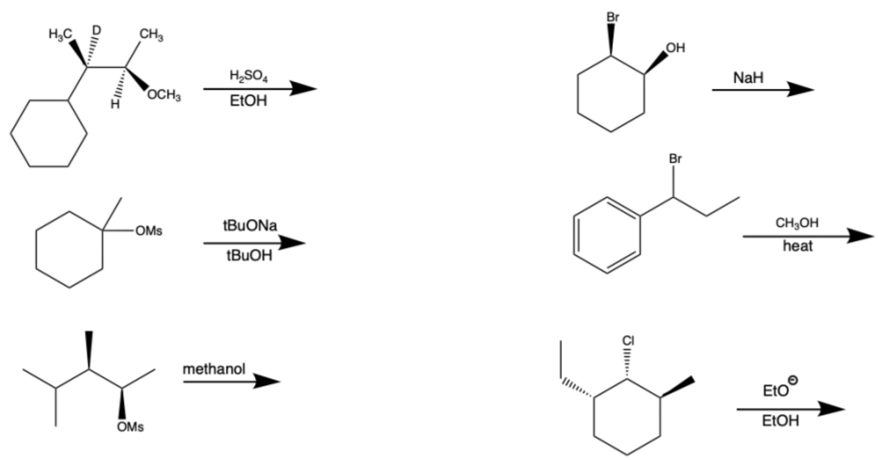


Figure 3. Sample questions in the session plan involved identifying reactions as SN1, SN2, E1, or E2, as well as illustrating all reaction mechanisms.

The first cumulative PBL questions covered material up to the first midterm, focusing on a perfume company developing specific fragrance compounds. The questions included five case-based scenarios, incorporating "What If" situations—such as altering reaction conditions like temperature or base bulkiness—to assess students' understanding. The PBL introduced gas chromatography as a key analytical tool in organic laboratories. Students analyzed pentan-3-ol and pent-2-ene, predicted the effect of a polar stationary phase on retention times, and proposed methods to improve separation for overlapping peaks. This section encouraged students to conduct independent research on chromatography.

Aroma Alchemy is a boutique perfume company trying to create "Celestial Bloom," a new perfume combining fruity esters, floral aromatics, and musk-like alkenes. However, issues in the chemical synthesis process are leading to unwanted by- products and low yields of key ingredients. Dr. Celeste Parfum asks your team to help solve these problems.

CASE 1. Substitution or Elimination? *The chemists are reacting three-bromopentane with sodium ethoxide in ethanol. They anticipate both pentan-3-ol and pent-2-ene.*
Reaction Details: Three-bromopentane reacts with sodium ethoxide (a strong base) in ethanol at high temperatures.

1. Explain: What are substitution and elimination reactions? How are they different?
2. Draw: Show the mechanism for the reaction that makes pentan-3-ol.
3. Draw: Show the mechanism for the reaction that makes pent-2-ene.
4. Propose: How could the chemists increase the amount of pentan-3-ol? (Hint: Think about the strength of the base or temperature.)
5. What If: What happens if the chemists use a large, bulky base like potassium tert-butoxide? Predict the product and explain why.

Figure 4. Sample questions in the session plan from the first PBL, which focused on distinguishing between substitution and elimination reactions, as well as the conditions that differentiate the two. Students were encouraged to think beyond the question itself and consider other examples seen in class or textbooks.

The second PBL built on earlier topics, introducing theoretical questions on radicals, C-H bond energies, and carbocation stability. Students took on the role of scientists tasked with identifying hazardous, unlabeled chemicals in an inventory. Using a list of alkyl halides with varying branching and reagents, including strong and soft bases, they performed reactions to deduce the identities of the compounds. Hints included specific functional group tests, such as the Finkelstein test for alkyl halides and the Lucas test for alcohols, prompting students to research these methods to solve the problems effectively.

