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Student Self-Efficacy and Attitude in Organic Chemistry: A Comparison of Two Pedagogical Approaches

Matthew Autry
Washington University in St. Louis

WASHINGTON UNIVERSITY IN ST. LOUIS

Department of Chemistry

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by

Matthew Autry

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Matthew Autry

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Dedicated to my parents.

ABSTRACT

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Professor Timothy Wencewicz, Chair

Organic chemistry is well established as a difficult steppingstone for undergraduate students pursuing degrees in the life sciences including the traditional fields of chemistry, biology, and medicine. Students come with a variety of learning styles and career interests which make it understandably difficult to meet everyone's needs, particularly with large classes. As a result of the perceived academic challenge, students are reasonably anxious and doubtful at the onset of a course in organic chemistry. To combat this general mindset, we developed an alternative version of our second semester organic chemistry course and ran it concurrently with the traditional version of the course. We postulated that a smaller class size, emphasis on real-world applications, and high levels of interactivity would boost student confidence and engagement. Specifically, we assessed student self-efficacy and attitude towards the subject upon completion of the courses. Self-efficacy as defined by the American Psychological Association and originated by the late psychologist Albert Bandura relates to "an individual's belief in his or her capacity to execute behaviors necessary to produce specific performance attainments."[1] The results were encouraging, implicating that our unconventional pedagogical approach could be used successfully in tackling an otherwise intimidating subject.

Chapter 1: Introduction

Organic chemistry is often seen as insurmountable for those required to take it. In a short amount of time, an immense amount of material is covered and tested. The number of students leaving programs as a result of taking organic chemistry can be incredibly high. Such has been the case at Miami University which saw attrition rates of 30 – 50% for pre-medical majors in the mid to late 2000's.[2] Difficulties in the comprehension of organic chemistry subject matter include the lack of problem solving algorithms, the requirement of three dimensional thinking, and the extensive new vocabulary.[3] The content itself is inherently challenging, but the sheer bulk and breadth of content covered in traditional organic chemistry courses is often seen as the primary obstacle.[4] At Washington University, this claim is reflected in student course evaluations (see the Appendix section).

The crushing study load can lead students to taking a brute force memorization approach when the real value of organic chemistry is in understanding its concepts. Rote memorization can arise more often from students who are either unaware of more effective learning methods or who are indifferent towards the material.[5] Memorization certainly has its place in learning, but it is difficult to be confident in anything when one lacks understanding of the fundamentals of a subject. Furthermore, when discussing such a large amount of content, it can be difficult to infuse effective and topically relevant applications to show students that what they are learning is truly worthwhile. We hypothesized that demonstrating real world relevance of organic chemistry topics would lead to an increased level of interest and engagement among student cohorts with the potential to translate into improved student self-efficacy, attitude, performance and learning outcomes.

1.1 Class Size

Traditional organic chemistry courses can be taught in large lecture halls where a sizeable number of students have limited access to the professor and less opportunity to ask questions even if they have genuine interest in the material. This historically has been the case at Washington University where organic chemistry class sizes average ~300 students per section. Of course, this also depends on an institution's size and resources related to number of instructors and teaching assistants. For large class sizes, traditional office hours may not be adequate to reach the full diversity of students, and there can be a severe lack of interactivity in the classroom, something that is known to be pivotal to student learning.[6]

The size of courses and focus on student:instructor ratio has long been a subject under scrutiny in the academy.[7] One would be hard-pressed to make a convincing argument stating that classrooms filled to the brim with sometimes hundreds of students are conducive to learning when compared to a more intimate setting with a smaller class size. A study performed in Turkey illustrated a negative correlation between the number of high school students per teacher and the students' achievement based on their Transition to Higher Education Exams.[8] Another study performed in Taiwan demonstrated that larger classes lower classmate supportiveness, student preparedness, and class participation compared to smaller classes.[9]

More research is necessary to achieve the ability to make more informed statements relating class size to student success. The effects of class size are difficult to isolate because this in part relies on the approach of the instructor to use the size of a class to his or her advantage.[10] Strategies of leveraging the advantages of a smaller class size vary greatly based on the instructor and desired learning outcomes. It is entirely possible to make a large class feel small, and a small class feel large. It does, however, stand to reason that smaller class sizes better enable an instructor to address individual learning issues and enhance engagement.[10]

Additionally, it can be difficult to isolate the direct effects of class size since the general classroom comes with a multitude of variables including class room layout, available technology, and scope of supporting programs/personnel. Undoubtedly, though, a smaller class size makes it easier for the primary course instructor to individually assess students on a case by case basis and adapt based on individual needs.[10] An example of a technique that can be used in an effort to boost this ability is Just-In-Time Teaching (JITT). JITT is a tool used by educators where "students are expected to do a pre-class activity, submit responses to this activity, and then the instructor uses these responses to tailor class to the specific needs of the students."[11] This pedagogical approach has been shown to improve classroom climate, student motivation and fostering deeper learning.[12]

All things considered, this topic of debate extends beyond the realm of chemistry and into all subject areas. As a topic of general education development, research analyzing the effects of class size on student learning outcomes, engagement, and performance can be universally valuable to the academy. We hypothesized that a reduction in class size and use of an open format classroom would improve student engagement and promote interaction (student-to-student and student-to-instructor) leading to potential improvements in student self-efficacy, attitude, performance and learning outcomes.

1.2 Interaction

Interaction in the classroom can come in many different forms depending on the subject being taught. Students can interact with each other via activities like quizzes or projects, for example.

Student interaction with the course instructor can take place during scheduled office hours or directly in the classroom when time allows. In the sciences, a physical interaction with the material itself is accomplished through a laboratory component. In chemistry courses, students gain experience by running chemical experiments and analyzing their results with a multitude of techniques. This helps make what they are learning in lecture more tangible and reinforces important theoretical concepts. All of these are utilized in the Washington University Chemistry Department. Additionally, the American Chemical Society's guidelines for laboratory courses at four year colleges include the following:

> "Science is a process of discovery. In the laboratory, students conduct experiments, solve problems, and use the scientific method. Collectively, a laboratory experience should be experiential with students gaining breadth and depth in their scientific skills. The laboratory program is experiential in nature and should be designed at a curricular level and structured so that skills increase with complexity as students progress through the curriculum."[13]

Even in a laboratory setting, though, it is possible to simply follow the instructions like a cookbook with little understanding of the underlying fundamental chemistry which may risk the ability of a student to achieve the desired learning outcome.

Students perceive a lower level of teacher interaction and experience less satisfaction in larger class sizes,[6] further exemplifying how class size is intertwined with the student experience. This deepens because greater levels of interaction with instructors and peers is beneficial to student success in addition to satisfaction.[6] Furthermore, student satisfaction is vital not just to their own success, but to that of the institution as well.[14] When collaboration with peers (student-to-student interaction) and instructors (student-to-instructor interaction) is done in conjunction, a learning environment may result where the scientific process truly shines.

1.3 Application

Harvard University states in their learning objectives that "students are more engaged and interested in a subject if it is clear how the information they are learning is relevant to the world around them."[15] Real world applications in the classroom can make the material more accessible and engaging, especially if it is geared towards the interests of students and resonates with current affairs. People go to college to get an education, but they are also there to gain self-awareness, navigate professional opportunities, and ultimately pursue a career path. Students often complain about taking 'required' classes that they deem irrelevant for them as individuals.[5] This is especially evident when such required courses are difficult. An investigation was performed with the results published in the *Journal of Chemical Education* where the investigators utilized the *Journal of Visualized Experiments'* peer-reviewed science education videos as homework to supplement lectures on different topics within general chemistry.[16] These videos heavily emphasize the applications of chemistry and their everyday uses. To assess how the videos affected student learning, they administered conceptual quizzes both before and after the videos were watched. The study found that this significantly improved student learning and understanding of foundational concepts as assessed by performance on the quizzes. Interestingly, they found that these results were consistent even with students that did not have positive feedback towards the videos. This study provides more evidence that application heavy approaches can help shift the perception of chemistry curricula from being seen as a battle for survival to a genuine, valuable learning experience.

Seeing their learning applied can cause students to become more persistent and experience improved attitudes and performance.[17] Chemistry permeates through a myriad of fields on a level that a lot of people might not recognize. Pharmaceuticals is an obvious application related to organic chemistry, but any material or substance manufacturing requires chemistry on at least some level. While the required amount of conceptual understanding may vary depending on the field, it nevertheless pervades a multitude of professions. At Washington University in St. Louis, a majority of students enrolled in the ‘sophomore’ organic chemistry course sequence are on the pre-med track. Hence, many of these students are chemistry and biology majors with a general interest in the life sciences. We hypothesized that framing the organic chemistry content with an emphasis on the life sciences would increase student engagement and better prepare students for the biochemistry course sequence and other interdisciplinary upper level courses that feature concepts from organic chemistry.

Chapter 2: Methods

When designing the alternative version of second semester organic chemistry, we sought to implement a smaller class size, increase the amount of application, and encourage interaction in a few different ways. Dr. Timothy Wencewicz taught the resulting alternative class while Dr. Kevin Moeller taught the traditional course. Both classes were administered at Washington University in St. Louis in the spring of 2019.

2.1 Class Size Adjustment

Reducing the class size was accomplished by simply setting an enrollment cap of 25 students. The traditional class contained 185 students by comparison.

2.2 Group Quizzes

With the reduced class size, interaction became much more viable. Entire class periods were dedicated to group activities like quizzes. These quizzes were designed to be challenging but fair, pushing the students to pool their knowledge of the subject matter to answer the questions. Throughout the period, the professor walked around the room to aid when students had questions or were stuck. In some instances, the quizzes were difficult to complete. The approach was adjusted to allow students to set up meetings outside of class to continue working together and turn in later. The quizzes often had a combination of easier questions followed by more challenging ones. The challenge questions could test the students' ability to recognize and analyze organic reactions in biological systems. A large component of students at Washington University follow the PreHealth track in their respective fields of choice, so biochemical applications and pharmaceutical examples were regularly utilized. See below in the Appendix section for an example of one of the quizzes administered.

2.3 Topic Specific Handouts

To facilitate learning during lectures, we designed topic specific handouts to streamline student note taking. Given that one of the challenges we aimed to address was the bulk of material, we used the handouts to simultaneously restructure content and implement more real-world examples. Due to the evolving nature of practiced organic chemistry, more focus was placed on unique mechanisms since understanding mechanisms would theoretically allow students to approach different problems from a conceptual angle instead of via memorization. Knowing mechanisms would allow the students to provide justifications for their answers as opposed to simply providing answers. The inclusion of reactions that would simply bloat the amount of content was avoided as reasonably as possible. In doing this, the goal was to include new and valuable learning opportunities while reducing the overall amount of content without sacrificing the quality of education being provided.

The handouts themselves were organized into different sections. A general outline for a typical handout is summarized below:

1. Recommended Textbook Reading
2. Recommended Textbook Problems
3. Topics in Organic Chemistry
4. Topics Related to Human Health
5. Additional Practice Problems
6. Further Reading in the Literature

Each handout introduced new functional groups or compound types being covered. They would generally start with an overview of the properties and fundamental aspects of the reaction types of interest. Along with the mechanism, molecular orbital theory would often be provided to give justification of the process. Space was given so that students could fill in blanks provided in lecture, most importantly of which was the drawing of arrows to illustrate the mechanism. Many structures were included ahead of time to provide the students with ample time to actively listen while still taking notes. Specific reaction examples were then reviewed to give context to the mechanism types being discussed. Once a few reactions were covered, the topic was expanded into more complex scenarios such as synthesis processes. Synthesis proposing is an incredibly important aspect of organic chemistry, particularly in the field of pharmaceuticals. To round things off for lectures, handouts were concluded with cross-field (often health) relevant applications. The final section was designed for individual student or group practice to be performed outside of lectures. Structures and reaction equations were generated utilizing ChemDraw. The packets went through several iterations during the preparation stages. See below in the Appendix section for the final version of our handout that covered ethers, epoxides, and thioethers.

Chapter 3: Qualitative Analysis Framework

3.1 Survey

To gauge the effect of both courses on student attitude and self-efficacy, a survey was designed and distributed via Qualtrics. The survey was designed with heavy influence from Esen Uzunitryaki and Yesim Capa Aydin's paper in the 39th volume of *Research in Science Education* titled "Development and Validation of Chemistry Self-Efficacy Scale for College Students."[18] Their study looked at student self-efficacy in chemistry as a whole, so our survey was adapted specifically to looking at the core competencies of organic chemistry. Inspiration was also taken from Villafane et al. and their article in *Chemistry Education and Research Practice* within which they more specifically studied self-efficacy in first semester organic chemistry.[19]

Questions were carefully formulated to be as neutral as possible without leading students to certain responses. The inquiries aimed to analyze how students personally felt about their understanding of the material and how well they could apply it. 16 questions in total were asked on the survey. The first 10 questions addressed student self-efficacy in 10 different competencies, while the remaining 6 were designed to garner feedback regarding the students' experiences and attitudes within the courses. For the self-efficacy related questions, the students ranked themselves from 1 to 9. The survey questions are listed below:

1. How well do you think you can explain the chemical theories discussed in organic chemistry? (Very poorly: 1, Very well: 9)
2. How well do you think you can identify organic functional groups?
3. How well do you think you can predict products if given the starting materials for a chemical reaction?
4. How well do you think you can write arrow pushing mechanisms?

5. How well do you think you can justify a result using molecular orbital theory?
6. How well do you think you can propose a synthesis strategy for a given compound?
7. How well do you think you can recognize real world applications of organic chemistry?
8. How well do you think you can differentiate between kinetic and thermodynamic products?
9. How well do you think you can interpret a reaction coordinate diagram?
10. If given a biological reaction, how well do you think you could apply what you've learned to propose a mechanism?
11. Did you feel like your professor was available to you to ask for help?
12. Was the classroom environment welcoming?
13. Did you find the class handouts to be helpful in improving your learning?
14. Would you recommend taking organic chemistry to a peer?
15. Generally, how would you describe your experience taking organic chemistry?
16. In the space below, please provide any additional feedback that you would like to expand upon. Elaborate and be as specific as you would like. Here are a couple of questions that may help you get started: What elements of the course did you enjoy that you would like to see used more in the future? What elements of the course did you dislike that you would like to see changed?

The scale is such that low values indicate poor self-efficacy. The same survey was administered to both tracks of the course via Qualtrics where the data was also organized and graphically illustrated. Institutional Review Board (IRB) approval was obtained in order to perform this survey.

3.2 Course Evaluations

The end of semester evaluations for each version of the course were pooled, organized, and openly coded by me with a focus on 6 main categories: Difficulty, student input, evaluations, emotional engagement, mental engagement, and real world effect. Specific keywords (codes) were searched for among the responses that corresponded with each main category. Each response was thoroughly read through and considered in context to establish these keyword groups. Percentages of responses falling into each category were calculated with the understanding that a single response could fall into multiple categories. As a consequence, the sum of the percentages would not be 100. The course evaluation question that was deemed most relevant to this study was "What would you like to tell other WashU students about taking this course?"

Keyword/code groups associated with the difficulty category included challenge/challenging, difficult/hard/tough, and doable/can do well (color coded red).

Keyword/code groups associated with the student input category included work/effort/practice/study/stay on top of material and time/keep up/procrastination (color coded pink).

Keyword/code groups associated with the evaluations category included curve and grade/letter grades (color coded orange).

Keyword/code groups associated with the emotional engagement category included enjoy/fun (color coded yellow).

Keyword/code groups associated with the mental engagement category included learning/understanding/foundation and interesting/fascinating/stimulating (color coded green).

Keyword/code groups associated with the real world effect category included relevance/applicability and usefulness/valuable (color coded blue).

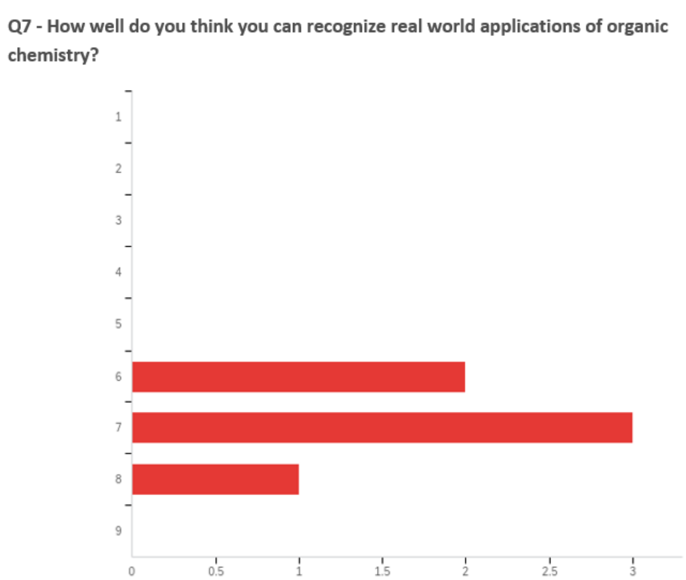
The color coded responses to the course evaluation question can be found in the Appendix section. Final counts and results were analyzed using Excel and illustrated with bar graphs.

Chapter 4: Results

4.1 Survey

4.1.1 Self-Efficacy (1 – 10)

The results of the study suggest that the courses each had different impacts on the attitudes and self-efficacy of the students involved. 24% of the students in the alternative course provided responses to the survey while 11.9% of the traditional course students provided responses. The low sample sizes are a large concern that should be pointed out. Increasing the number of participants would help make the results more robust. That being said, question 7 (self-efficacy regarding real world applications), question 9 (self-efficacy regarding reaction coordinate diagrams), and question 10 (self-efficacy regarding biological reaction mechanism proposal) showed statistically significant differences between the courses at an alpha (p-value) of less than 0.05 utilizing the T-test. Questions 7 and 9 were significant at alpha levels less than 0.025.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
7	How well do you think you can recognize real world applications of organic chemistry?	6.00	8.00	6.83	0.69	0.47	6

Figure 1: Alternative course data for survey question 7

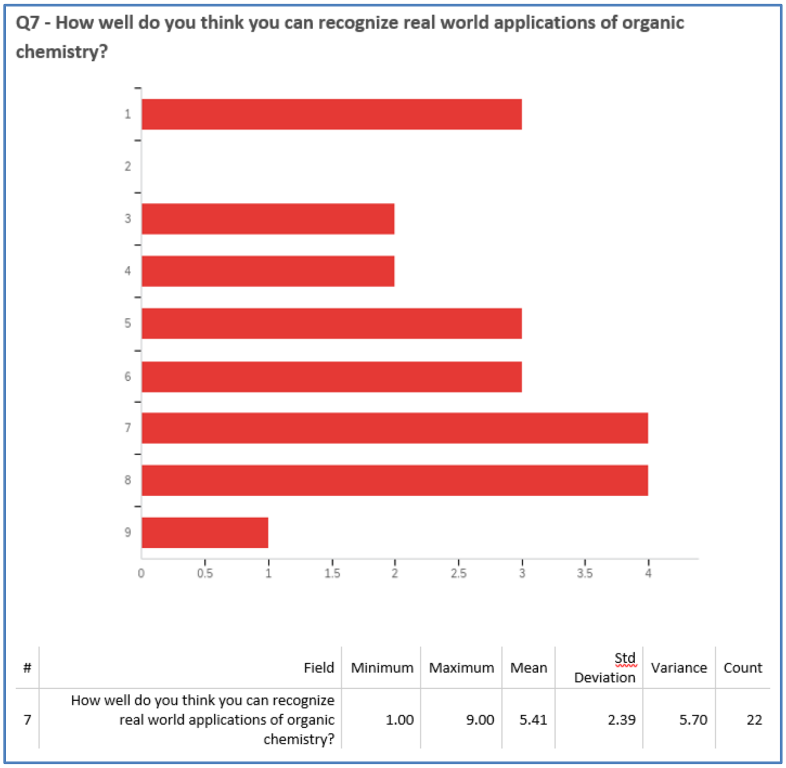


Figure 2: Traditional course data for survey question 7

Question 7	Alternative Course	Traditional Course
Number of Observations	6	22
Mean	6.83	5.41
Standard Deviation	0.69	2.39
Variance	0.47	5.70
t-value	2.35	
Degrees of Freedom	26	
Alpha (one tail)	< 0.025	
Question 9	Alternative Course	Traditional Course
Number of Observations	6	22
Mean	7.83	5.82
Standard Deviation	1.77	2.39
Variance	3.14	5.69
t-value	2.12	
Degrees of Freedom	26	
Alpha (one tail)	< 0.025	
Question 10	Alternative Course	Traditional Course
Number of Observations	6	22
Mean	6.83	5.05
Standard Deviation	1.95	2.08
Variance	3.81	4.32
t-value	1.81	
Degrees of Freedom	26	
Alpha (one tail)	< 0.05	

Figure 3: Data summary and statistical analysis for questions 7, 9, and 10

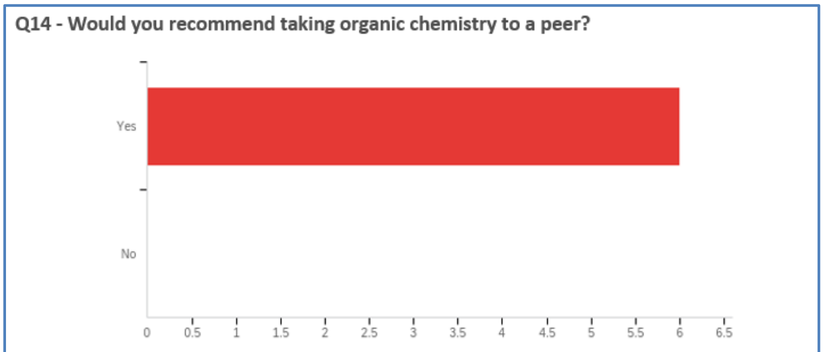
While differences in averages are not necessarily statistically significant on their own, it is worth noting that all but question 2 (self-efficacy regarding functional groups) resulted in a higher average response from the alternative course students compared to the traditional course.

