The Role of Multiple Teaching Strategies in Promoting Active Learning in Organic Chemistry

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Abstract: We have introduced four alternative teaching strategies into our yearlong organic chemistry course and have assessed changes in student performance relative to the same course taught by the same instructors using a more traditional lecture format. These strategies, which include reading worksheets, dialogues, in-class worksheets, and role-playing, allow the professor to move through a learning cycle that may effectively accommodate the students' needs and multiple learning styles. The reading worksheets guide students through the concept phase and dialogues help students identify the importance of the concepts as they articulate these ideas for themselves. Group worksheets and role-playing provide opportunities for peer-interaction, application of knowledge, creativity, and self-expression. Others have shown that active learning strategies neither enhance nor diminish a student's ability to retain factual information, a finding that is supported by our study. Our data from this one study show, however, that students taught by a more traditional approach demonstrate a greater variation in final exam performance between first and second semesters than those taught using a combination of techniques. This result reflects a shift in emphasis from the professor as an information source to the actively engaged student taking responsibility for his or her own learning. This study suggests that these methods, when used in a consistent fashion in conjunction with interactive lecturing, provide a broad base to facilitate student learning and aid in the development of higher order thinking skills.

Introduction

> In this life, we want nothing but Facts, sir; nothing but Facts!...[T]heir eyes swept the inclined plane of little vessels then and there arranged in order, ready to have imperial gallons of facts poured into them until they were full to the brim.
>
> --Charles Dickens

Such begins *Hard Times* [1] and many an organic chemistry class. Many of us persevere in the passive delivery of facts even though we may realize that it is a losing battle against the overwhelmingly rapid accumulation of new information. How do we find a balance between the ever expanding body of knowledge that undergraduate students are expected to learn and our teaching of the process of learning, i.e., the balance of content versus process? In addition, we face the challenge of an increasingly diverse student body, many of whom have different learning styles than our own. Changing from the teacher-centered, lecture paradigm in science education to a more student-centered approach is a daunting task in the face of these issues. Faculty often shy away from trying teaching strategies other than the lecture because of the difficulty of demonstrating that these strategies make a difference. How do we know that we are reaching the majority of students or impacting their learning in any way? An insightful editorial pointed out the challenges of documenting results from "experiments" in the "swampy" but relevant area of student learning [2].

Inspired by numerous workshops and articles on learning theory, we began two years ago to incorporate several alternative teaching strategies into our yearlong course in organic chemistry and to document changes in student performance. At the beginning of this study, the two-semester organic chemistry sequence was taught in a modified lecture format. Classes were interactive in that they allowed student questions and comments, but the primary mode of content delivery was a formal lecture by the professor. In undertaking this study, each instructor shifted the focus of the class to student-centered learning. Lectures were limited to short explanations of material students did not understand. The bulk of the class was conducted using multiple active-learning strategies: reading worksheets, dialogues, in-class group worksheets and role-playing. Throughout the study one of the two authors consistently taught the first semester, and the other one taught the second. Our goals in this study were to determine if students benefited from these strategies in recognizably valuable ways. Was their learning of factual knowledge enhanced? Were students' critical thinking skills improved? Were students more engaged in their own learning?

We chose four teaching strategies to address specific student learning needs as we perceived them. Our objectives were threefold: to promote students' productive preparation time before each class, to develop students' ability to articulate concepts, and to accommodate the different learning styles of our increasingly diverse student body. The multiple strategies we employed may be seen to address the needs of several different learning styles as described by Kolb [3]. The "assimilator," who wants to know the concept and usually responds well to lecture, may still be accommodated in the new format through the use of guided reading worksheets. The "diverger," who needs to understand why ideas are important, benefits from the more frequent discussions and dialogues. The "convergers," who want to see the concept applied, are involved through dialogues and in-class group worksheets. The "accommodators" are by nature most dynamic and require the least active intervention by professors. They may benefit the most from role-playing and dialogues.

Reading Worksheet--Stereochemistry

1. What are the differences between the terms *chiral, mirror image, enantiomer,* and *chiral carbon*?
2. How can you tell if a particular carbon in a molecule is chiral?
3. What is the definition of the term *stereocenter* or *stereogenic center*?
4. What are the rules for interpreting perspective views of molecules? Fischer projections?
5. What features may exist in a molecule that will cause the molecule to be achiral (even though carbons within the molecule may be chiral)?
6. What is optical activity, and who has it? How is it measured?
7. What is an absolute configuration of a chiral molecule?
8. What are the rules for labeling carbons as *R* and *S*?
9. How can reactions generate chiral molecules?
10. How do you explain the difference between *enantiomers*, *diastereomers*, and *meso* forms?
11. How may you resolve enantiomers?
12. One stereoisomer of glucose is sweet and the other is bitter. How can you explain this observation?
13. What terms did you not understand after reading this paper?
14. What concepts do you need to review to understand this chapter?