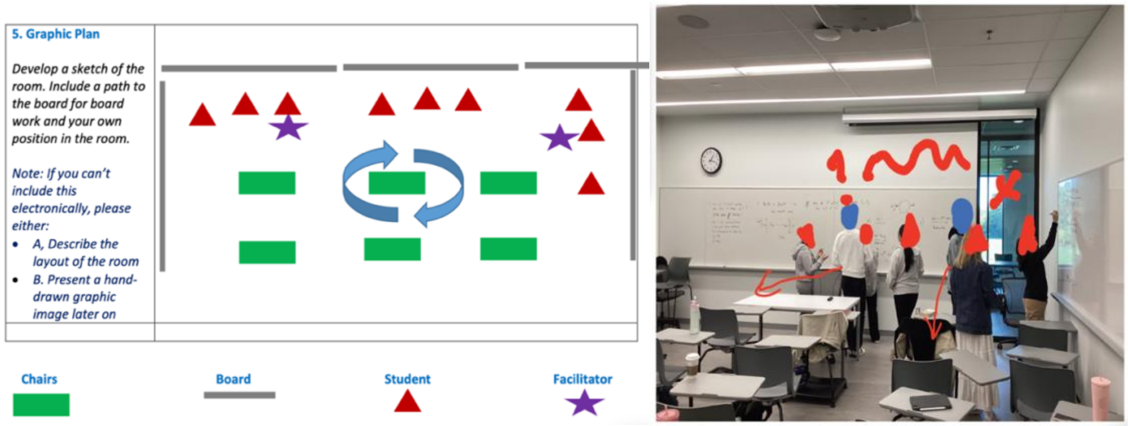


Figure 5. A graphic plan of the layout for the FSG session (left) which promoted an active classroom where all students were engaged at the board. The rotation ensured that every student attempted and reviewed all the different questions. An actual photo of a session (right), taken by the Program Assistant, provided a real-life example. The student faces were covered by the Assistant, with blue representing my face and my co-facilitator's face, while the red dots represented student faces. The arrows indicated the directions in which groups of students rotated to attempt other questions after the five minutes were up.

Out of the 20 average attendees, 6 consistent students were specifically observed to test the hypothesis. In this active environment, three women, who were not friends before but became friends during the course, consistently participated in questioning, demonstrating great engagement and attention. Additionally, three individuals worked quietly on their own without interacting with anyone or contributing to group discussions. Later in the course, one student experienced a positive change in their study habits and performance, which he also acknowledged and reflected upon, as explained later.

Each session, regardless of the question type, evaluated the responses of the 6 students based on time and accuracy. For accuracy, a scale of 0-3 was applied:

- 0: Completely incorrect, with the concept and execution both wrong.
- 1: The general knowledge or idea was correct but the execution was wrong in a pathway or mechanism (e.g., recognizing a substitution reaction occurred instead of an elimination, but confused SN1 for SN2, or vice versa).
- 2: The execution was mostly correct, with minor errors such as incorrect arrow-pushing.

- 3: Fully correct, with no errors.

In terms of timing, each question set was designed to take less than five minutes to complete, including its various components. For instance, tasks such as predicting the reaction and drawing the mechanism were expected to take under a minute and there would be a total of five of these in a set. This guideline helped assess whether students completed questions within or exceeded the five-minute mark—the standard time.

The two PBL-specific sessions served as a cumulative measure of students' retention of knowledge, particularly since they followed test sessions when the material should still have been fresh in students' minds. These PBLs also theoretically provided opportunities for students to improve and learn more effectively in the course, as each session built on prior knowledge and prepared students for the upcoming week's content and quizzes or self-assessments.

Results and discussions

Student Engagement and Participation Patterns in Tutorials

During the initial tutorials, which followed traditional passive methods, student seating revealed their engagement levels. Proactive students eager to learn typically sat near the front, while less engaged students, often focused on claiming attendance or copying answers, occupied the back. Some back-row students engaged in irrelevant activities, such as using phones, and one even arrived without paper or pen. Many did not attempt the self-quizzes, waiting instead for the TA to provide answers.

The TA encouraged students to engage in discussions and even invited them to solve problems on the board, but participation was limited and hesitant during the initial weeks. As expected, the students at the front were more open to interacting with those around them, regardless of whether they were friends or strangers–observed through many students introducing themselves to each other. This openness led to productive discussions and collaborative problem-solving. Some "alpha" students took the initiative to identify mistakes and guide others in the group toward the correct answers and concepts, such as distinguishing between stereoisomers and reagent conditions.

In contrast, back-row students rarely interacted with their peers. However, as the course progressed into reaction mechanisms, some began to participate minimally, seeking answers rather than engaging deeply with the material. For example, the student beside me made a superficial attempt at problem-solving and showed little interest in understanding the reasoning behind E1 or E2 mechanisms, prioritizing quick answers instead.