Question	Alternative Course Average	Traditional Course Average	t	p
1. How well do you think you can explain the chemical theories discussed in organic chemistry?	6.17	5.18	1.15	< 0.15
2. How well do you think you can identify organic functional groups?	7.17	7.18	- 0.01	--*
3. How well do you think you can predict products if given the starting materials for a chemical reaction?	5.00	4.68	0.42	--*
4. How well do you think you can write arrow pushing mechanisms?	6.33	5.32	1.16	< 0.15
5. How well do you think you can justify a result using molecular orbital theory?	6.00	5.14	1.36	< 0.10
6. How well do you think you can propose a synthesis strategy for a given compound?	4.17	3.95	0.24	--*
7. How well do you think you can recognize real world applications of organic chemistry?	6.83	5.41	2.35	< 0.025
8. How well do you think you can differentiate between kinetic and thermodynamic products?	6.67	5.73	1.48	< 0.10
9. How well do you think you can interpret a reaction coordinate diagram?	7.83	5.82	2.12	< 0.025
10. If given a biological reaction, how well do you think you could apply what you've learned to propose a mechanism?	6.83	5.05	1.81	< 0.05

Figure 4: Self-efficacy survey questions with average responses, t-values, and p-values (one tail)
--* indicates p-values larger than 0.15

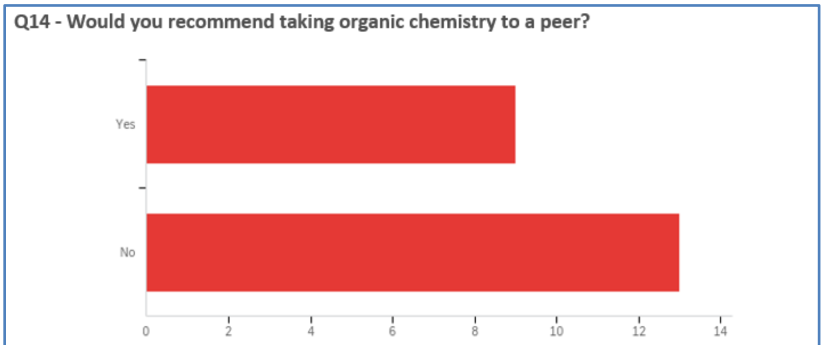
4.1.2 Attitude (11 – 16)

In the attitude section of the survey, the results for questions 14 and 15 were particularly interesting. Question 14 asked the survey takers if they would recommend taking organic chemistry to their peers.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
14	Would you recommend taking organic chemistry to a peer?	1.00	1.00	1.00	0.00	0.00	6

Figure 5: Alternative course data for survey question 14

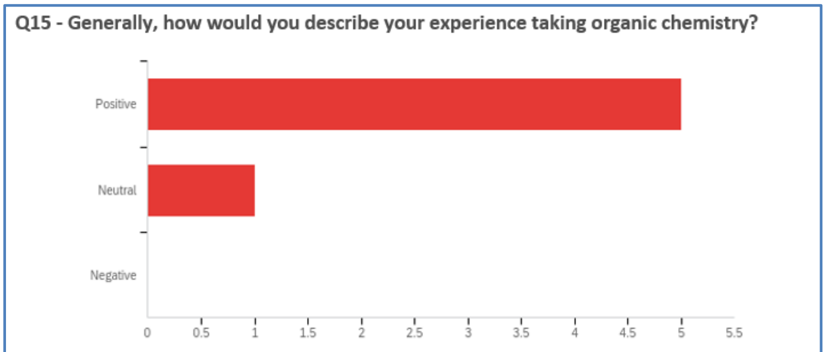


#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
14	Would you recommend taking organic chemistry to a peer?	1.00	2.00	1.59	0.49	0.24	22

Figure 6: Traditional course data for survey question 14

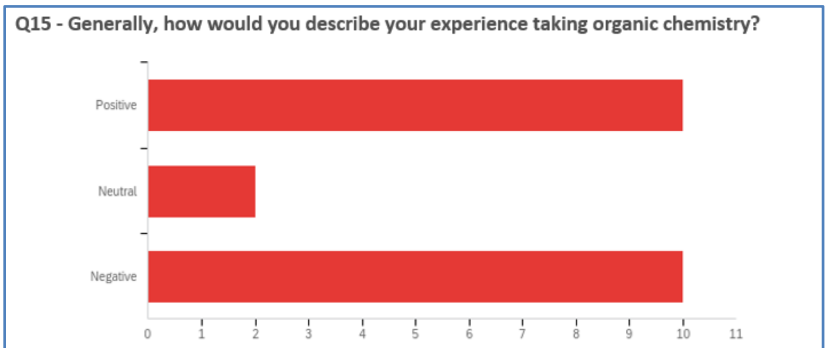
The survey takers from the alternative course were unanimous in their response, all saying that they would recommend taking organic chemistry. This is different from the traditional course survey takers, over half of whom responded saying no.

Question 15 asked survey takers about their general experiences in their respective courses.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
15	Generally, how would you describe your experience taking organic chemistry?	1.00	2.00	1.17	0.37	0.14	6

Figure 7: Alternative course data for survey question 15



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
15	Generally, how would you describe your experience taking organic chemistry?	1.00	3.00	2.00	0.95	0.91	22

Figure 8: Traditional course data for survey question 15

The alternative course students all replied with either positive or neutral, with the majority being positive. The traditional course students were more split, with equal numbers stating that their experience was positive and negative.

Questions 11 through 14 were all yes/no questions and were analyzed statistically using the Chi Square test with 1 degree of freedom. However, it should be noted that the Chi Square test is not as reliable when the sample size is as small as it is in this study. Therefore, Fisher's exact test was utilized as well.

Question	Alternative Course		Traditional Course		Chi Square	p-value (alpha)	Fisher Exact
	Yes	No	Yes	No			
11. Did you feel like your professor was available to you to ask for help?	6	0	20	2	0.59	> 0.10	1
12. Was the classroom environment welcoming?	6	0	19	3	0.92	> 0.10	1
13. Did you find the class handouts to be helpful in improving your learning?	6	0	17	5	1.66	> 0.10	0.55
14. Would you recommend taking organic chemistry to a peer?	6	0	9	13	6.62	< 0.025	0.018

Figure 9: Summary of responses to survey questions 11 – 14, Chi square, p-value (from Chi), and Fisher exact value

Question 14 results suggest a statistically significant difference between the alternative and traditional courses at a p-value of < 0.025. The Fisher exact result of 0.018 reinforces the Chi square test. Questions 11 – 13 do not possess significant differences.

4.2 Course Evaluations

Response rates were much higher for the evaluations than they were for the survey. 72% of the students in the alternative course provided responses while 28% of students in the traditional course provided responses. 18 students provided responses from the alternative course while 52 students provided responses from the traditional course.

The end of semester evaluations showed interesting distributions in their respective responses regarding the question "What would you like to tell other WashU students about taking this course?" The responses from the alternative course students seemed to lean toward the main categories of mental engagement and real-world effect while the traditional course students seemed to emphasize the difficulty and student input categories.

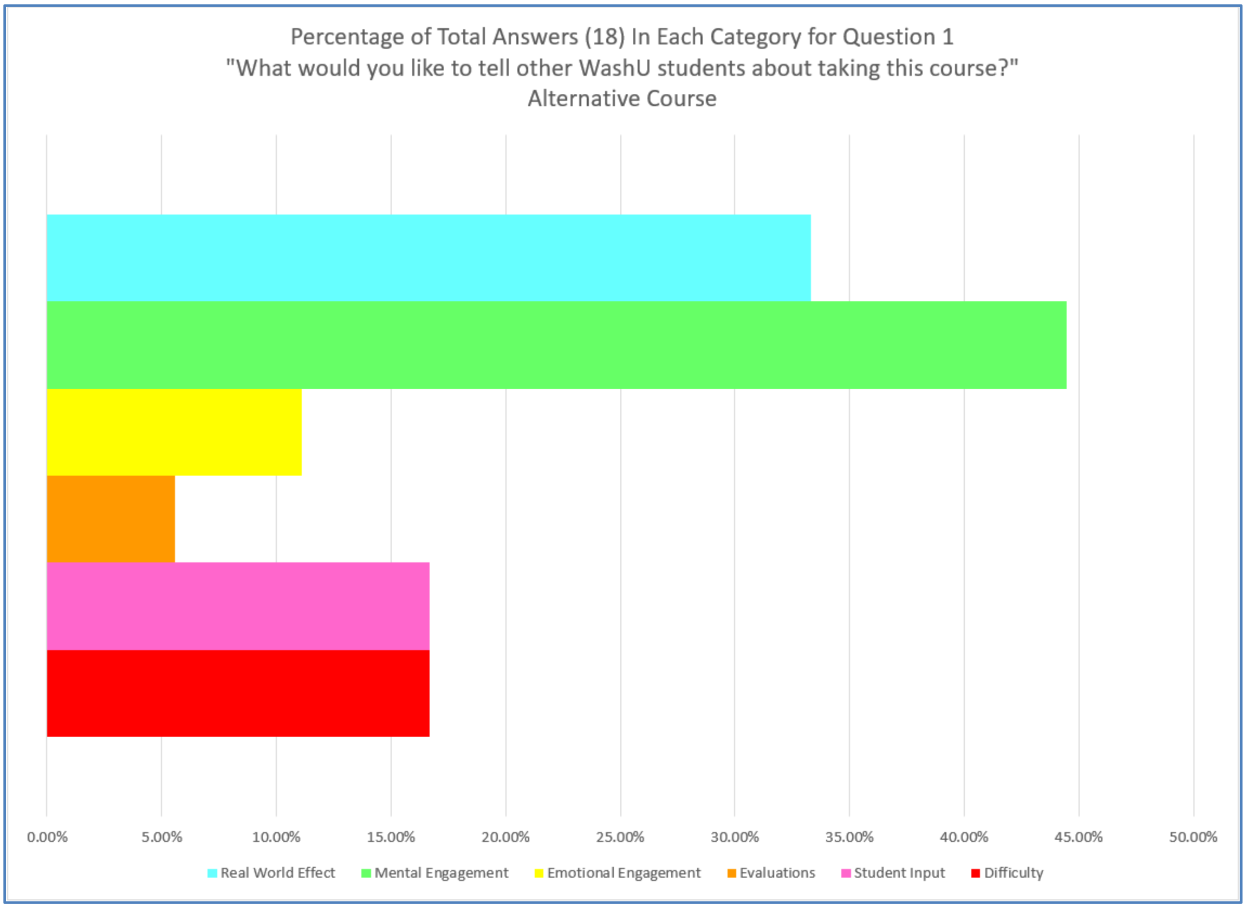


Figure 10: Summary of alternative course category response rates

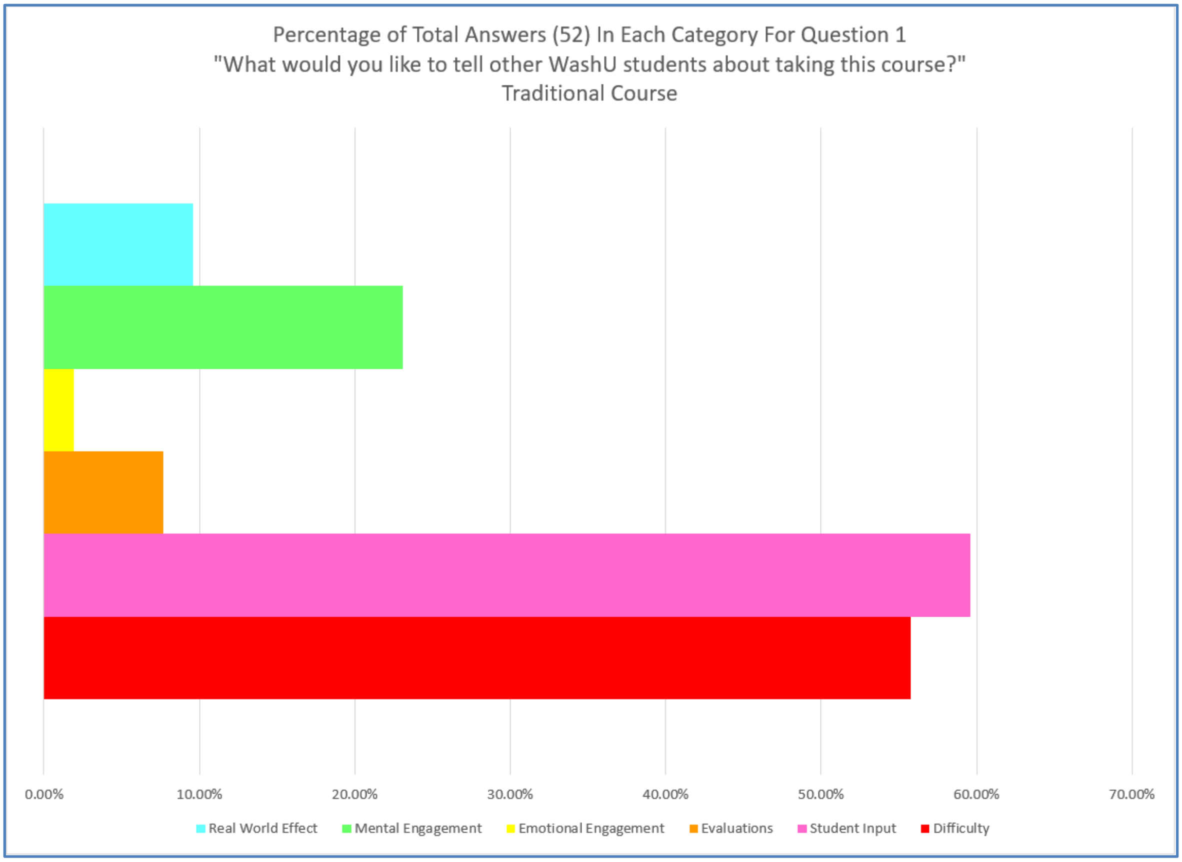


Figure 11: Summary of traditional course category response rates

Chi Square tests with 1 degree of freedom were performed separately on each category to test for statistically significant differences between the courses.

Question: What would you like to tell other WashU students about taking this course?	Alternative Course Mentions		Traditional Course Mentions		Chi Square	p-value (alpha)	Fisher Exact
Category	Yes	No	Yes	No			
Difficulty	3	15	29	23	8.24	< 0.01	0.0056
Student Input	3	15	31	21	9.87	< 0.01	0.0023
Evaluations	1	17	4	48	0.092	> 0.10	1
Emotional Engagement	2	16	1	51	2.75	< 0.10	0.16*
Mental Engagement	8	10	12	40	2.99	< 0.10	0.13*
Real World Effect	6	12	5	47	5.68	< 0.05	0.027

Figure 12: Summary of evaluation responses, Chi square, p-value (from Chi), and Fisher exact value
* Indicates conflicting conclusions between Chi squared and Fisher tests

Again, Fisher's exact test was also applied to provide more insight to a relatively small sample size. The difficulty and student input categories appear to be significantly different between the courses at a p-value < 0.01. Both are reinforced by Fisher exact values of 0.0056 and 0.0023 respectively. The evaluation category did not show significant difference between the courses. The emotional engagement and mental engagement categories initially appeared to be significantly different between the courses based on the Chi squared test at a p-value < 0.10, but the Fisher exact values of 0.16 and 0.13 oppose this conclusion. The real world effect category appears to be significantly different between the courses at a p-value < 0.05 and is reinforced by a Fisher exact value of 0.027.

Chapter 5: Discussion

The results of the study are enlightening. Our changes to the framework for the alternative course have elicited what appears to be a clear divergence in attitude towards organic chemistry when compared to the traditional course. Based on the analyzed student feedback, we can say that students were more likely to recommend taking the alternative version of the course than they were the traditional version. The difficulty, student input, and real world effect categories from the course evaluation question were significantly different between the cohorts. The focus of responses from students in the traditional course was far more associated with its difficulty and how much work the students had to put in. Alternative course students' responses focused more on the real world effects and applicability of organic chemistry. This aspect in particular makes clear that we are on the right track for improving the outlook on organic chemistry and helping students see its value. One thing that should not be implied is that difficulty or high levels of student input are inherently negative things. They are simply observed to be less of a focus in the alternative course student responses when asked what they would tell their peers.

The results addressing student self-efficacy are less pronounced but nonetheless encouraging that our changes had a positive effect. In particular, it is interesting that the alternative course students reported a higher self-efficacy on average for all but one of the addressed competencies. Three of these competencies were significantly higher for the alternative course students than they were for the traditional course students.

Regarding how this study can be improved, we clearly would benefit from sampling larger pools of students. This could help make the outcomes more robust. Acquiring higher response rates would have been simple in theory but potentially difficult in practice without influencing the student responses in one direction or another. Offering extra credit might have elicited more responses, but the desire was for students to provide their thoughts and feelings with as little outside sway as possible. This is also why completing the survey was not made mandatory. In the end, though, this approach may have been overly cautious. Students that choose to respond of their own volition might not represent the average student in the class. They may deign to participate based on their performance in the course, opinion of the instructor, or any number of reasons that are not immediately known. On its own, simply giving the students freedom to opt out could skew the data.

Another way to gather more data would be to run the course across multiple years, tweaking and adjusting along the way to better meet our goals. This presents a challenge due to the difficulty in maintaining a solid control across multiple iterations of the class. The difficulty is exacerbated when different instructors teach the different course versions. Student responses to surveys and course evaluations could be associated more so with the difference in the quality or style of instructor as opposed to the course structure and design itself. This would be less of a concern if the course versions were always taught by the same instructor. Keeping the instructor constant might help to alleviate the lack of control on some of these variables.

Dr. Wencewicz ran an alternative course again in the Spring of 2022. This presents a great opportunity to gather more data and give more strength to the study. Further analysis of the student evaluations could bring to light more information to be used to make the organic chemistry experience as beneficial as possible. It should also be noted that this class was much larger. It would be intriguing to see the effects of that change. Having data from two semesters where the instructor and general approach were kept constant could help us to understand more directly how class size affects student attitudes.

Within a study such as this, the challenge of control brings up a unique set of questions at each level of the project even if the instructor is kept the same. Could the population of students that elect to enroll in the smaller, alternative version of the class have different motivations, majors, and career goals from the average student in the traditional course and, if so, cause a skewing of the results from the onset? Establishing control over an aspect of the study such as this would require the removal of enrollment as a choice which has its own problems associated with it.

In addition to acquiring more data, adding a layer of nuance to the data collection might help to strengthen our understanding of the results in light of the concerns regarding control. For example, the same or similar surveys could be distributed at the beginning of the semester as well as at the end. Insight towards how self-efficacy and attitude change over the course of the semester could help us isolate what factors influence the results. Running the surveys at the beginning might allow us to know whether or not each student population is starting on equal ground when it comes to confidence as well. Measuring student self-efficacy at these two time points would, in theory, enable us to better understand the relative improvement or decline in student confidence as they progress through the material. How the results change over time could also help to address another concern, which is the reporting of false or misplaced confidence.

We could feasibly improve the data analysis phase particularly for the student course evaluations. As stated earlier in this document, the student evaluations were openly coded into six categories. In addition to being openly coded, artificial intelligence software could be used to reinforce and double check the appropriateness of the categorizations. Even if unintentional, open coding alone has the potentiality of introducing bias. Sophisticated software might help to alleviate this concern.