Figure 1. Reading worksheet on stereochemistry for completion prior to class discussion.

Reading Worksheets

We tracked student study habits before implementing these changes by having the students keep study diaries. The students' own records indicated that few of them faithfully read assignments prior to exams, and all too often student study time was limited to no more than the day before an exam. Thus, one rationale for change was the need to engage students in thinking about the information prior to each class. One tool for accomplishing this is the use of reading worksheets.

Reading worksheets evolved from an idea presented at an American Association of Colleges and Universities conference and are related to the study questions or help sheets many faculty use. These represent no more than about 15 questions that lead students through the important concepts in their assigned reading. Since textbook content can be overwhelming, these questions are designed to help them see the forest for the trees (Figure 1). In addition, these sheets have two important questions at the end of each one: "What terms did you not understand after reading this chapter?" and "What concepts do you need to review to understand this chapter?" These worksheets are due before beginning a new chapter and are graded essentially on a pass/fail basis. The answers are illuminating because they reveal that students may not recognize what they do or do not understand. These sheets are reviewed by the professor faithfully before the next class, with special attention given to the last two questions so student problems can be addressed in class in a timely fashion. Class time can thus be used more efficiently in discussing concepts students find difficult, rather than spending time on material that they already understand from the reading. In this sense, these strategies actually help save class time in terms of content coverage.

Dialogues

One of the simple lessons learned from teaching is that organizing our thoughts to explain concepts to students solidifies our own understanding of the material. We know we understand a concept well when we can comfortably and lucidly explain it to others, particularly via writing, which demands a great deal of mental ordering for ideas to make sense to the reader. Studies have shown that "writing can be a powerful prod to the expansion, modification, and creation of mental structures" [4]. The dialogue is a written assignment where a situation, conversation, or phenomenon is presented to the students, who are asked to explain this concept or observation in writing to someone who is not a chemist or to a classmate that does not have their facility with the material (Figure 2). Our goals in creating this type of exercise are to increase student comprehension of chemical concepts and to help them draw from the knowledge base they have accumulated as they present reasonable responses to a problem.

The challenge in creating these assignments is the presentation of a problem or observation that is neither too specific nor too broad. Students will typically complete 8–12 of these assignments per semester, so one has to be judicious in the choice of topics. A problem that is too broad impedes the students' ability to focus their understanding and makes it more difficult for the instructor to identify a particular difficulty.

The process we have utilized in administering these dialogue assignments is to hand them out in class and have students turn in the completed response after one or two class periods. A salient feature of the dialogue is that any misconceptions are instantly revealed upon reading student responses. Because a written explanation provides more detail than just a simple answer on a problem set, we gain greater insight about a student's level of understanding. Any misconceptions can then be corrected in a timely fashion, not after the next exam when several weeks have elapsed since the material was discussed in class. A less tangible outcome of these assignments is that students see chemistry as a more creative process with many approaches and solutions to a problem.

Dialogue—Substitution Reactions

You are at Starbucks having coffee and you run into a friend from organic class.

you: Hi, where have you been lately? I have not seen in you class for several days.

friend: I'm having a difficult time getting up early for an 8:25 class.

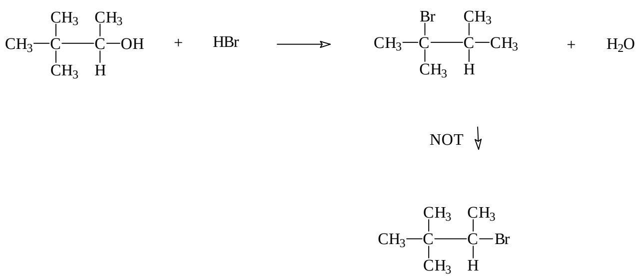


Figure 2. Dialogue assignment in which students provide a written explanation about rearrangements in S_N1 reactions of alcohols.

Group Worksheet—Conformations

Sight down the C-2--C-3 bond and draw Newman projections for 2-methylbutane.

Identify ones that would be called **staggered**.
Would any of these also be called *anti*?
gauche?
Identify ones that would be called **eclipsed**.

What is the **torsional angle** for an eclipsed conformation?
For a *gauche* conformation?
For an *anti* conformation?