Engagement and Performance of Attendees in FSG Sessions

In the FSGs that I led, the three proactive women consistently achieved high results according to my metric system, maintaining this trend throughout the semester. The table below illustrates their performance, with the left split cell representing accuracy on a scale of 0 to 3, and the right split cell indicating time. An upward arrow in the time column signifies that they took more than the expected five minutes to complete each problem set.

Table 1. Accuracy and Time Results for Active Group Members Across Sessions

	Sept 23		Sept 30		Oct 7		Oct 14 (PBL 1)		Oct 21		Nov 4		Nov 11		Nov 18 (PBL 2)		Nov 25	
Group member 1	2	↓	3	↓	3	↓	3	↓	3	↓	3	↓	3	↓	3	↓	3	↓
Group member 2	2	↓	3	↑	3	↓	2	↓	3	↓	3	↑	3	↑	3	↓	3	↓
Group member 3	3	↓	3	↓	3	↓	3	↓	3	↓	3	↓	3	↓	3	↓	3	↓

These students exemplified what it meant to be engaged in active learning, as seen in their consistent results during regular sessions and cumulative PBL activities. They demonstrated full comprehension of the material and actively participated in peer instruction, engaging in thoughtful discussions and brainstorming with fellow students. For example, when tasked with drawing and explaining how hybridization allows for the bonding of methane, these students went beyond the correct answer and described the bonding in molecules such as ethene and ammonia. In another instance, when asked to draw and graph the energy profiles of Newman conformations for $CH_3CH_2CH(CH_3)_2$ (**Figure 2**), the students completed the task so quickly that they began discussing a problem involving different steric hindrance groups until time was up, showcasing both their efficient use of time and effectiveness in applying the concepts.

The three passive students sitting at the back initially demonstrated results consistent with expectations, reflecting struggles in areas such as general stereochemistry, bonding theories, and Newman conformations. They often faced challenges with timing, frequently taking more than five minutes to complete tasks, and their answers were prone to inaccuracies. For instance, they struggled to differentiate between enantiomers and meso compounds, had difficulty identifying the conditions required for various mechanisms, and frequently misapplied mechanisms or made errors in arrow pushing and electron flow (**Figure 3**). Consequently, their scores were consistently low, typically 0s or occasionally 1s, due to poor timing and limited accuracy.

Table 2. Accuracy and Time Results for Passive Individuals Across Sessions

	Sept 23		Sept 30		Oct 7		Oct 14 (PBL 1)		Oct 21		Nov 4		Nov 11		Nov 18 (PBL 2)		Nov 25	
Individual 1	2	↑	1	↑	0	↓	1	↑	1	↑	1	↑	1	↓	1	↓	0	↓
Individual 2	0	↑	1	↑	0	↑	0	↑	0	↑	1	↑	1	↑	1	↓	1	↓
Individual 3	0	↑	1	↑	0	↑	1	↑	2	↑	2	↓	2	↓	3	↓	3	↓

Positive Changes in Study Habits Through Encouragement and Healthy Competition

After the first midterm, I noticed that three individuals were consistently passive in their engagement. Their response times were long, and their accuracy was low, which I suspected might be reflected in their test scores—though they chose not to share them with me. This observation prompted me to amend my hypothesis. I wanted to explore whether it was possible to foster improved study habits within an active learning environment. To implement this, I tried to incorporate these individuals into various groups that demonstrated strong engagement and collaboration.

Individuals 1 and 2 remained reluctant throughout, often disengaging shortly after being placed in a group. They would return to their seats after five minutes, either taking notes passively or using their phones. At that point, I stopped pushing and decided they could serve as a control group or comparison.

In contrast, Individual 3 followed a different trajectory. Placed in a group with the three women mentioned earlier, he initially struggled to participate, as he recognized their outstanding results and performance times, which he found a bit intimidating. However, after the first PBL session, he began contributing to problem-solving through my encouragement and the group's inclusiveness. Over time, his results improved, and a key milestone was his development as a systemic thinker. For instance, after the second PBL session, which focused on basic radical theories and carbocation stability, he asked me insightful questions about distinguishing initiation, propagation, and termination in radical reactions—topics that were scheduled for later classes. Furthermore, he gained confidence as he recognized his steady progress and improvements during the sessions. When approaching me with past midterm problems, instead of asking me for explanations, he would first explain his thinking and everything he already understood in detail before seeking my feedback. These results demonstrated his growing interest in the material and his improvement in organic chemistry throughout the semester, driven by his shift from passive to active learning.