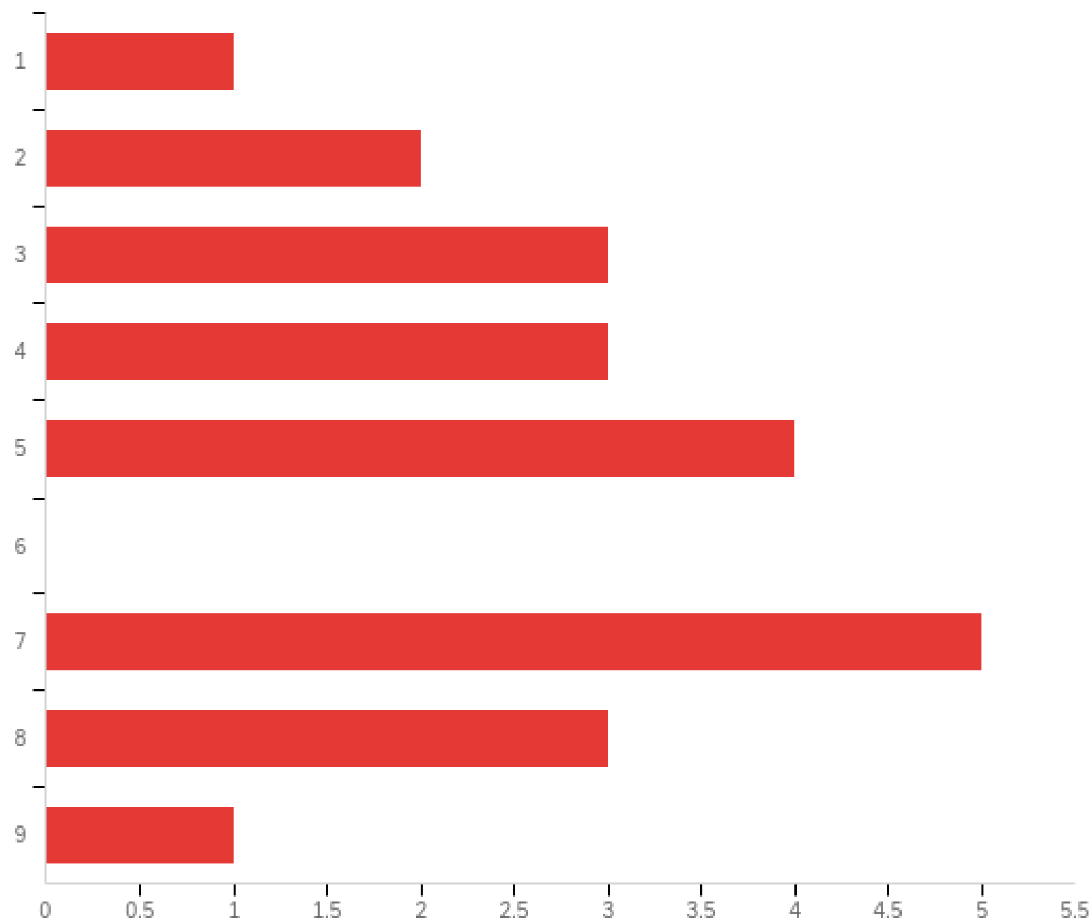
Ultimately, a long term goal would be to attempt to study whether or not student self-efficacy and attitude has a direct impact on student academic performance. One would think that the more confidence a student has, the more naturally a drive and work ethic would develop that pushes them towards academic excellence. This would need to be closely investigated, however. It is possible that student self-efficacy impacts how well students perform, but an argument could also be made that high levels of performance would impact and improve self-efficacy. Villafane *et al.* provide evidence that the relationship is more reciprocal in nature, indicating an interplay where they build off of each other.[19] Some put forth that "self-efficacy mediates the relationship between achievement and interest in that achievement in science leads to higher science self-efficacy, which in turn serves to strengthen students' academic goals."[20] The direction of cause and effect could also depend on the individual. Study habits, learning styles, motivations, interest, and many other factors could come into play. Control would once again become a concern when deciding how to gauge this performance. Different instructors will generally give different exams, but if all assessments were kept the same across the cohorts, we could have a potentially useful measuring tool.

Finally, a follow-up study could be performed by surveying the participants years after their enrollment in the course. Knowing what degrees, graduate programs, and careers they ended up pursuing and whether or not they recall their organic chemistry experience as a source of positivity or influence would be helpful.

Chapter 6: Appendix

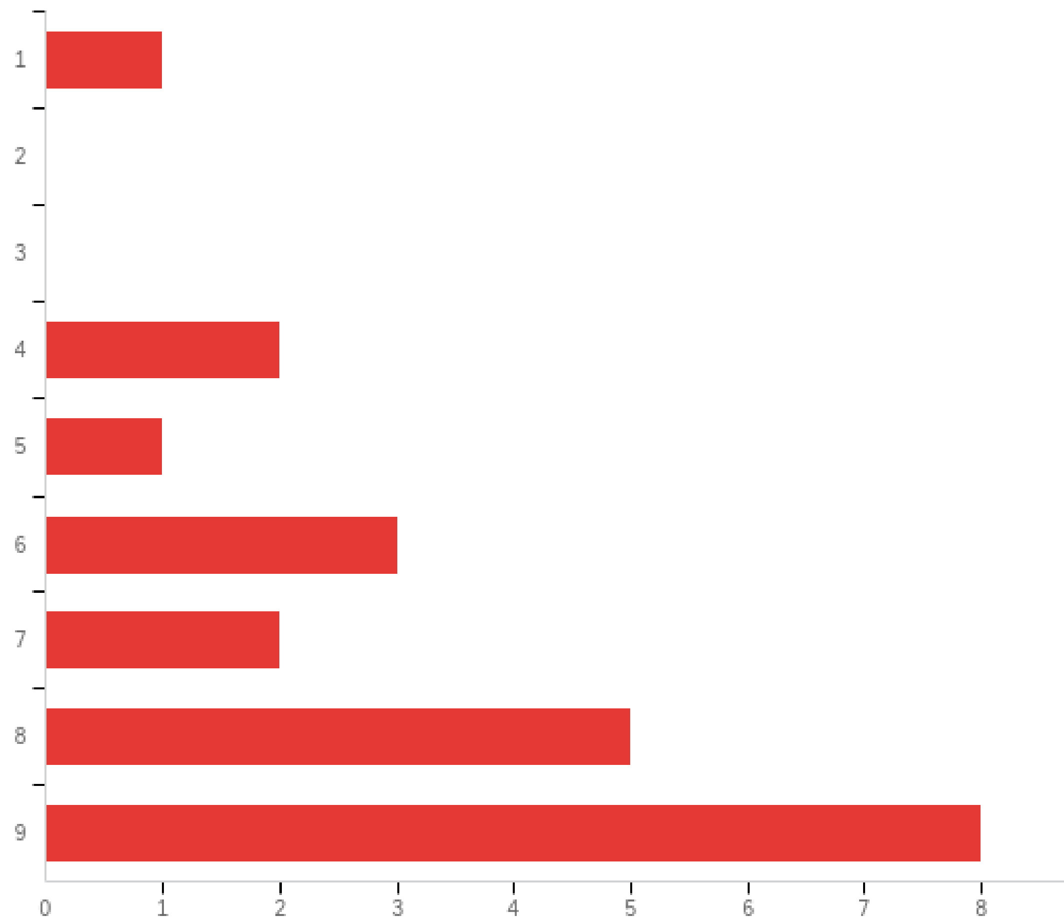
6.1 Survey Results Extended: Traditional Course

Q1 - How well do you think you can explain the chemical theories discussed in organic chemistry? (Very poorly: 1, Very well: 9)



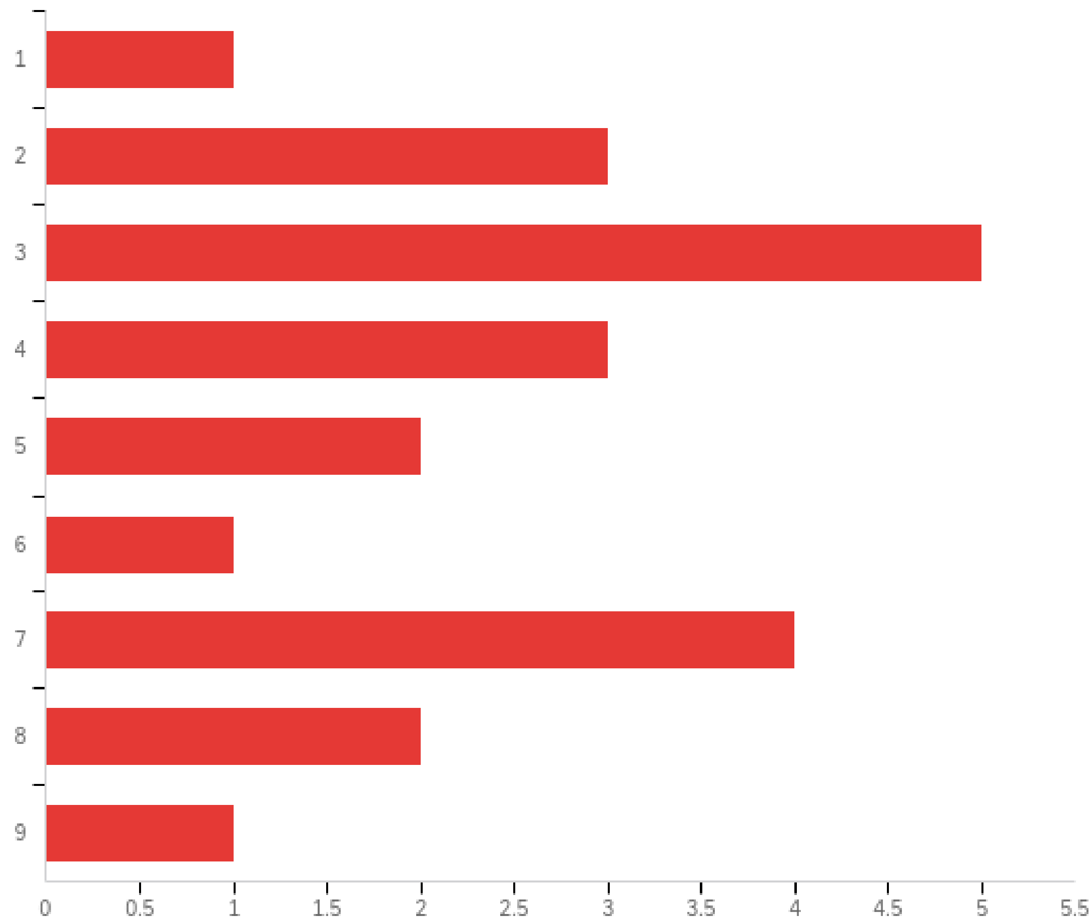
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How well do you think you can explain the chemical theories discussed in organic chemistry? (Very poorly: 1, Very well: 9)	1.00	9.00	5.18	2.25	5.06	22

Q2 - How well do you think you can identify organic functional groups?



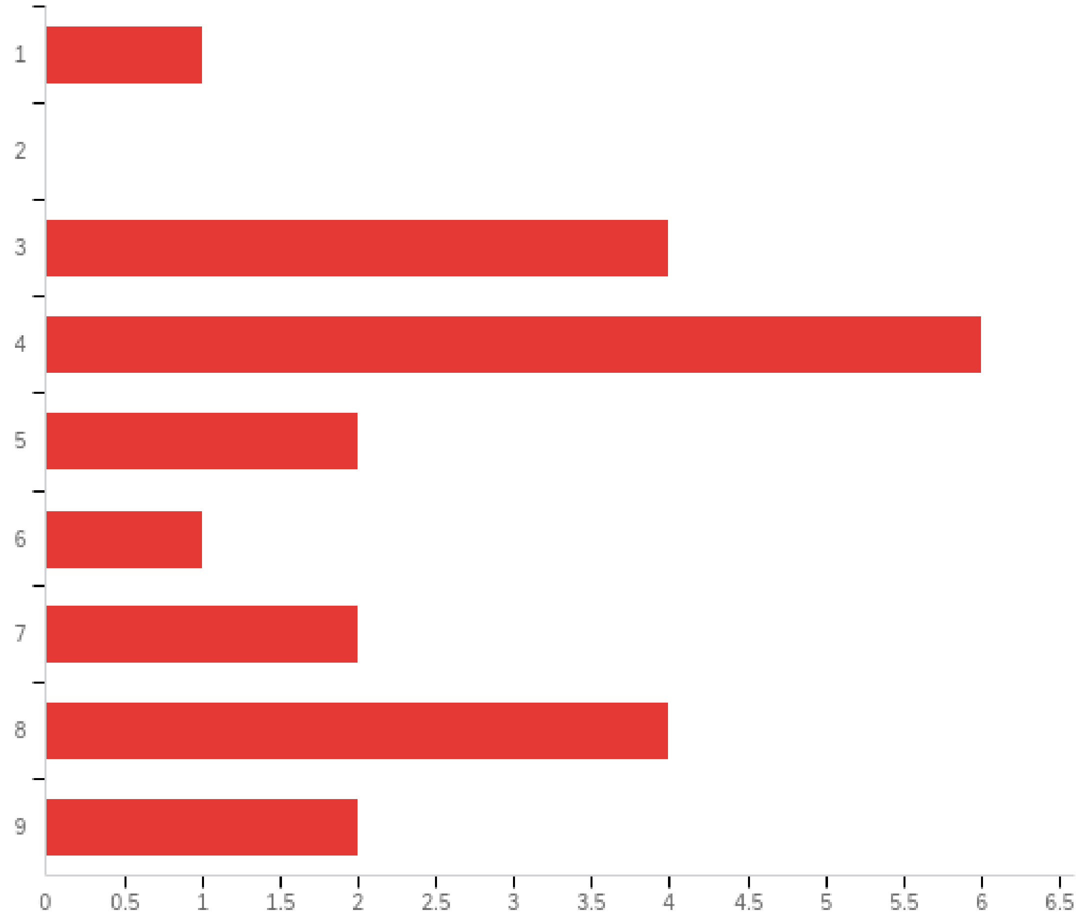
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
2	How well do you think you can identify organic functional groups?	1.00	9.00	7.18	2.10	4.42	22

Q3 - How well do you feel you can predict products if given the starting materials for a chemical reaction?



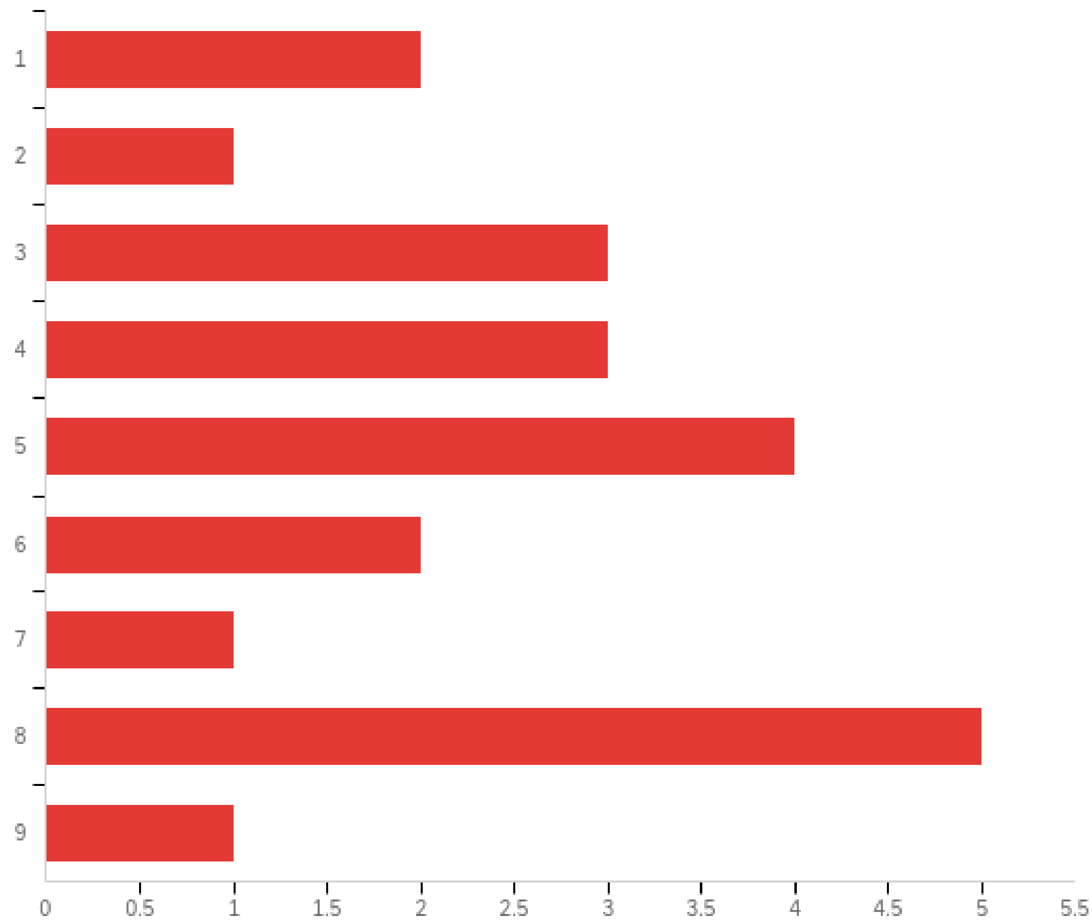
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
3	How well do you feel you can predict products if given the starting materials for a chemical reaction?	1.00	9.00	4.68	2.28	5.22	22

Q4 - How well do you think you can write arrow pushing mechanisms?



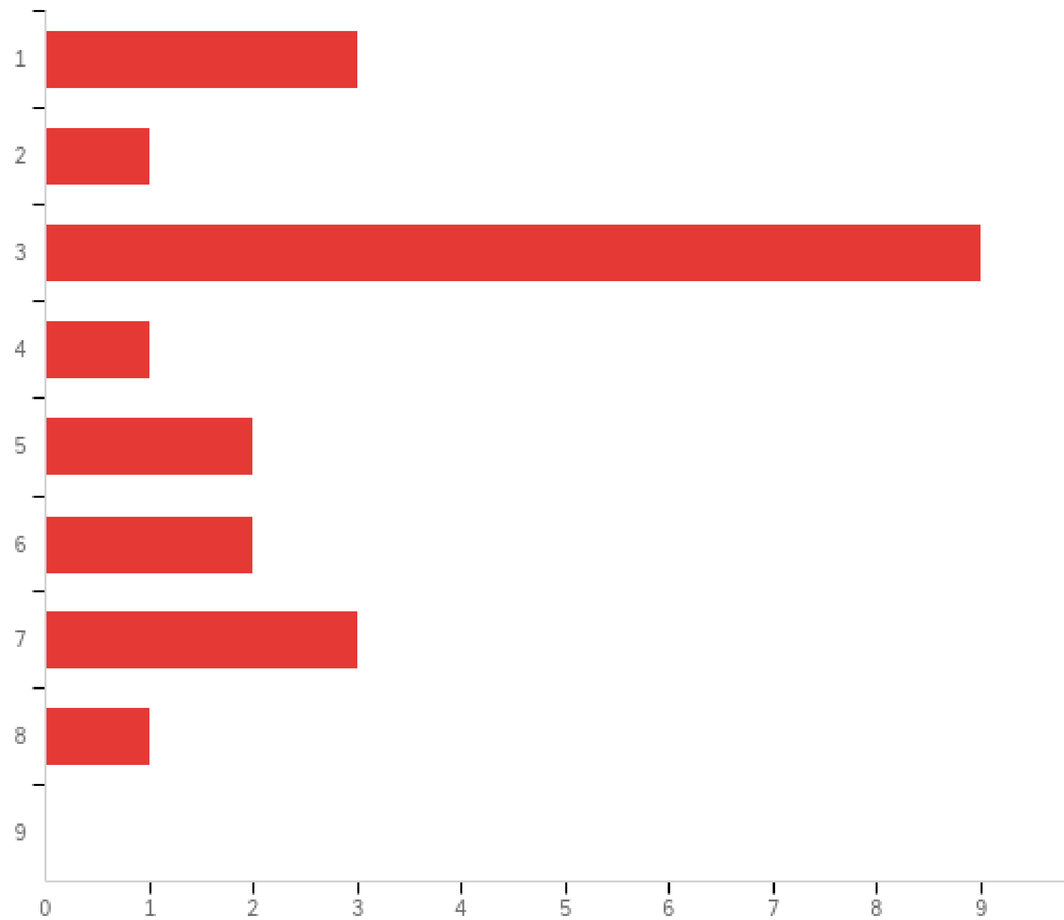
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
4	How well do you think you can write arrow pushing mechanisms?	1.00	9.00	5.32	2.26	5.13	22

Q5 - How well do you think you can justify a result using molecular orbital theory?