Figure 3. Group worksheet in which students use models and work together in teams of 3-5 to answer questions concerning conformational analysis.

you: You should get to sleep earlier. This class is very fast paced and you don't want to fall behind.

friend: You're right. I'm already confused about a reaction I saw in the book. Do you think you might be able to explain it to me?

you: Sure, I have a couple of minutes.

friend: I wish I had time right now but I'm going to be late for lab. Do you think you could leave a written explanation in my box?

you: Sure, I'll give it a try.

friend: Great. Here's the problem. By the way, could I have the explanation by ***Monday, February 6?***

3,3-dimethyl-2-butanol and HBr react to form 2-bromo-2,3-dimethylbutane. I need you to explain to me why 2-bromo-2,3-dimethylbutane is the observed product, **not** 2-bromo-3,3-dimethylbutane, which is what I expected. Please write out a **mechanism** for this product formation, that way I can really understand why this product is formed.

In-Class Group Worksheets

Reading worksheets help students address the fact-finding aspects of learning. Dialogues help students develop understanding as they articulate concepts and gain confidence as they begin to see themselves as experts on a subject. In addition, we hope to encourage students to think beyond the facts and to develop higher order thinking skills, such as analysis, evaluation and integration. The use of collaborative and cooperative learning strategies is designed to challenge students and to promote learning through peer interactions [5, 6]. In-class assignments consist of one or several problems that require students to work in groups of three or four. These assignments ideally require the explanation of a theoretical concept in addition to a problem. This type of activity creates an environment where students and instructors perform as a team. Students gain understanding of chemical concepts through discussions with their peers, and the instructor quickly learns which concepts are confusing to the students.

Figure 3 shows an example of a group worksheet designed to probe students' understanding of molecular conformations. These worksheets are administered at different times during the class period: at the beginning to recall or reinforce material from a previous class or to introduce new material, during the middle of the class period to refocus student attention or at the end so that students can immediately apply information learned during class. The intricacies of group dynamics in such assignments are beyond the scope of this paper [7]. Suffice it to say that some groups work very well together, but the professor must consistently encourage other groups while circulating around the room.

Role-playing

Certain learners, such as convergers or accommodators, benefit most from hands-on activities such as laboratory exercises. Another way to address these groups and add a dynamic and creative aspect to the classroom climate is through role-playing. The ideas involved in the two major types of nucleophilic substitutions reactions, S_N1 and S_N2, lend themselves well to this activity. Students are divided into teams of 5–10 people and charged with presenting one of the two mechanisms in dramatic style. The handout shown in Figure 4 guides them in the content that should be covered in their presentation. Students work together outside of class to plan and rehearse. This exercise may be adaptable for large classes either during recitation/discussion sessions or by involving a small subset of the entire class that rotates throughout the term.

Role-playing engages students in a playful manner, raising class morale. Again, however, the students who are actively engaged have a learning advantage over those who are passive bystanders. On essay questions relating to these mechanisms, students answered more completely those questions relating to the particular mechanism that they helped illustrate compared to questions concerning the one that they only watched.

Assessment

We assessed improvements in student learning upon the incorporation of these strategies by comparing classes two years apart. The first class was taught primarily with the use of interactive lecturing, whereas students in the class two years later experienced extensive use of all of these active learning techniques. Both groups had the advantage of a small classroom setting as each class studied had 24 students. The same standard American Chemical Society (ACS) exam (shortened to reflect only first-semester material) was given to students at the end of the first semester, and a modified ACS organic chemistry exam (Form 1991) was given at the end of each of the second semester classes. The ACS exam was shortened to allow inclusion of a second section that consisted of several questions requiring more content integration

S_N1 and S_N2 Mechanisms of Nucleophilic Substitution Reactions--The Play

Each group needs to construct their "play" so that the following components are included or illustrated:

The Cast

An organic "molecule" with appropriate bonding "atoms" and a "leaving" group

The Plot

The molecule gets "attacked" by the nucleophile.
The leaving group is displaced; the nucleophile is added.

Complications, Conflicts

How will the stereochemistry be affected?
What is the rate-determining step?
How do steric effects impact the reaction?
What factors can stabilize intermediate steps?

Resolution or Climax

The product is formed!

Figure 4. Guidelines for groups developing a role-playing scenario on the S_N1 or S_N2 mechanism.

Table 1. Final Exam Results

Teaching Method	Semester	Number of Students	Average Score	Standard Deviation
Traditional[a]	First Semester	24	81.7	12.6
	Second Semester	25	64.2	17.5
Non-traditional[b]	First Semester	24	74.0	11.6
	Second Semester	24	67.7	18.8

[a]Traditional instruction consisted of interactive lecturing. [b]Non-traditional instruction included the use of reading worksheets, dialogues, in-class group worksheets or role-playing in additon to interactive lecturing.

and explanation. The average final exam grades reported for the second semester reflect the combined scores of the two sections.