Keys to Success in the Course: Motivation, Participation, and Consistency

Based on my observations and discussions, I concluded that all students attending the FSGs were motivated to succeed and cared about their performance in the course. However, the real question was why some students remained passive despite committing to attend. Some may have simply been shy or introverted in this environment, which was understandable, while others might have relied on the "leeching method"—passively absorbing information from teachers, others' answers, or notes,[3] a strategy they had become familiar with in secondary school and even in many university courses. The real reason, however, was that while the FSG sessions were welcoming, they were also competitive, driven by "alpha" students—such as the group of three knowledgeable women who confidently showcased their expertise. I had witnessed these students going beyond the questions and actively teaching others, which aligned with the goal of the sessions: active participation and peer instruction. In this competitive environment, students who weren't as confident in chemistry faced two options: they could remain passive to avoid the spotlight, as seen in Individuals 1 and 2, or they could recognize the strength of their peers and ask themselves, "What can I do to improve?" like Individual 3 did. I observed both reactions in students, which reflected how competition could push some to change their study habits to improve themselves.[4]

A key component of the FSGs, particularly with cumulative PBLs, was the importance of consistency over sporadic participation. This was evident during term test weeks when attendance doubled on Mondays, with around 40 students crowding the room. The influx of newcomers, many attending for the first time, often felt out of place among regular attendees who had already established rapport with me and my co-facilitator. This disconnect made it challenging for newcomers to stay engaged with the problem sets, as they lacked the familiarity and collaboration seen in regular participants. Instead, many resorted to taking pictures of solutions from the board. This approach will not only risk students losing the photos among thousands in their camera rolls, but it will also fail to promote genuine understanding. If students rely on recognition rather than active problem-solving, which helps retain concepts, they will struggle to recall solutions during tests, leading to uncertainty when faced with similar questions.[5]

Limitations and Future Steps

While the project successfully implemented active learning methods like PBL to foster student engagement and learning, several limitations were identified that impacted its scope and methodology. Due to ethical considerations, no quantitative data or grades were collected or disclosed, and students' performance was evaluated solely through qualitative observations or informal assessments. This approach, while offering valuable insights into student interactions and behaviors, limited the ability to analyze objective metrics of success, such as grading systems aligned with university standards, or identify statistical errors.

Additionally, the size of the classroom significantly influenced the effectiveness of these FSGs. In my project, working with a group of 20 students yielded positive results that answered my hypothesis, but I am curious about the threshold at which PBL ceases to be effective. This is something that could be explored further if resources allow. Smaller class sizes generally enhance PBL success by fostering better collaboration, more equitable participation, and smoother group interactions. In contrast, larger classrooms often face challenges such as reduced student engagement, unequal participation, and difficulties in monitoring group dynamics, all of which can undermine the effectiveness of PBL.[6]

In conclusion, the implementation of PBL in CHM242 fostered engagement and critical thinking, with proactive students excelling in accuracy and problem-solving. The transformation of a previously disengaged student into an engaged and successful learner proves that it is never too late for students to improve their study habits. Achieving this requires both effort from the students and an environment that promotes collaboration and constructive competition, driving self-improvement.

References

1. Kilroy, D. A. Problem Based Learning. *Emergency Medicine Journal* **2004**, *21* (4), 411–413.

2. Goode, G. S.; MacGillivray, L. The Construction of Systems Thinking Pedagogy during a Professional Development Institute. *Journal of Pedagogical Research* **2023**.

3. Kooloos, J. G. M.; Bergman, E. M.; Scheffers, M. A. G. P.; Schepens-Franke, A. N.; Vorstenbosch, M. A. T. M. The Effect of Passive and Active Education Methods Applied in Repetition Activities on the Retention of Anatomical Knowledge. *Anatomical Sciences Education* **2019**, *13* (4), 458–466.

4. Park, S. Does the Relationship between Competitiveness and Student Achievement Vary Based on the Culture of Competitiveness? Evidence from Pisa 2018. *International Journal of Educational Research* **2024**, *127*, 102438.

5. Kintsch, W. Recognition Learning as a Function of the Length of the Retention Interval and Changes in the Retention Interval. *Journal of Mathematical Psychology* **1966**, *3* (2), 412–433.

6. Olson, J. C.; Cooper, S.; Lougheed, T. Influences of Teaching Approaches and Class Size on Undergraduate Mathematical Learning. *PRIMUS* **2011**, *21* (8), 732–751.