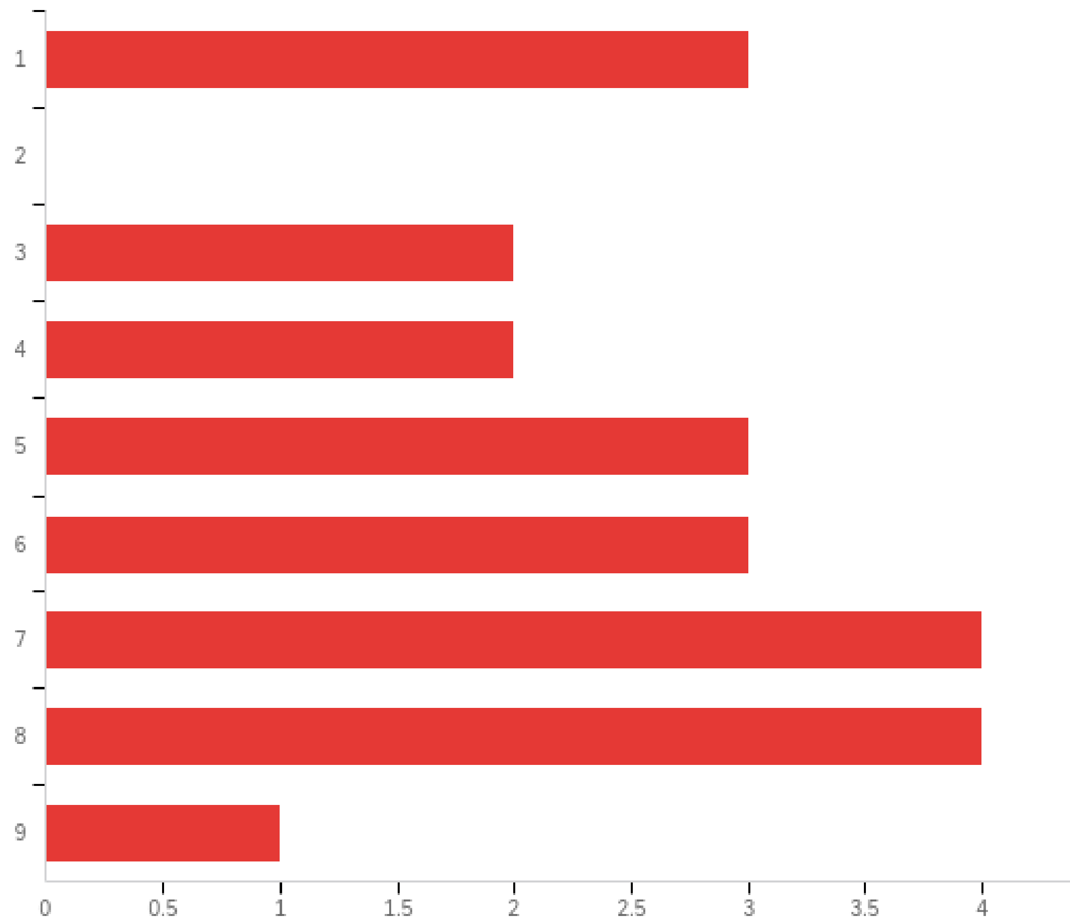
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
5	How well do you think you can justify a result using molecular orbital theory?	1.00	9.00	5.14	2.36	5.57	22

Q6 - How well do you think you can propose a synthesis strategy for a given compound?



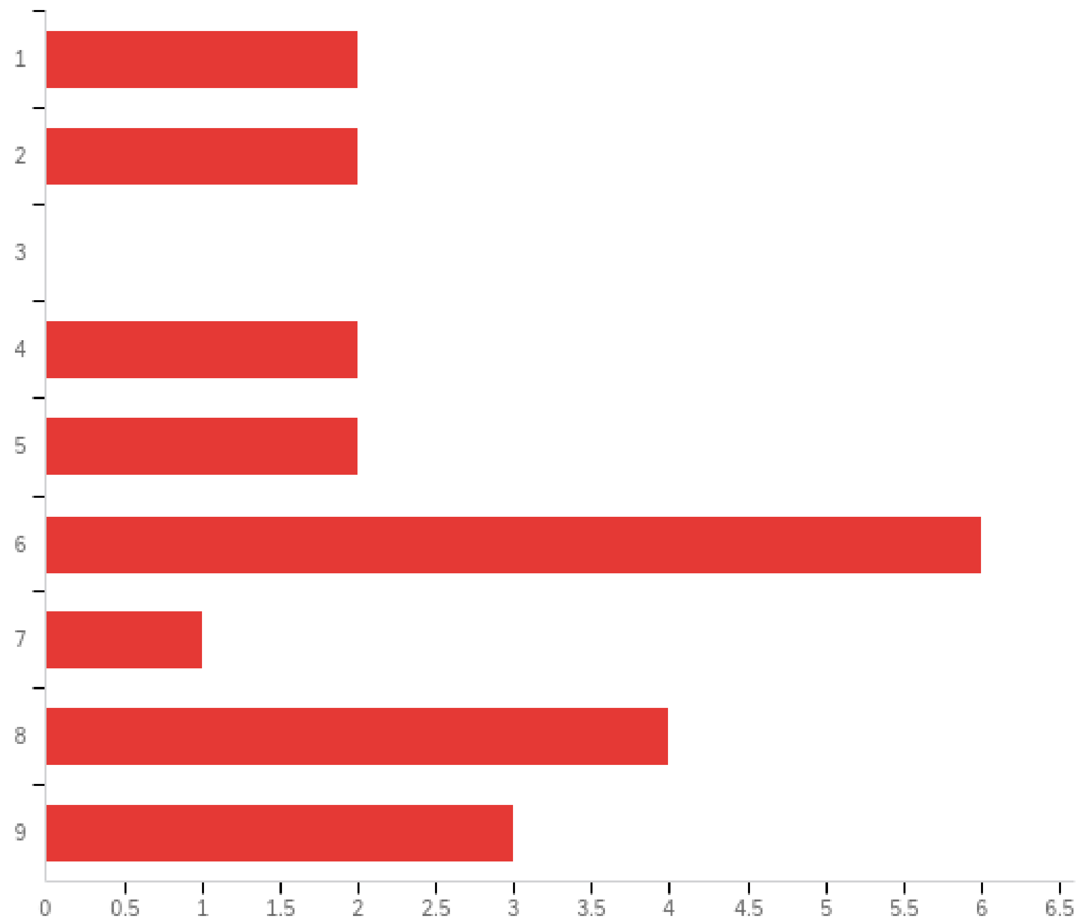
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
6	How well do you think you can propose a synthesis strategy for a given compound?	1.00	8.00	3.95	2.06	4.23	22

Q7 - How well do you think you can recognize real world applications of organic chemistry?



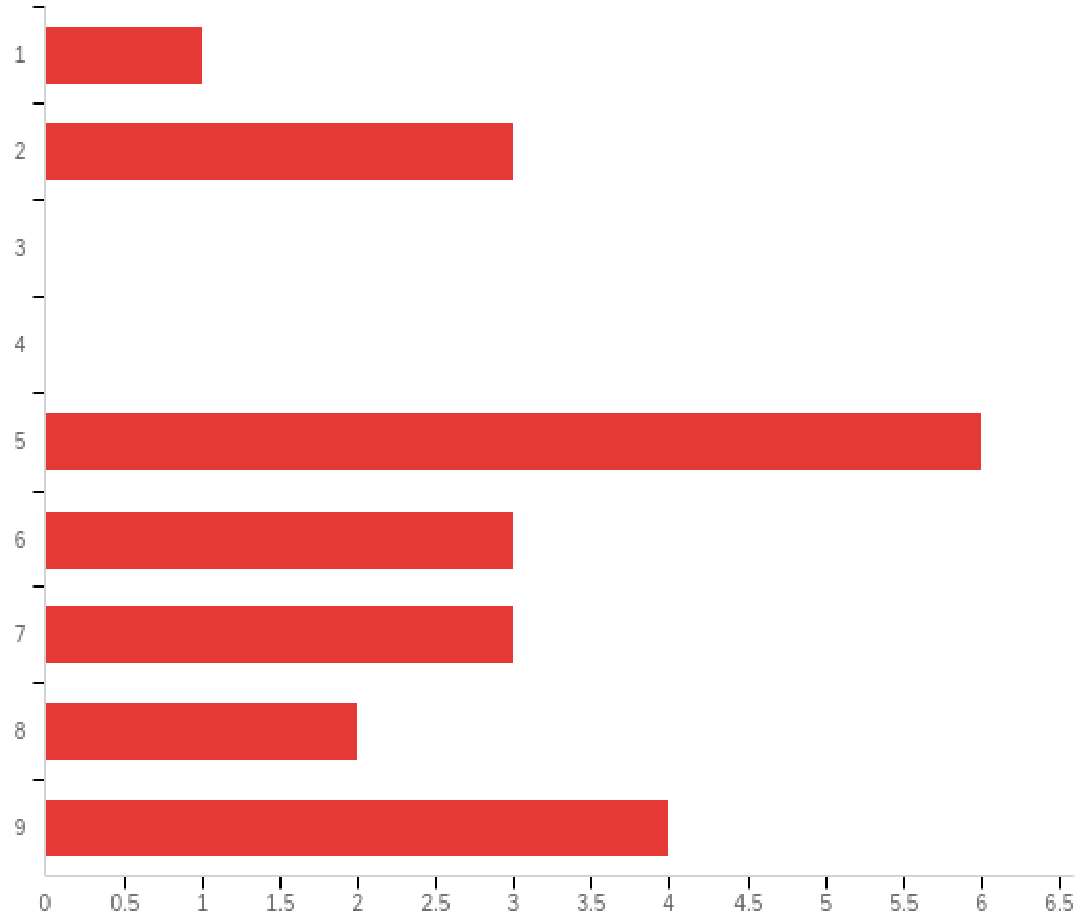
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
7	How well do you think you can recognize real world applications of organic chemistry?	1.00	9.00	5.41	2.39	5.70	22

Q8 - How well do you think you can differentiate between kinetic and thermodynamic products?



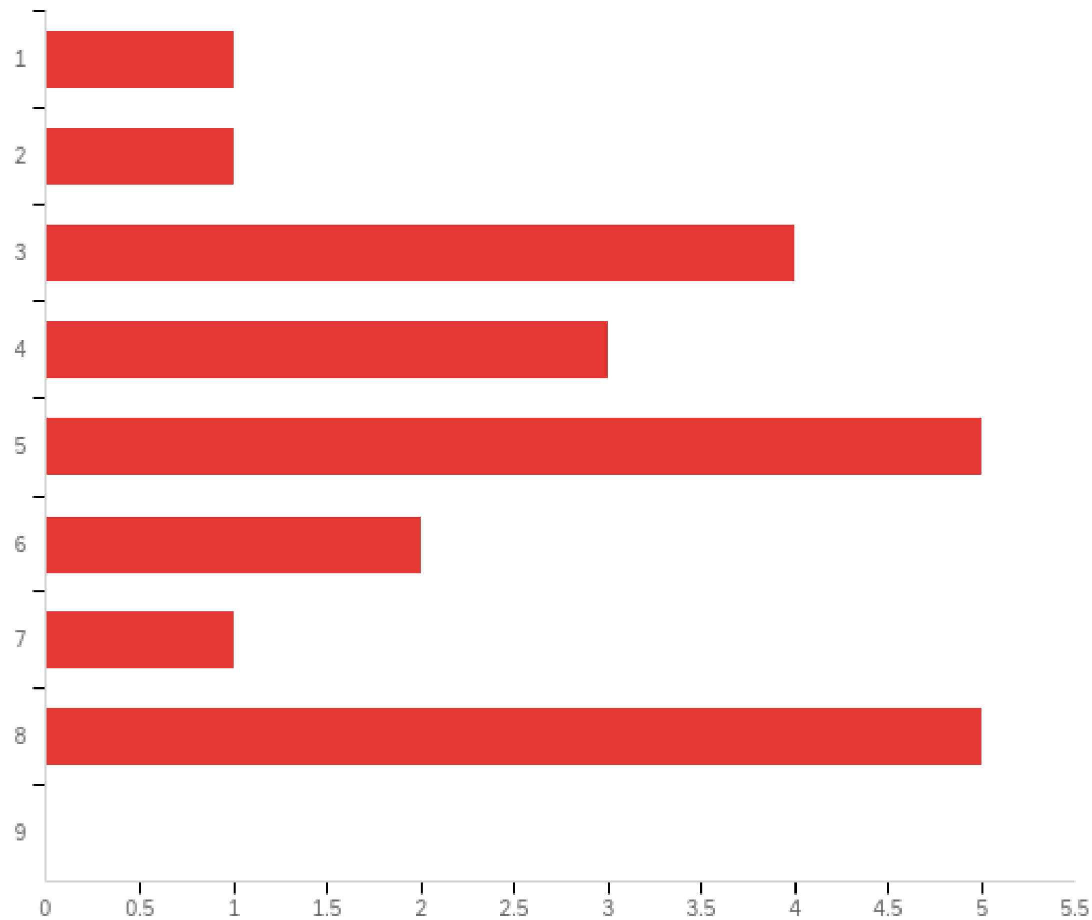
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
8	How well do you think you can differentiate between kinetic and thermodynamic products?	1.00	9.00	5.73	2.47	6.11	22

Q9 - How well do you think you can interpret a reaction coordinate diagram?



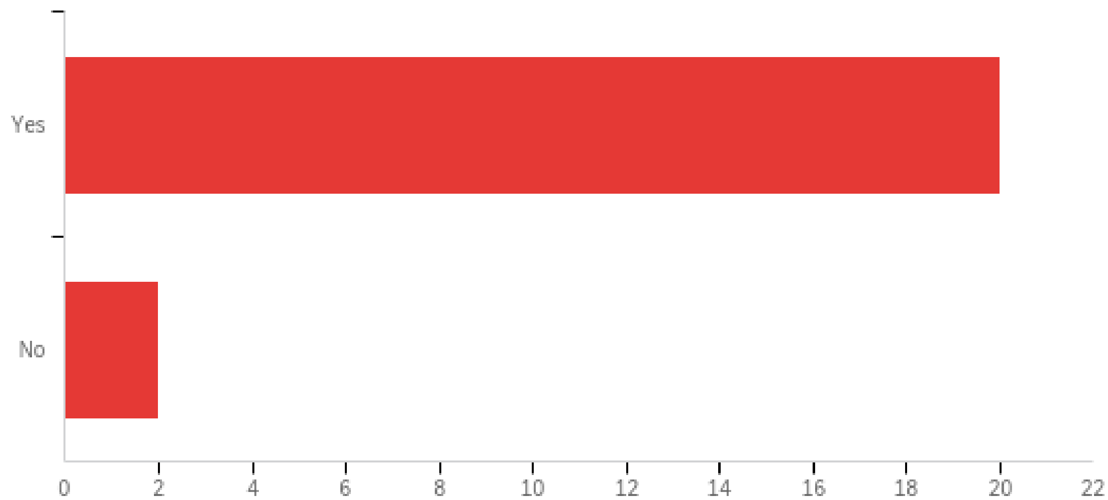
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
9	How well do you think you can interpret a reaction coordinate diagram?	1.00	9.00	5.82	2.39	5.69	22

Q10 - If given a biological reaction, how well do you think you could apply what you've learned to propose a mechanism?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
10	If given a biological reaction, how well do you think you could apply what you've learned to propose a mechanism?	1.00	8.00	5.05	2.08	4.32	22

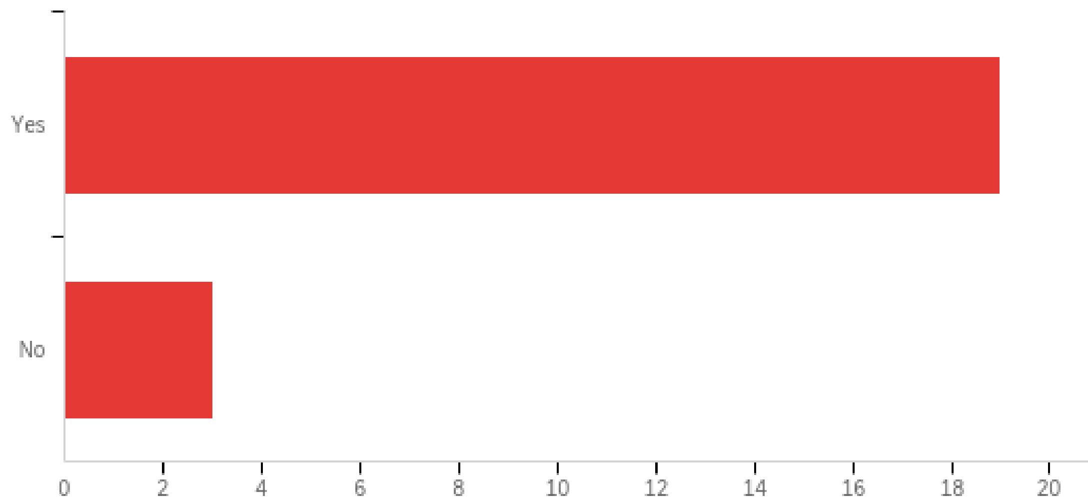
Q11 - Did you feel like your professor was available to you to ask for help?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
11	Did you feel like your professor was available to you to ask for help?	1.00	2.00	1.09	0.29	0.08	22

Elaborate (optional):
I went in to a few office hours and Moeller was always there and able to help. His way of explaining things made sense and helped so much.
Office hours were always beneficial and helpful
There were a lot of opportunities to go to office hours and get help for Organic Chemistry, but a lot of the times I was behind so I felt like I wouldn't be caught up with the questions that other students had in office hours.
He held a lot of office hours, which a lot of professors don't do.
Both Prof.'s Barnes and Moeller held many office hours, making themselves very available.

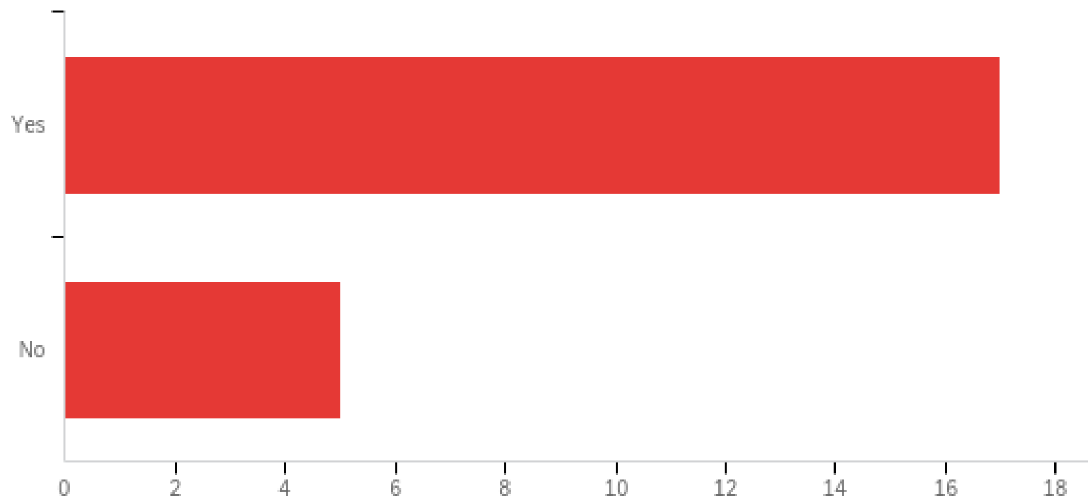
Q12 - Was the classroom environment welcoming?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
12	Was the classroom environment welcoming?	1.00	2.00	1.14	0.34	0.12	22

Elaborate (optional):

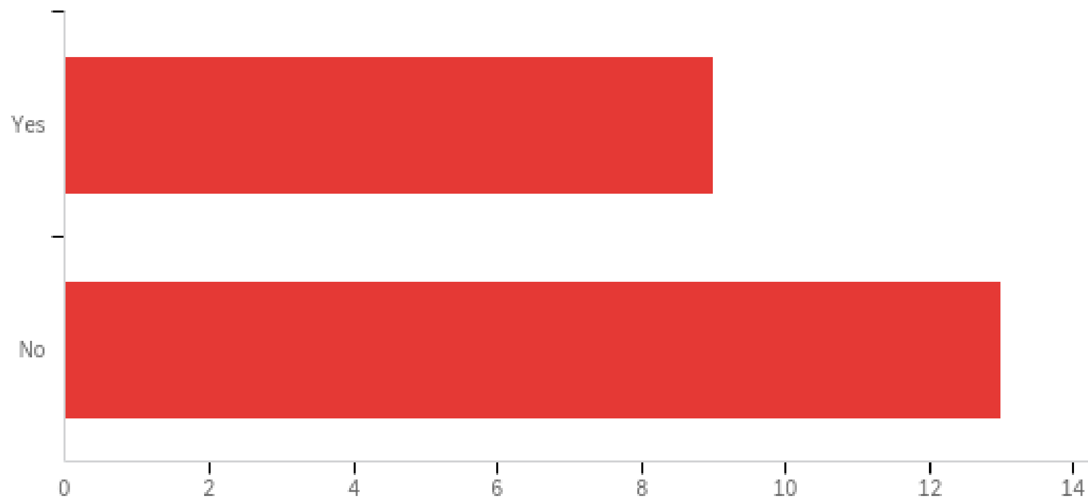
Q13 - Did you find the class handouts to be helpful in improving your learning?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
13	Did you find the class handouts to be helpful in improving your learning?	1.00	2.00	1.23	0.42	0.18	22

Elaborate (optional):
I don't know if there were class handouts?
There were not many class handouts.
The handouts were incredibly helpful.