Determining the impact of these pedagogical changes on student learning in our study is handicapped by the short-term nature of our project and the small student population involved. The results we obtained, however, provide useful information for further studies. A two-way analysis of variance (ANOVA) comparing semester with method was used to assess average final exam scores. Others have shown that active learning strategies neither enhance nor diminish a student's ability to retain factual information [8, 9], and our study further confirmed this finding. When we examined the main effect of either semester or method, there was no statistically significant difference in average final exam scores between the classes taught by interactive lecturing and those taught with multiple instructional strategies. As expected for a cumulative two-semester sequence, students in the first semester did perform significantly better than students in the second semester regardless of method of instruction ($F_{(1, 93)} = 14.219$, $p = 0.001$). The average final exam scores and standard deviations are shown in Table 1.

An unexpected trend arose when we examined the two-way interaction of both semester and method. Students taught by a more traditional approach, that is, interactive lecturing, showed a greater variation in final exam performance between the first and second semester than students taught with multiple active learning strategies ($p = 0.076$) (Table 1). The average final exam scores decreased dramatically between the first and second semester for students taught only by interactive lecturing. However, the decrease was substantially less for students taught using a combination of techniques. Although this result is not statistically significant at the level of $p < 0.05$ because of the small population, the p value shows a trend that merits further investigation. These data suggest that the performance of students taught with a multiplicity of active learning styles may be less dependent on the instructor or difficulty of the material. This result reflects a shift in emphasis from the professor as an information source to the actively engaged student taking responsibility for his or her own learning [10, 11].

In addition to the standardized multiple choice exam that tests primarily for factual knowledge, questions that required integration and application of knowledge, such as those in Figure 5, were presented to the students in the second semester as part of the final exam. When both classes were compared, the class that benefited from active learning strategies scored an average of 78% compared to a score of 43% on these questions for the class that was taught in the modified lecture format, based on this single two-year study. Given that both classes had the advantage of small class size and some classroom interaction, these differences may be meaningful. These results emphasize the need for assessment materials that evaluate a student's higher order thinking skills to substantiate the value of innovative methods in enhancing intellectual development.

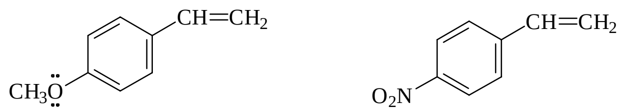
Conclusion

The use of these four strategies allows the professor to move through a learning cycle that may effectively accommodate the students' needs and multiple learning styles. The reading worksheets guide students through the concept phase, and dialogues help students identify the importance of the concepts and articulate these ideas for themselves. Group worksheets and role-playing provide opportunities for peer-interaction, application of knowledge and creativity, and self-expression. These activities also address the different needs of visual, auditory, and kinesthetic learners [12]. We believe that using a variety of classroom activities to address different levels and styles of learning is vital to successful instruction. We chose these specific methods because they best suited our personalities and class formats.

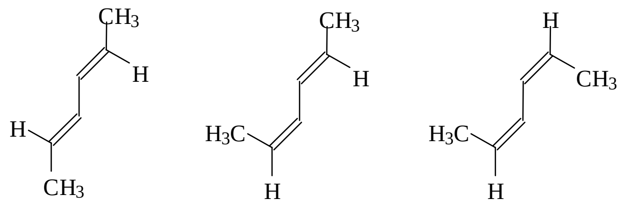
Professors may select from a variety of techniques designed to accomplish these goals in their individual classrooms.

These strategies result in more student involvement, a more dynamic classroom, and a broader engagement of students with different learning styles [13]. Some studies indicate that these methods do lead to better retention, application of knowledge to other situations, motivation for further learning, and enhanced problem-solving ability [14]. This study suggests that these methods, when used in a consistent fashion in conjunction with interactive lecturing, provide a broad base

1. You know the mechanism of HBr addition to alkenes, and you know the effects of various substituent groups on electrophilic aromatic substitution. Use this knowledge to predict which of the following two alkenes reacts faster with HBr. ***(a) Explain your answer by drawing resonance structures of all intermediates. (b) Write the product for the reaction that occurs faster***.



2. Consider the following three dienes:



1 2 3

Compound 1 undergoes Diels–Alder reaction at 35 °C.
Compound 2 undergoes Diels–Alder reaction only at 150 °C.
Compound 3 ***does not*** undergo Diels–Alder reaction at all at 150 °C.
Explain these differences in reactivity. The dienophile involved in all three reactions is the same.

Figure 5. Final exam questions that required content integration and explanation.

to facilitate student learning and aid in the development of higher order thinking skills.

For the experienced professor with a fine-tuned set of lecture notes, these strategies are much more time-consuming, both in designing the exercises and in assessing student performance. After an initial time investment in design, however, the grading load is manageable, especially with creative strategies such as peer-grading or random, spot grading. The stimulating classroom environment and excitement of learning experienced by both student and professor make the effort well worthwhile. In the final analysis, however, each professor is left with the sticky choice of balancing the dual demands of students' learning factual content versus learning how to learn.

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