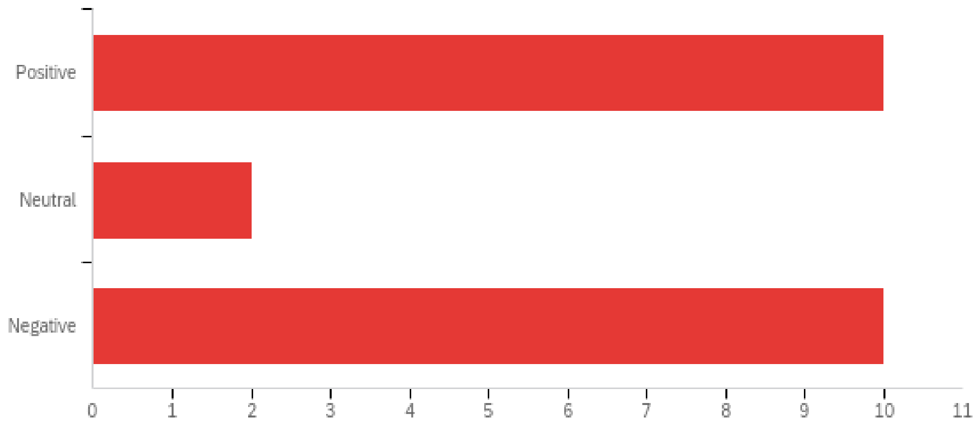
Q14 - Would you recommend taking organic chemistry to a peer?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
14	Would you recommend taking organic chemistry to a peer?	1.00	2.00	1.59	0.49	0.24	22

Elaborate (optional):
Taking organic chemistry II was a bonding and growth experience.
The organic chemistry classes at WashU are very difficult as compared to other classes at WashU, especially second semester organic chemistry. I would not recommend taking organic chemistry unless if it required for some reason. There is so much memorization that I would not recommend taking it.
I would only recommend if you are going into a field where this would be relevant. I found the class content important and could see how to apply it in certain places but it was also a very difficult class that took up a lot of time outside to work on.
Unless you have to take organic chemistry as a requirement, I would not recommend the class to a peer. It is extremely helpful and fast paced. If you get behind or did not understand the previous semester, it is extremely hard to catch up and there are limited opportunities available to seek out help compared to general chemistry or intro biology.
It was extremely hard and a lot of work.
not unless you need it lol

Q15 - Generally, how would you describe your experience taking organic chemistry?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
15	Generally, how would you describe your experience taking organic chemistry?	1.00	3.00	2.00	0.95	0.91	22

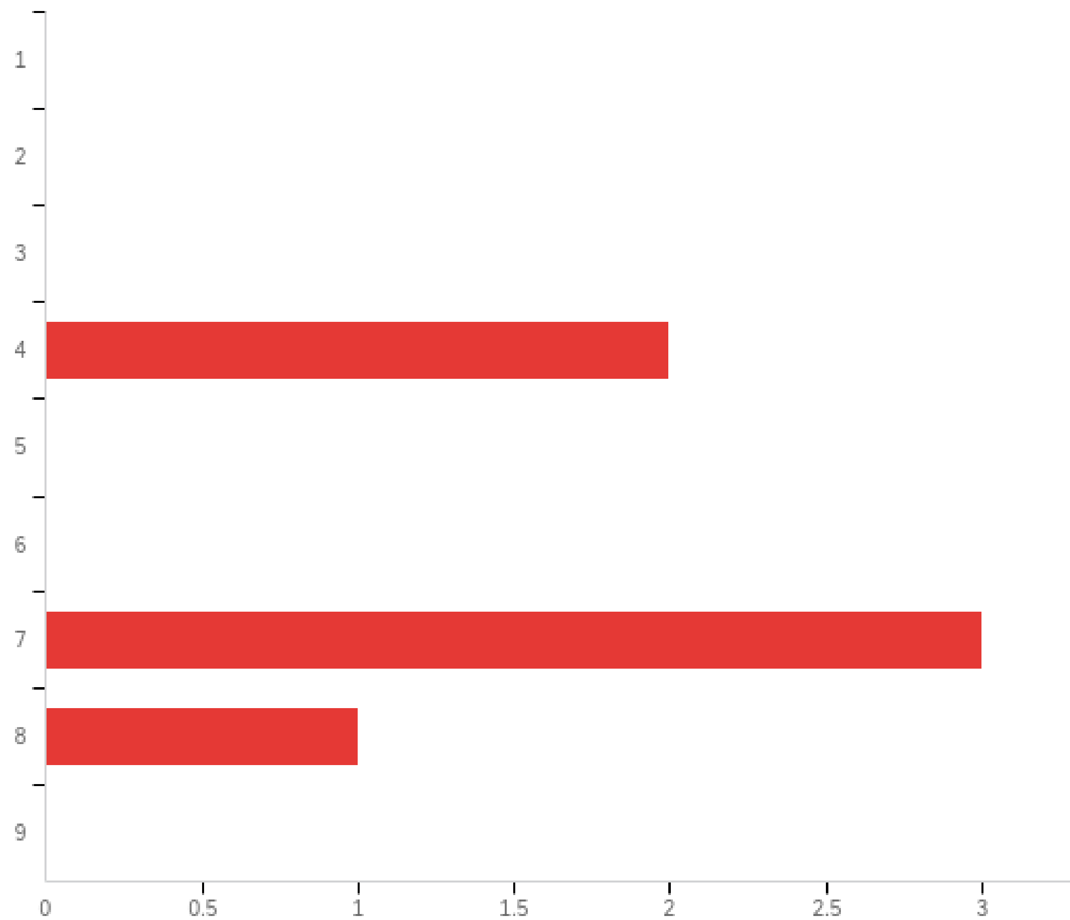
Elaborate (optional):
It's hard, and sometimes it reaches beyond the scope of what I need to know for my future career, as well as for my major. However, it is required. I know some other schools do not go into the same extent of the material we are learning in organic
It was hard and so much, but I enjoyed help hours and studying with friends. Overall, when the hard work paid off it was an amazing feeling.
I struggled significantly in Organic Chemistry, but it was not at the fault of the professor.
A lot of my friends took organic chemistry over the summer, so I didn't have many friends in the class, unfortunately. The labs were difficult and I felt as if the explanations of them and of the chemistry behind them were sometimes unclear. It is difficult to manage the material in organic chemistry because there are so many resources, such as RPMs and PLTL for General Chemistry, but these resources don't exist for Organic chemistry (although office hours and help sessions do exist). It's harder to get one on one help, especially from other students.
The teaching was fine, but the exams were ridiculously difficult and undermined student's confidence in their understanding of the material. Even if a student receives a B with the curve, a grade in the 30s or 40s is incredibly demoralizing and makes students feel as if they don't understand any of the material. There is a reason no one wants to take organic chemistry at WashU. A school shouldn't be actively encouraging it's students to take courses at other institutions. I genuinely found the material to be interesting, so it's a shame I don't feel like I truly learned it.
very difficult and very very very anxiety inducing

Q16 - In the space below, please provide any additional feedback that you would like to expand upon. Elaborate and be as specific as you would like. Here are a couple of questions that may help you get started: What elements of the course did you enjoy that you would like to see used more in the future? What elements of the course did you dislike that you would like to see changed?

I enjoy the notes we are sent so that we have more time in class to listen. However, I wish there was some sort of recitation section at least once during the week so I could practice with others, and not feel judged, and ask a TA questions on a more personal level.
I enjoyed the help sessions that the TAs held every Tuesday night. Those sessions saved my grade and sanity - the extra help was incredibly needed and also showed me that my fears that perhaps I just was not able to do well in the class were just false. I also really enjoyed the test format. Letting us choose the reactions to answer ensured that with the immense amount of information that we needed to know it was still manageable.
Having handouts was very helpful. I feel like the class material could be better learned if individuals were able to study in a small group setting similar to the structure of PLTL or BTL.
I did not like the prelab quizzes for lab. I felt that these were often asking me about specific details to make sure I read the lab and not about the actual chemistry behind it. I also did not like how little lab impacted our grade. It was very frustrating to spend so much time on labs and then have the whole lab grade be worth only the amount of about one unit exam. It would be better if lab was a separate class (like in general chemistry) so that we can show that we did well on lab on our transcript.
I enjoyed how Chem 262 focused more on how organic chemistry was related to biology. Moreover, I think the handouts that the professor used were extremely helpful. They pinpointed background knowledge that could easily get glossed over when reading the textbook. They also made my notes more organized and made it easier to study for exams. One of the reasons why Chem261 was difficult was because the professor used powerpoints with the occasional chalkboard work. I didn't like how half of the course was basically shoving every possible functional group down our throats. There has to be a better way to teach the mechanisms for the functional groups than just bombarding us with them.
Slower pace, too many obscure mechanisms on exams (not the ones emphasized in class), more time spent developing the basics
I would like to see more emphasis on the justification for mechanistic steps. Sometimes mechanisms feel too much like memorization.?

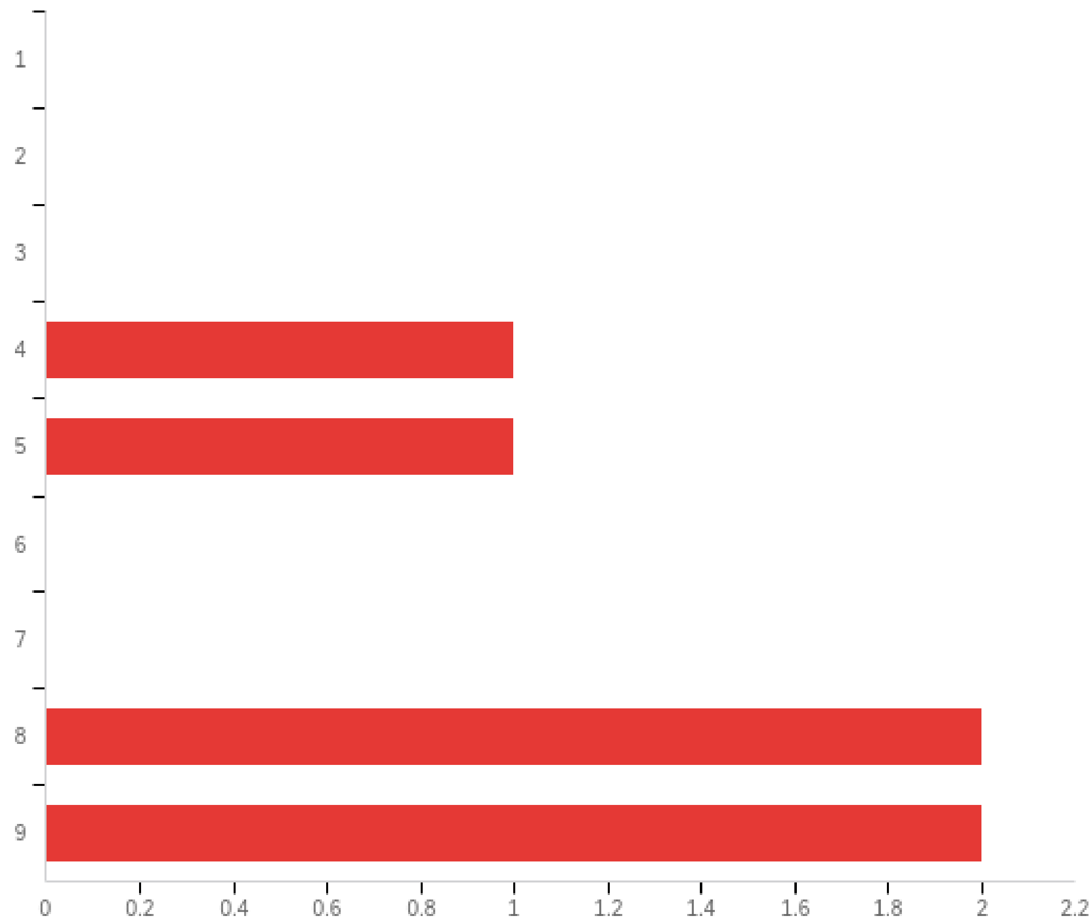
6.2 Survey Results Extended: Alternative Course

Q1 - How well do you think you can explain the chemical theories discussed in organic chemistry? (Very poorly: 1, Very well: 9)



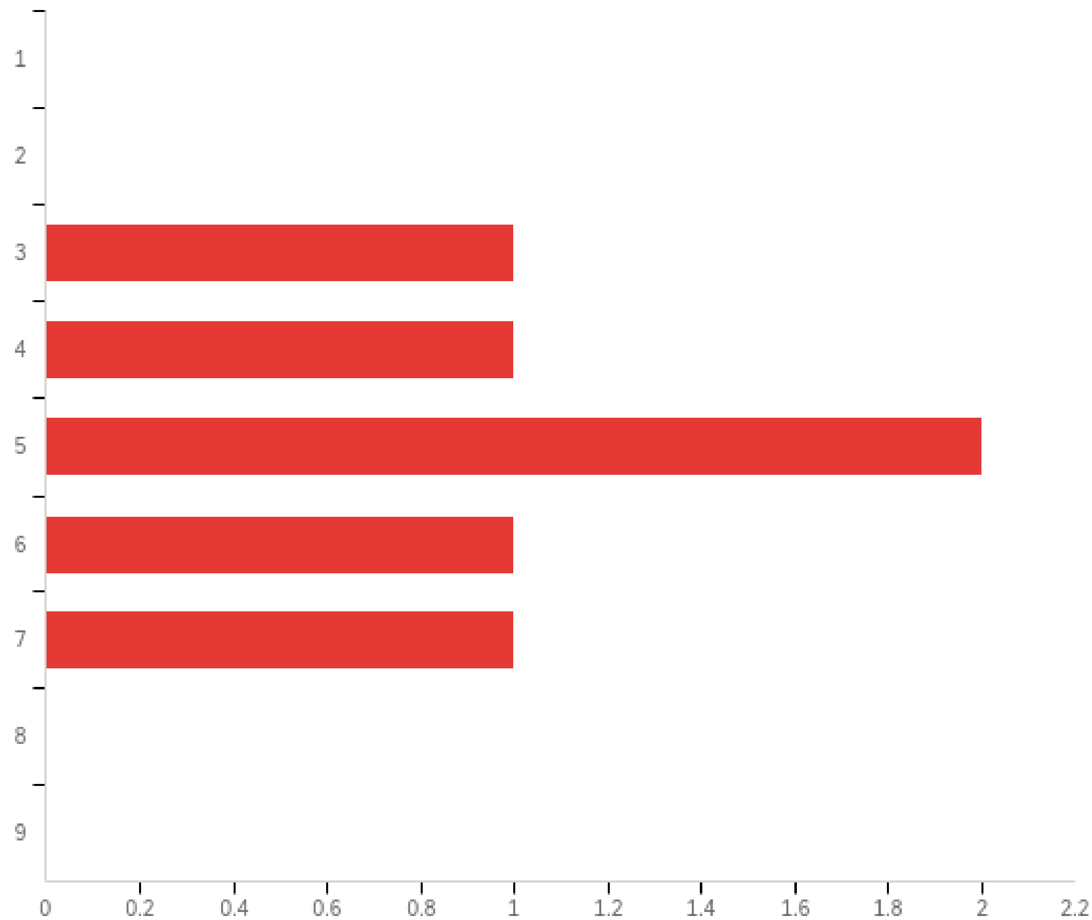
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How well do you think you can explain the chemical theories discussed in organic chemistry? (Very poorly: 1, Very well: 9)	4.00	8.00	6.17	1.57	2.47	6

Q2 - How well do you think you can identify organic functional groups?



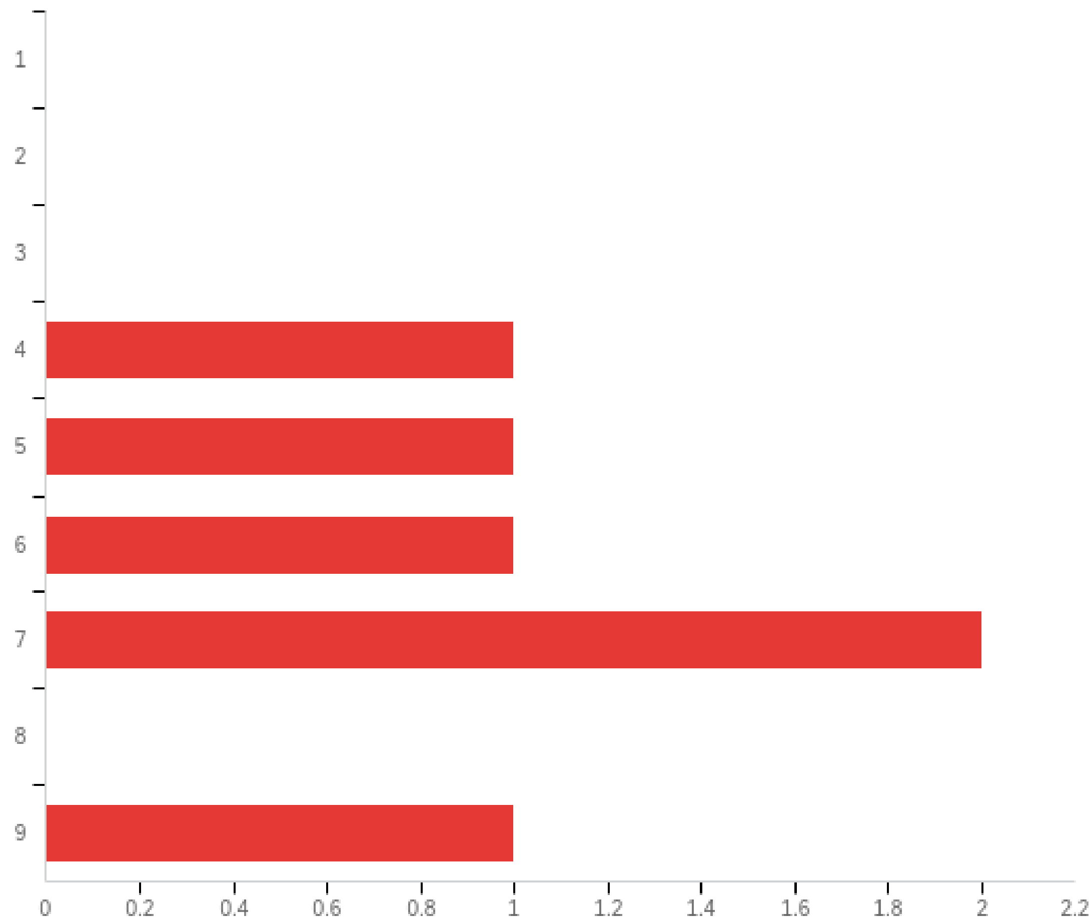
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
2	How well do you think you can identify organic functional groups?	4.00	9.00	7.17	1.95	3.81	6

Q3 - How well do you feel you can predict products if given the starting materials for a chemical reaction?



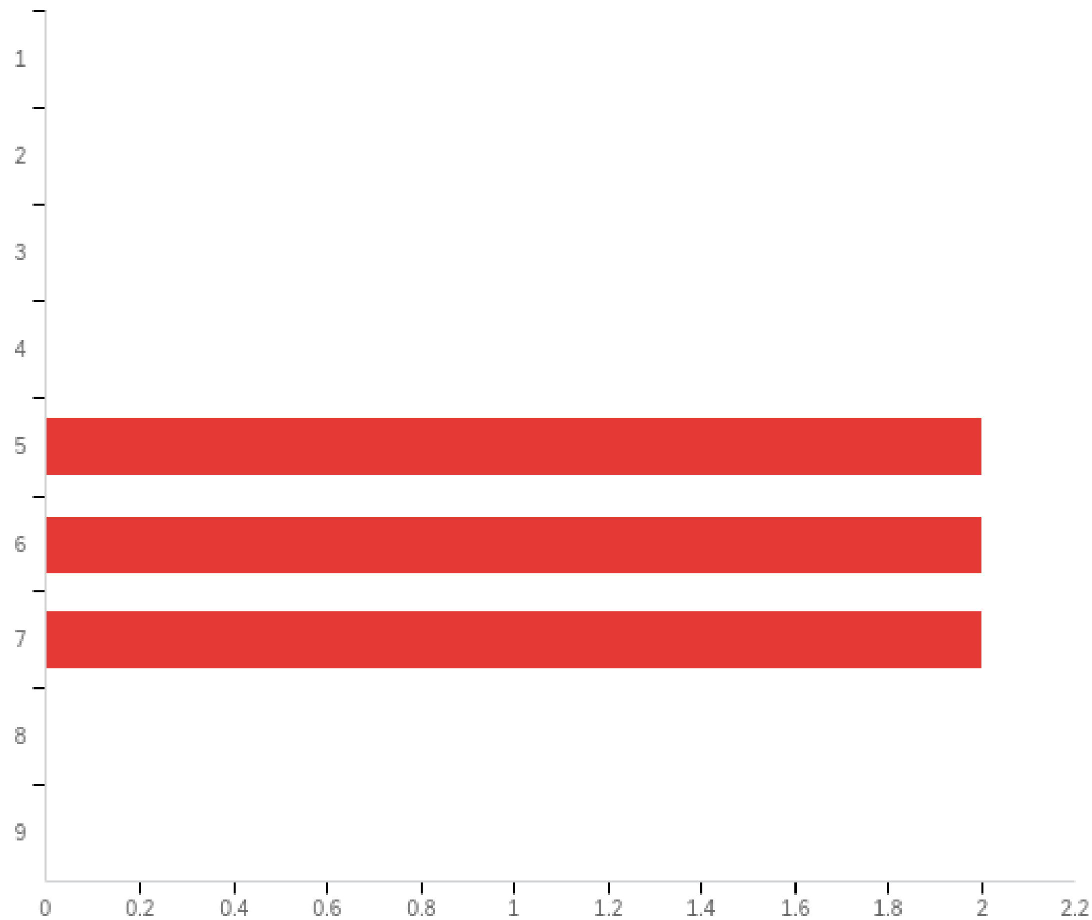
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
3	How well do you feel you can predict products if given the starting materials for a chemical reaction?	3.00	7.00	5.00	1.29	1.67	6

Q4 - How well do you think you can write arrow pushing mechanisms?



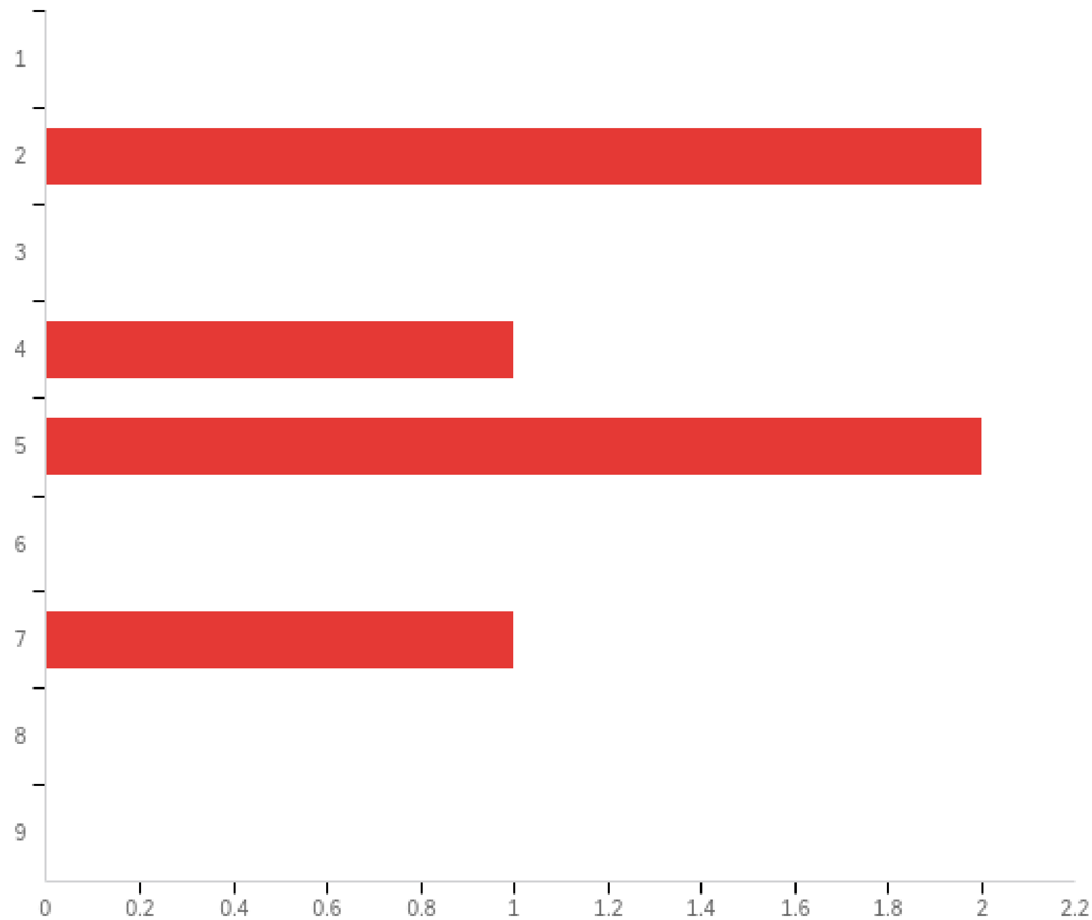
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
4	How well do you think you can write arrow pushing mechanisms?	4.00	9.00	6.33	1.60	2.56	6

Q5 - How well do you think you can justify a result using molecular orbital theory?



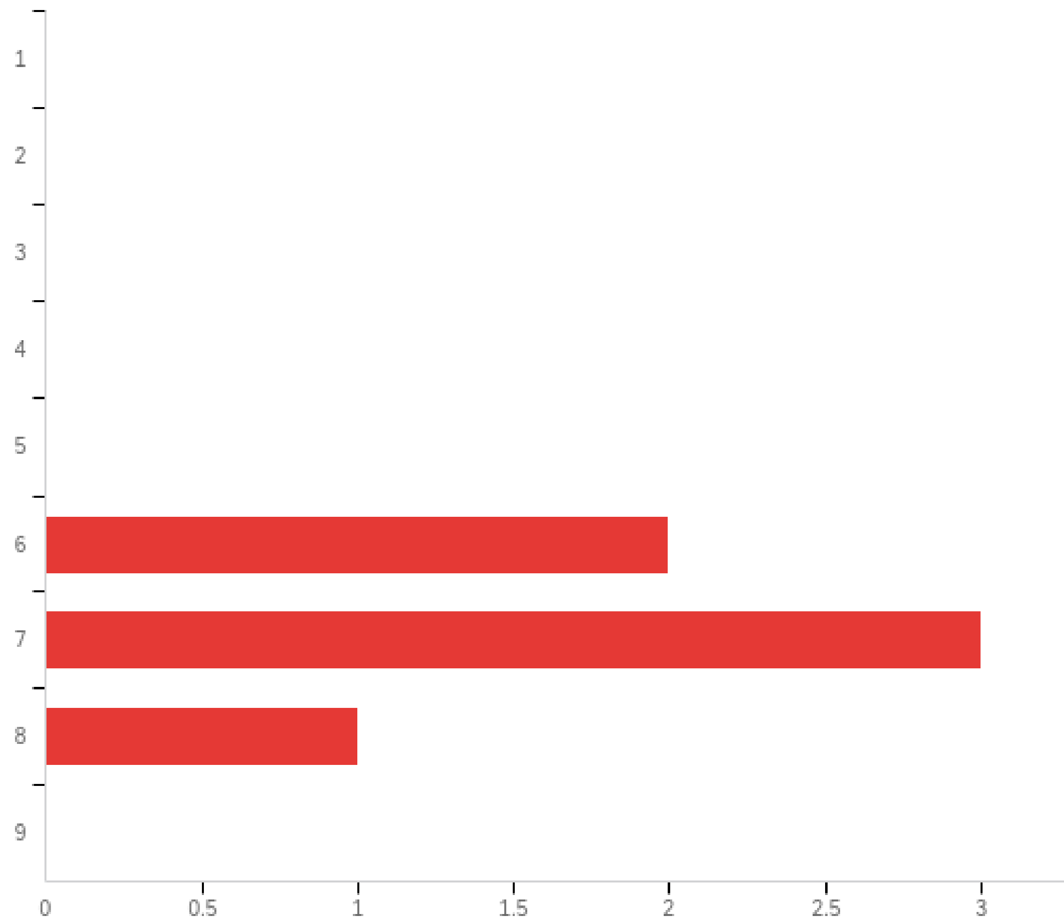
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
5	How well do you think you can justify a result using molecular orbital theory?	5.00	7.00	6.00	0.82	0.67	6

Q6 - How well do you think you can propose a synthesis strategy for a given compound?



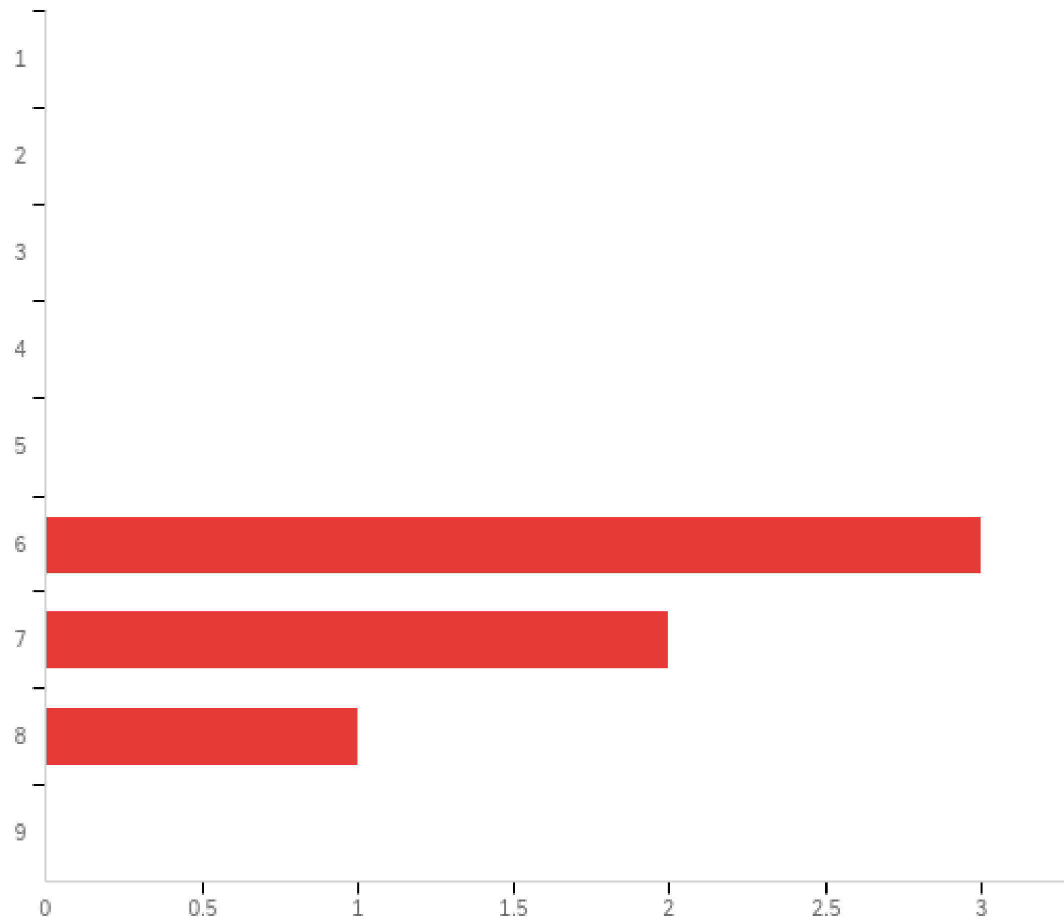
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
6	How well do you think you can propose a synthesis strategy for a given compound?	2.00	7.00	4.17	1.77	3.14	6

Q7 - How well do you think you can recognize real world applications of organic chemistry?



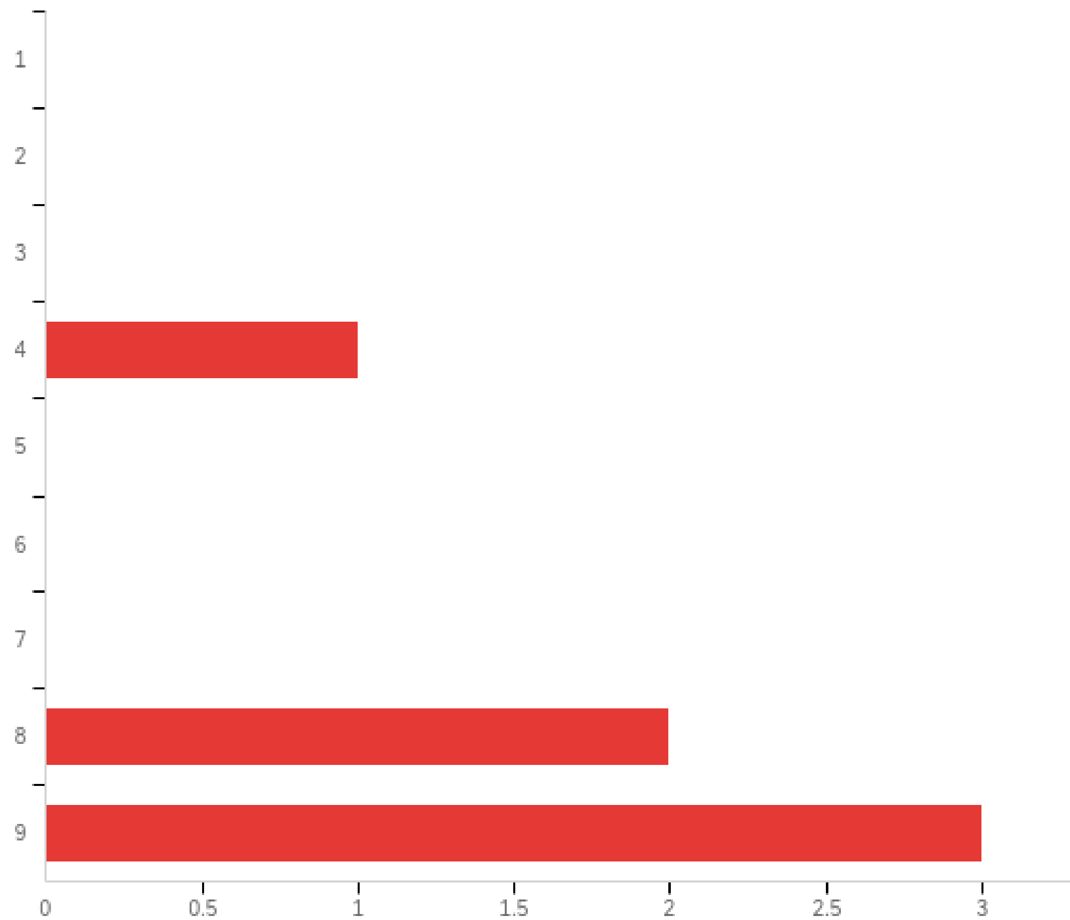
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
7	How well do you think you can recognize real world applications of organic chemistry?	6.00	8.00	6.83	0.69	0.47	6

Q8 - How well do you think you can differentiate between kinetic and thermodynamic products?



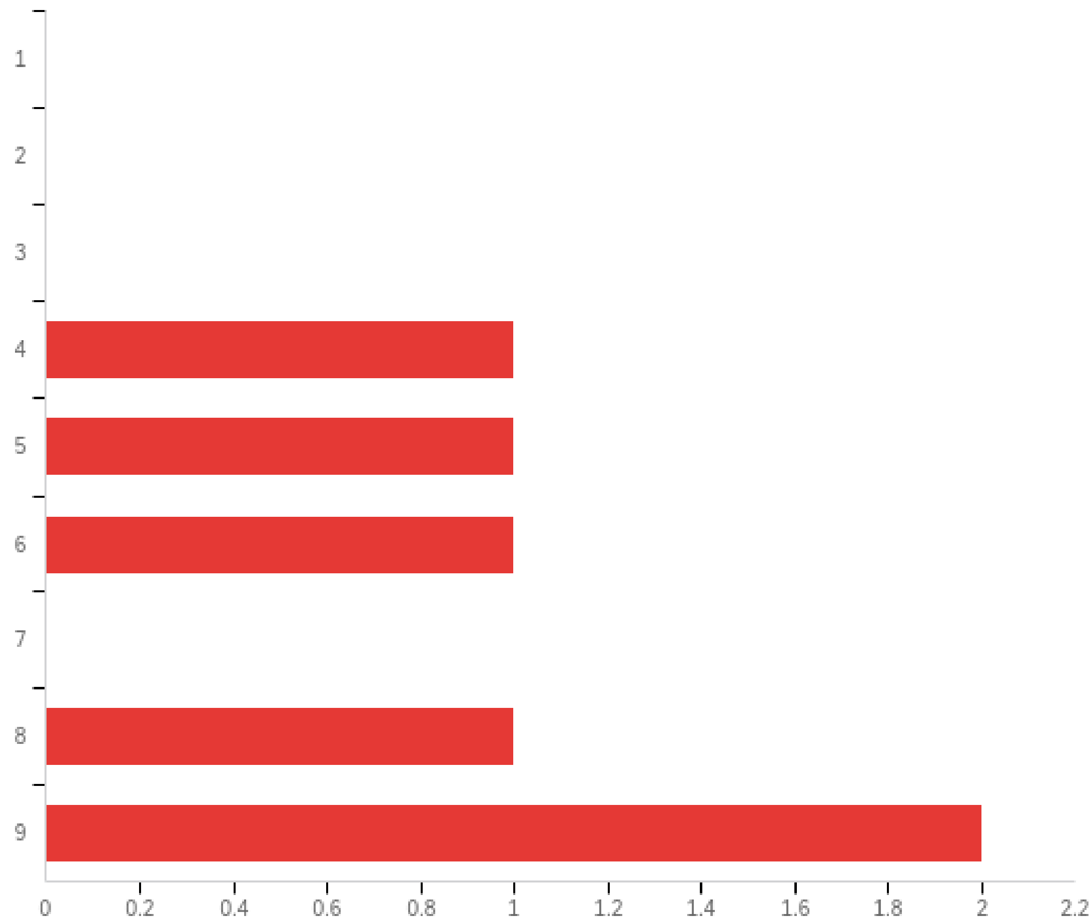
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
8	How well do you think you can differentiate between kinetic and thermodynamic products?	6.00	8.00	6.67	0.75	0.56	6

Q9 - How well do you think you can interpret a reaction coordinate diagram?



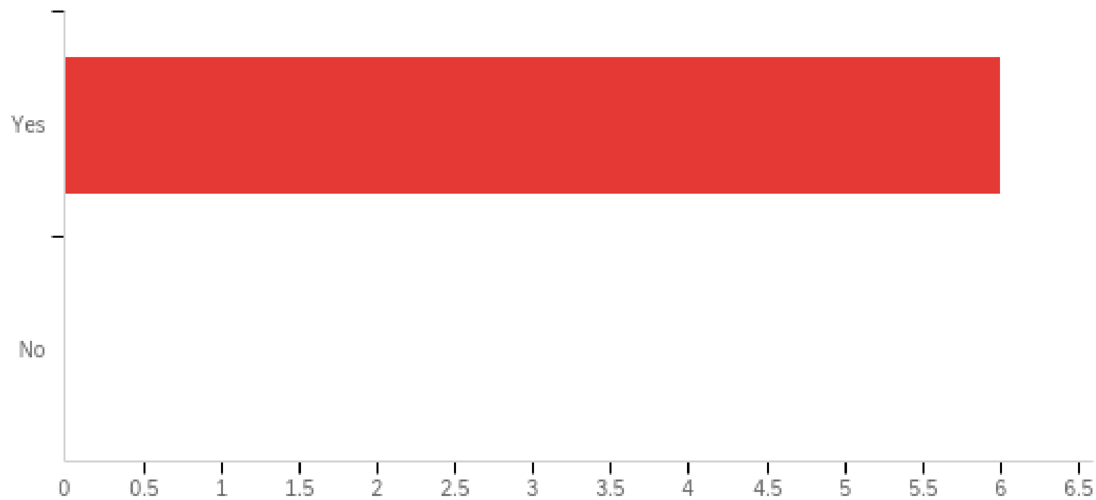
#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
9	How well do you think you can interpret a reaction coordinate diagram?	4.00	9.00	7.83	1.77	3.14	6

Q10 - If given a biological reaction, how well do you think you could apply what you've learned to propose a mechanism?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
10	If given a biological reaction, how well do you think you could apply what you've learned to propose a mechanism?	4.00	9.00	6.83	1.95	3.81	6

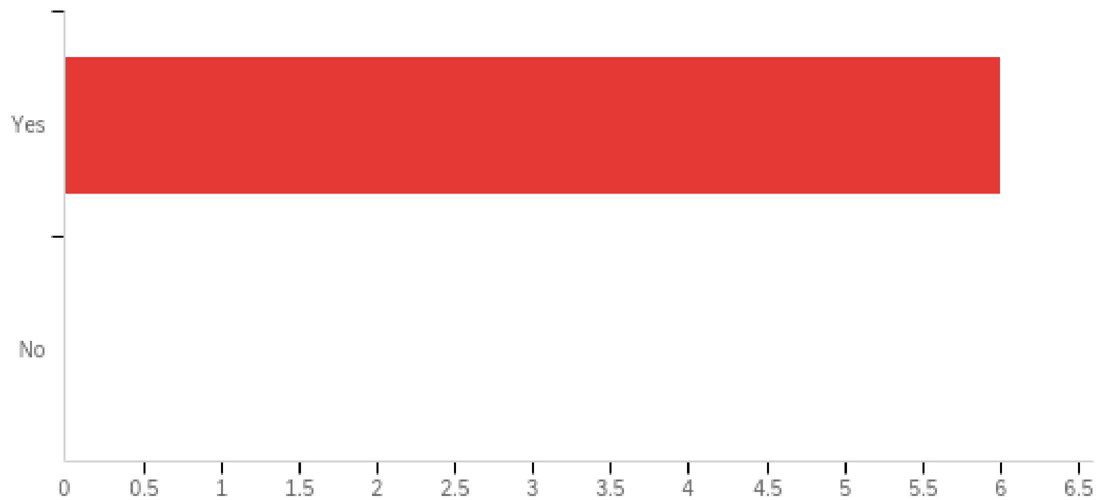
Q11 - Did you feel like your professor was available to you to ask for help?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
11	Did you feel like your professor was available to you to ask for help?	1.00	1.00	1.00	0.00	0.00	6

Elaborate (optional):
Prof. Wencewicz not only available but visibly excited to answer student questions, always welcoming
Both professors I had for organic chemistry (J. Barnes and T. Wencewicz) were exceptional and took the time to answer pretty much every question they could. Dr. Barnes held an astounding number of office hours, which were really helpful for reinforcing important concepts and making sure I kept pace with the class. The smaller organic chemistry in a biological context class I was in with Dr. W was tailored to ensure that students were understanding all the reasoning behind the science instead of memorizing reactions. The slower pace and emphasis on conceptual understanding really helped me learn organic chemistry and maintain that information, so I had to do only a minimal amount of review when I took the MCAT this last January.
Tim Wencewicz (Chem262) was wonderful and always accessible! So was Prof. Barnes (Chem261).

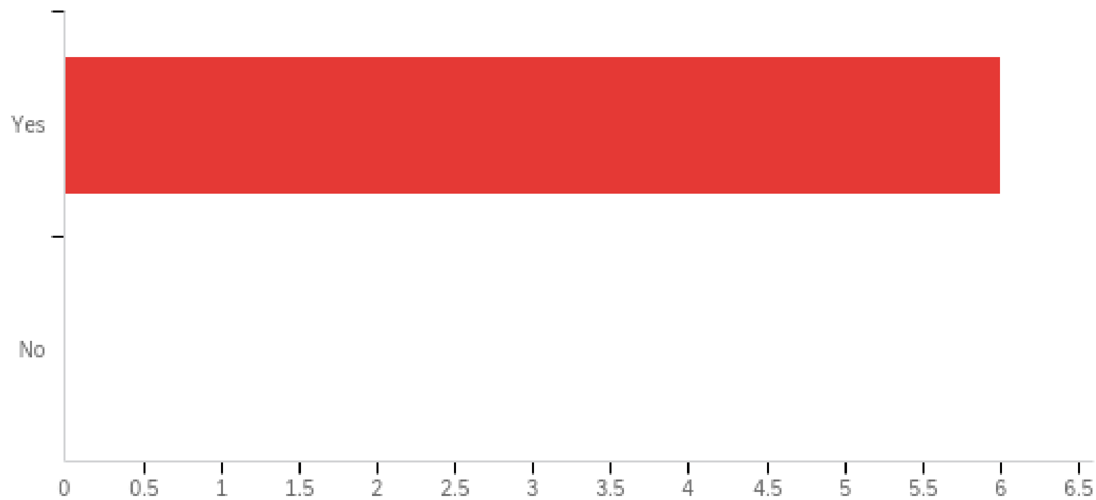
Q12 - Was the classroom environment welcoming?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
12	Was the classroom environment welcoming?	1.00	1.00	1.00	0.00	0.00	6

Elaborate (optional):

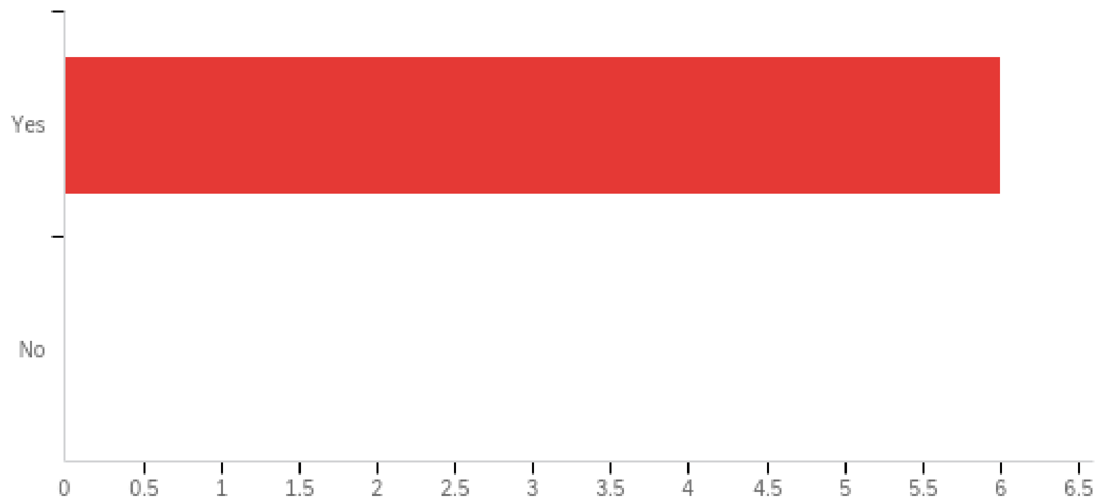
Q13 - Did you find the class handouts to be helpful in improving your learning?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
13	Did you find the class handouts to be helpful in improving your learning?	1.00	1.00	1.00	0.00	0.00	6

Elaborate (optional):
Handouts were 99% of what I learned
The class notes I received in my smaller Organic Chemistry 2 class were very useful for taking notes. They have a very helpful framework for note-taking actively instead of just being printouts of the notes, and I really appreciated them around exam time.

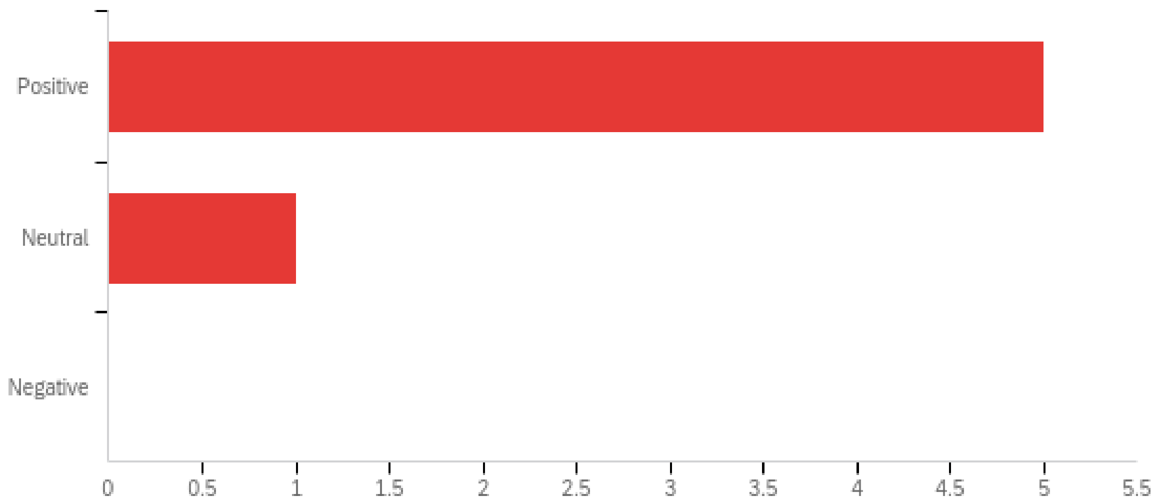
Q14 - Would you recommend taking organic chemistry to a peer?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
14	Would you recommend taking organic chemistry to a peer?	1.00	1.00	1.00	0.00	0.00	6

Elaborate (optional):
If this is not in one's interest, the person wouldn't like it. However, if the person is pre-med, a bio major etc., I would highly recommend they take it at WashU because I gained a huge understanding and appreciation for organic chemistry that many of my classmates who took it elsewhere did not.

Q15 - Generally, how would you describe your experience taking organic chemistry?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
15	Generally, how would you describe your experience taking organic chemistry?	1.00	2.00	1.17	0.37	0.14	6

Elaborate (optional):
The class was very interesting despite its difficulty. If I put in the time, then it wasn't so bad. However, I didn't appreciate the tests being so hard that they needed to be scaled 20-30% to match a regular science grading curve. Despite receiving a "good" score, getting almost half of the points off on an exam is an awful feeling and I felt like I didn't deserve my grade. Also, the ability to drop my final exam was REALLY helpful both semesters. I take really heavy class loads and not having to take one exam is huge during the stress of finals week. Dropping the final has not been allowed since my year and many students would be forever grateful if that policy were to be reinstated. Finally, I absolutely LOVED my smaller, pilot organic chemistry 2 class with Dr. W. I learned so much in that class that I still remember now, an entire year later. The smaller class size and the more biological context for the information presented made the chemistry so much more fascinating and exciting. As an aspiring doctor, I was much more interested to learn about the chemistry behind drug interactions in a human body than the difference between chlorination and bromination SN2 mechanisms in isolation.

Q16 - In the space below, please provide any additional feedback that you would like to expand upon. Elaborate and be as specific as you would like. Here are a couple of questions that may help you get started: What elements of the course did you enjoy that you would like to see used more in the future? What elements of the course did you dislike that you would like to see changed?

(See previous comments for greater detail) Highlights from earlier comments about possible changes: - Ability to drop the final exam (I was allowed to do so, but that policy has since been removed) - better exams so that they don’t need to be scaled by 20-30% to compare to other science classes (no other classes have 60% be an A grade) Things I loved: - Everything about the smaller Pilot class I took with Dr. W. The class pace, the class setup, the material covered - everything was exceptional and I tell anyone who needs to take orgo to be on the lookout for this opportunity if it comes up again - professor accessibility - contextualizing the chemistry with real world examples (This was the biggest determinant for whether I remember something or not - I might not remember the stereochemistry of various reaction products, but I will never forget that the racemic thalidomide given to European women as a treatment for morning sickness resulted in limb development problems. This kind of information helps keep me interested and also makes me care about what I am learning since there are very real consequences to this knowledge which are often overlooked in the classroom setting.

I enjoyed having worksheets we were able to refer to as it was helpful in directing our focus for each chapter. I think having lots of practice is important, so any ways that arrow pushing or conceptual practice can be done for the material would be great.

I think that the rationalization required to earn points on many of the chem exams required a very worthwhile thinking process, but I don't think that we were always given the tools to develop this thinking process independently. For example, in chem 261, we often had a full page of just ranking compounds based on stability or likelihood to react with a given nucleophile or something of that sort, and we just never learned how to do those kinds of questions. I was fine to figure this out on my own, as demonstrated by my A+ in Orgo I and II. But, not all of my peers were. And, its often questions like these that are the salient points of orgo that will be called upon in upper level courses; this is currently happening for me now in chem 482. So, i think that chemical logic should be emphasized before exams.

6.3 Course Evaluations with Color Coded Analysis: Alternative Course

Question 1: What would you like to tell other Wash U students thinking about taking this course?

Read the textbook

If you cab find literally any way to take this class with Professor Wencewicz rather than the larger section, do.

Taking the bio section of organic chemistry was a great decision. I **enjoyed** organic chemistry so much more during second semester than first semester. I appreciated that the material was focused toward things that were **relevant** to students who weren't chemistry majors, and framing reactions in a biological context made them a lot more **interesting** and easier to remember. The course pace was a little bit slower second semester than first semester, but I think I **learned** more second semester because the slower pace allowed me to **understand** concepts at a deeper level rather than memorizing surface–level facts.

Professor Wencewicz is amazing and makes **learning** organic chemistry a ton of **fun**. His class is fantastic and he does an excellent job of explaining topics in a way that makes sense.

Take the smaller section. It is a **valuable learning** experience where your answers are much more easily answered. I **learned** so much more about organic chemistry in this section than I did in the large section.

This course is a much more digestible version of organic chemistry, and I still feel like I **learned** the same amount of core material. If you put in the **work** this is an excellent course.

Very helpful course. if your taking Orgo at WashU, then take it with Moeller, barnes or Wencewicz. Dr. De la Cruz is always fabulous for orgo lab.

This section of organic chemistry 2 is very helpful for students who want to **learn** more about the **applications** of organic chemistry to biological systems and other **relevant** fields, and I would recommend this section for any pre–health student especially.

take orgo w Wencewicz if you can

I think for the specific pilot section of 261 that if you have a strong foundation in chemistry is a really information course with a strong instructor and I would highly recommend. If you are someone who tends to struggle, this class will **challenge** you in different ways than the general lecture. I believe I genuinely **learned** more in this section than I would have in the other section, but this section is not **curved** so take that risk as you will.

Not as bad as the reputation organic chemistry gets.

This course is incredibly **challenging** and Prof. Wencewicz has high expectations for his students. But, if you want to **learn** something really **valuable** and fundamental to the basis of our world, and you approach the course material with this attitude, you will thrive in this course. The professor is great and a good attitude goes a long way.

This course was absolutely phenomenal. The emphasis on biological **relevance** made this course so **fascinating** and easy to **apply** to my life.

Wencewicz places a larger emphasis on core concepts and will not waste your time. Plenty of **practice** is available to test yourself on the concepts. Wencewicz's explanations are crystal clear and he truly cares about his students.

This is a biochemistry–focused version of organic chemistry which does an excellent job of tying the material to real biomedical and synthetic **applications**

Organic chemistry was definitely one of the **hardest** classes to understand the concepts. It recommend only taking this course if you genuinely have a strong interest and a strong foundation in chemistry.

Take it with Professor W if at all possible, if not best of luck

keep up with the material!

6.4 Course Evaluations with Color Coded Analysis: Traditional Course

Question 1: What would you like to tell other Wash U students thinking about taking this course?

This is a very **challenging** course. If you don't put the **effort** to **understand** the material, the chance of doing poorly in the class is very probably.

Orgo is the **hardest** class I have taken so far and you will have a **lot of materials** to memorize.

It is a terrific way to think about **bio–molecules** and in one semester turns chemistry from an intimidating monster to a tamable beast.

This class tests your discipline. Schedule yourself and **work** on the coursework every day. If you let yourself get lazy you will die.

Do not procrastinate in this class because you will fall behind and you will struggle to study for the exams last minute. Best way to study is to briefly review the lectures after each lecture date so that you can follow along next lecture. Utilize the textbook for **practice** problems.

Its a **tough** course but you do get a **good foundation**.

This class is all about **understanding** the mechanism and being able to explain why certain reactions are favored over others

This course has a lot of **difficult** material. I highly recommend **staying on top of the mechanisms** and going to office hours.

Orgo is very **challenging** but **useful** and Moeller is a great professor to teach the course.

Don't stress that much, go to office hours,and focus on **learning** the reagents/effects of reactions over the mechanisms, and then just **practice** arrow pushing.

I think Professor Moeller did a phenomenal job teaching the course. He was really enthusiastic about teaching the class, and he was well organized which is incredibly helpful in a subject like organic chemistry. It is still a very **challenging** course, and I think it is very important to **stay on top** of course material, but if you **keep up**, **practice** with old exams, and utilize just some of the many resources that the course has available, you should be able to do well. There is a lot of resources offered if you are struggling, and I think that was a nice option to have. Overall, this was a very well run course. While it was definitely very **challenging**, was well worth it.

Be prepared to **work**. Also make sure you **keep up** with the course material. But getting a good **grade** in this course is very attainable.

Very good course. It's **hard work** but manageable.

It is totally manageable if you **work** at it and **stay on top** of the material.

Orgo is **hard**, mostly because of the sheer quantity of material the class covers in one semester. I don't think I can physically fit all the different reactants in my head at the same time.

It is important to **stay up to date** on your reading and to go to office hours.

Organic chemistry requires a lot of **practice** to do well. I had other classes with exams that aligned with organic chemistry exams, which significantly impacted my ability to study for them. Make sure you have the **time** to take this class before doing so.

Very **challenging** course, need to **study a lot**

This course is very **hard**, there's a reason no one want to take it at WashU. It's not impossible to do well, but the tests make it feel that way.

Definitely make sure you are **up to date** with the lectures and READ ALL THE READINGS. He won't go over some of the mechanisms that you need to know for the tests because they are in the book. Also this class is a lot of memorization so keep that in mind.

Print out the notes before hand!

Course requires a lot of **practice**. Seek help from the professor or the TAs readily

The course although very **challenging**, is do–able with **hard work**.

It's really **hard**. Don't take it unless you have to.

Organic Chemistry II requires a lot of **work** and **effort**, but if you put in the **time**, you can get a good **grade** and take a lot out of it. I didn't know that chemistry was so important to my path of becoming a doctor until I took this class with Professor Moeller. He is extremely knowledgable about the chemical workings of **biological aspects** like DNA and great to **learn** under, but he does go really fast over the content. Make sure to have your lectures printed out already so you only have to draw the structures or **keeping up** during class will be **difficult**.

Prepare to be sad

Hard course, but you'll **learn** a ton. Definitely the more **fun** semester of organic chem for premeds.

Straightforward class. Very fair lecturer and **grading**. You will need to spend ~**40 hours** per exam, assuming you went to lectures, to get a high **grade** (B+/A–/A).

Moeller is a fantastic professor. He knows his stuff, and although it is **difficult** material, he is very engaging and super available to help. This is a class that requires you to **work** a lot on your own and keep yourself **caught up**. If you are able to do that, you will do well.

It's very **difficult**—make sure you allow yourself adequate **time** every day or week to study and prepare adequately for exams.

It's really **hard** to get an A but with a lot of **work** a **B** is very doable.

This is a **difficult** but extremely well–taught course. **You get out what you put in**. The professor is amazing and very willing to help students **learn** the material in whatever way he can.

Dr. Moeller is awesome. He's really there to help you succeed (and genuinely wants you to), which is great. Orgo is one of those classes where if you put in the **time**, you'll do well. So you just have to be prepared to have a part time job lol

This class is great! Take it here, not somewhere else! It'll be **hard** but also worth it.

It's **interesting** and contains real world **application** of organic chemistry to biology and pharmaceutical drugs

it is so **hard**, you need to not **fall behind** if you want to do well

Professor Moeller was a fantastic instructor. Beware of other professors though because organic chemistry is a very professor dependent course.

Organic chemistry is conceptually very **interesting** but a fairly **difficult** course.

its a whole lotta **work**

Hard course

It's very **difficult**, but if you put the **time** in you can make it easier on yourself.

Super **time** consuming and **challenging**. Be careful how many other classes you take with it

try not to if you don't have to

Organic chemistry is a very rewarding experience when taught by Professor Moeller. This course is **challenging**, but worth it!

It's really **challenging**, and I cannot say I fully understand organic chemistry, but I'm glad that I took it, and that I have **learned** something from the course.

This course is incredibly fast paced but **intellectually stimulating**. It's not as bad as everyone says it is.

It's **hard** and you have to put in the **work**, but it isn't impossible.

Professor Moeller is one of the best science teachers I have had at WashU, but organic chemistry is just an extremely **hard** course. I probably studied **40+ hours** for about every exam. The exams are fair, but just an extremely large load of material.

Take it. It has a terrible reputation, and after going through first semester it may seem like there's no point in it, but this class was actually phenomenal.

It is **work** but it is worth it

Organic Chemistry is a very **difficult** class and definitely requires you to put in a lot of **time** and **effort** studying along the way. Witing till the last minute to study for orgo exams does not work as it is a lot of material.

I found this course **interesting** because of it involves many **biological processes** in the body and Dr. Moeller tied it well to **medicine**. Dr. Moeller has great office hours and provided good resources with the old exams.

6.5 Example Handout

I. Chapter 14: Ethers, Epoxides, and Thioethers

a. Recommended Sections: 1–5, 7–15

b. Recommended Problems 2, 4, 5, 7, 9, 11–18, 20–22, 25, 26–28, 33–41, 42 (only A,F,G,H,C), 43, 45, 49, 52 (part a only), 53–55.

c. Topics in Organic Chemistry:

- **i.** Reaction Mechanism
- **ii.** Reaction Energy Landscapes
- **iii.** Frontier Theory
- **iv.** Transition State Theory
- **v.** Thermodynamic Control of Reactions
- **vi.** Chemical Equilibria
- **vii.** Functional Group Interconversion
- **viii.** Regioselectivity and stereoselectivity
- **iv.** Synthesis of chiral compounds

d. Topics Related to Human Health:

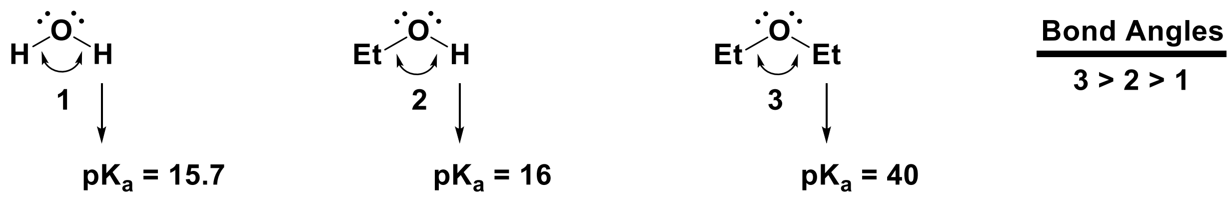
- **i.** Chemical Safety
- **ii.** Enzyme Reactions
- **iii.** Vitamins and Cofactors
- **iv.** Medicinal Chemistry
- **v.** Reactions Encountered in Metabolism

____

Print Student Name Here

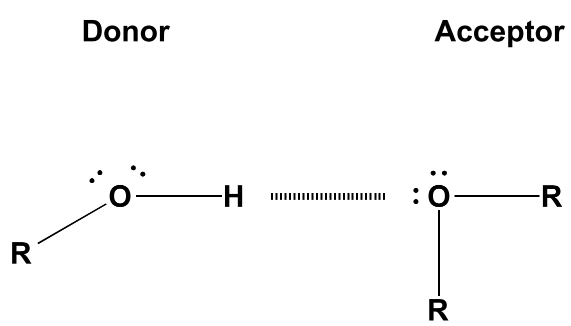
II. General Formula/Structure/Properties (Ethers)

a. Structure



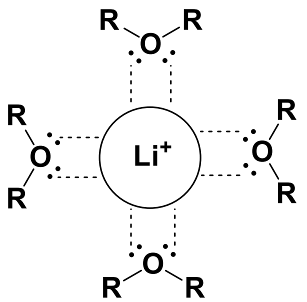
b. Properties

i. H-bonding

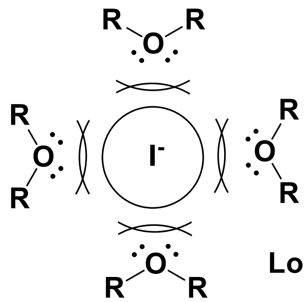


Draw orbital justification for H-bonding

ii. Ion Solvation

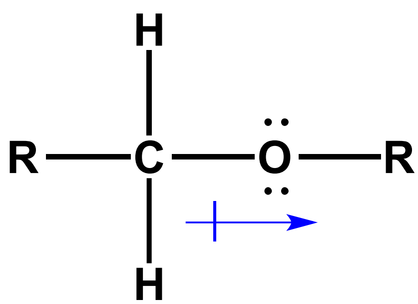


Cations only!



Lone pair repulsion

iii. NMR and IR Spectroscopy

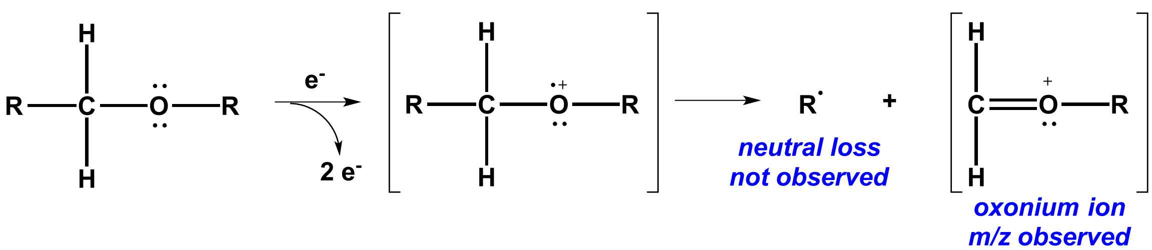


^{1}H d (ppm) 3.5 – 4

^{13}C d (ppm) 65 – 90

IR n (cm^{-1}) 1000 – 1200 (weak)

iv. Mass Spectrometry



III. Synthesis of Ethers

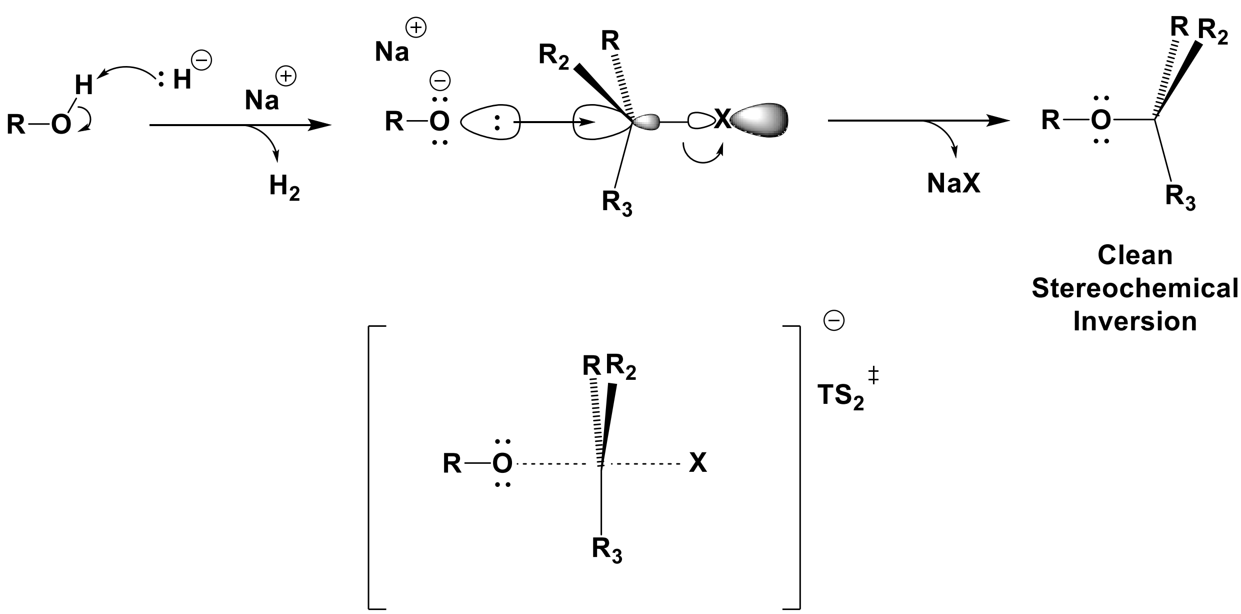
a. Williamson Ether Synthesis (S_n2)

$$R{-}OH \xrightarrow[\text{2. } CH_3I]{\text{1. NaH}} R{-}OMe$$

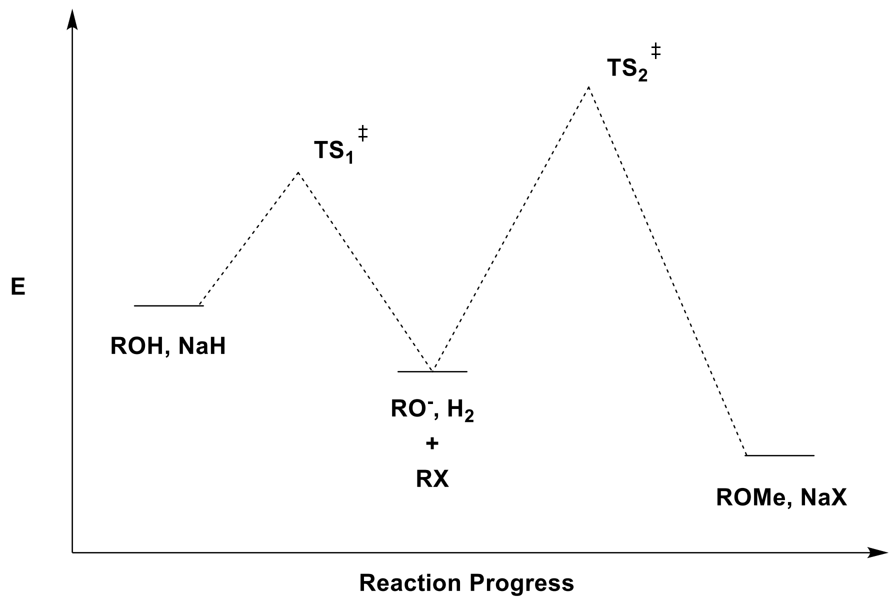
Choice of base depends on pK_a of alcohol

Alcohol:	**Me—O—H**	vs	**Ph—O—H**
pK_a:	**16**		**10**
Base:	**NaH**		**K_2CO_3**

i. Mechanism and Stereochemistry (S_n2):

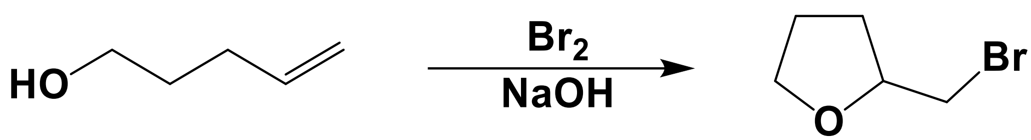


ii. Reaction Coordinate Diagram



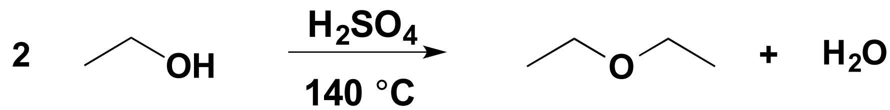
b. Cyclic Ether Synthesis (Bromohydrin Reaction)

- We are doing this in place of Alkoxymercuration-Demercuration.



i. Mechanism

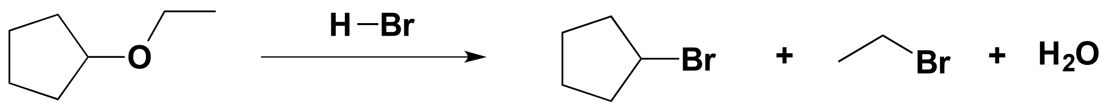
c. Industrial Scale Synthesis of Diethylether



i. Mechanism

IV. Reactions of Ethers

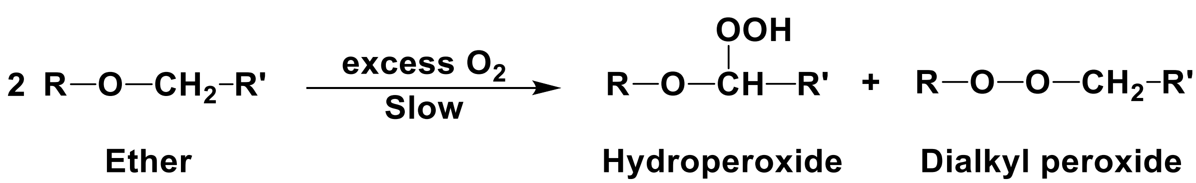
a. Cleavage by HX (Works best with HBr and HI.)



i. Mechanism

b. Autoxidation (Chemical Safety)

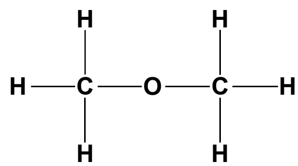
i. You are not responsible for this mechanism.



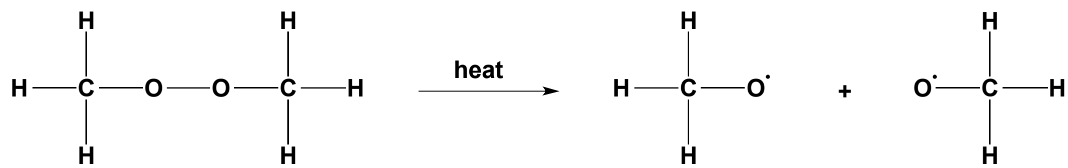
c. Peroxides

i. Properties

C–O
335 kj/mol



C–O
157 kj/mol



ii. Synthesis

pKa = 15.7

$$H{-}\ddot{\underset{\cdot\cdot}{O}}{-}H \xrightarrow[\text{NaOH}]{2\ \text{Me—I}} Me{-}\ddot{\underset{\cdot\cdot}{O}}{-}Me$$

pKa = 11.7

$$H{-}\ddot{\underset{\cdot\cdot}{O}}{-}\ddot{\underset{\cdot\cdot}{O}}{-}H \xrightarrow[K_2CO_3]{2\ \text{Me—I}} Me{-}\ddot{\underset{\cdot\cdot}{O}}{-}\ddot{\underset{\cdot\cdot}{O}}{-}Me$$

Dangerous!

d. Chemical Test for Peroxides

$$R{-}O{-}O{-}R \ + \ 2\,KI \xrightarrow{H_2SO_4} 2\ R{-}OH \ + \ I_2 + K_2SO_4$$

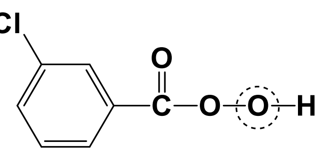
i. Mechanism

V. Epoxides

Ring Strain: 25 kcal/mole | 15 kcal/mole | about 0 | about 0

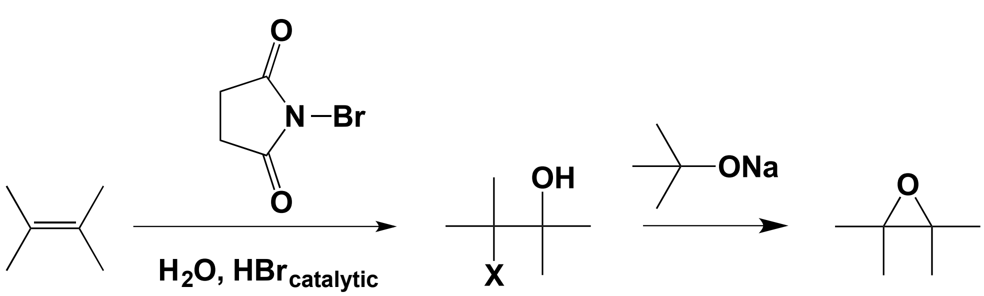
VI. Synthesis of Epoxides

a. Peroxyacid Epoxidation

MCPBA = 

i. Mechanism

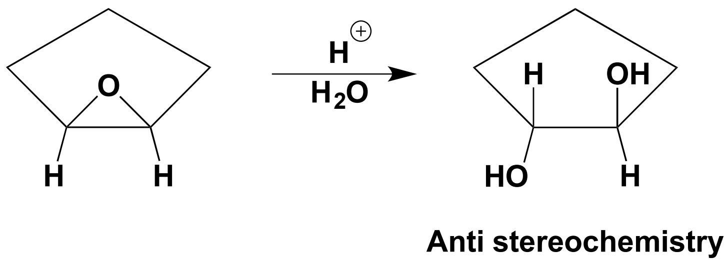
b. Base Promoted Cyclization of Halohydrins



i. Mechanism

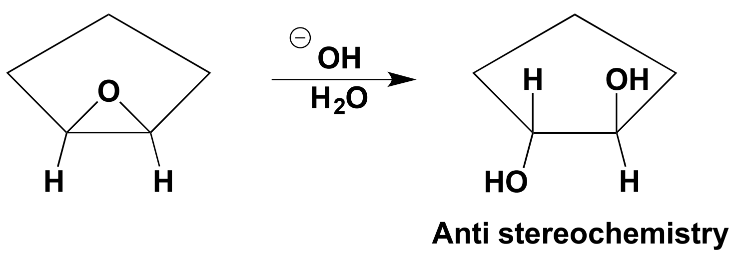
VII. Reactions of Epoxides

a. Acid-Catalyzed Opening



i. Mechanism

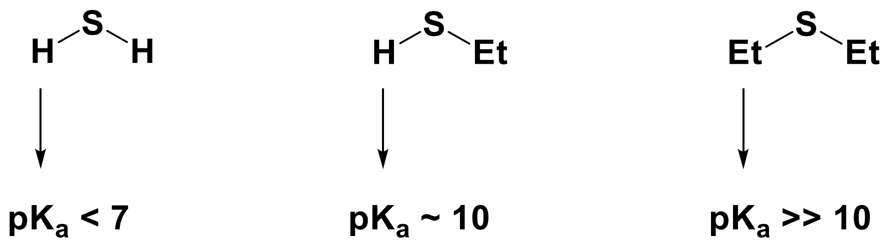
b. Base-Promoted Opening



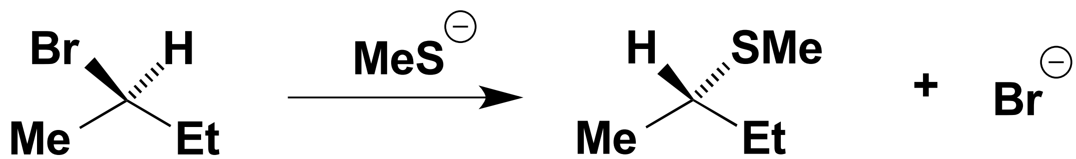
i. Mechanism

VIII. Thioethers

a. Structure/Properties



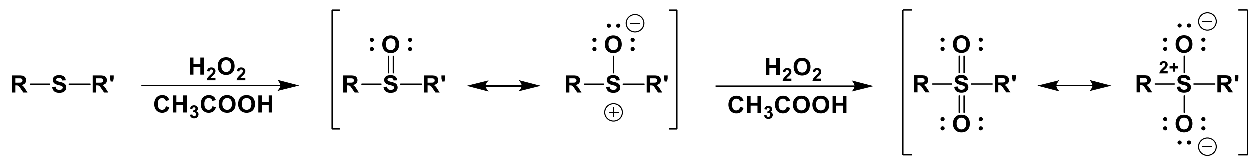
b. Synthesis of Thioethers (Williamson)



i. Mechanism

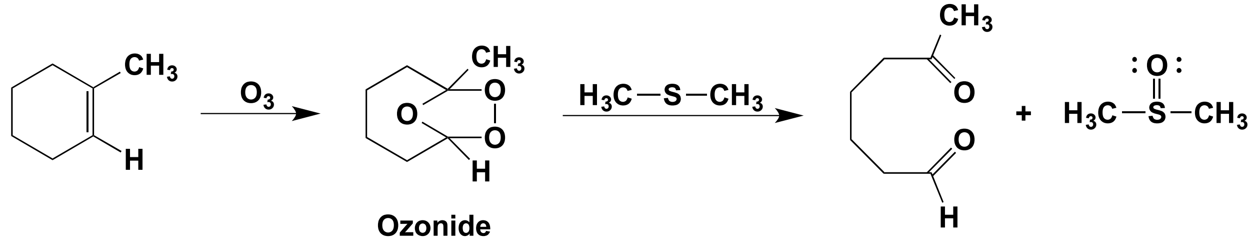
c. Reactions of Thioethers

i. Oxidation to Sulfoxides and Sulfones

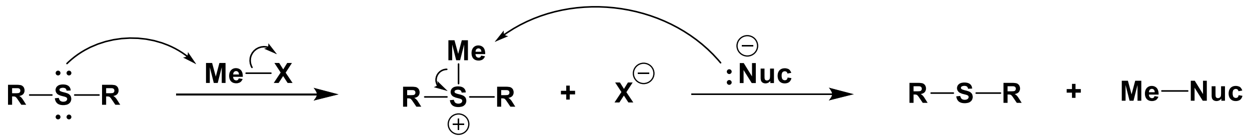


- **Mechanism**

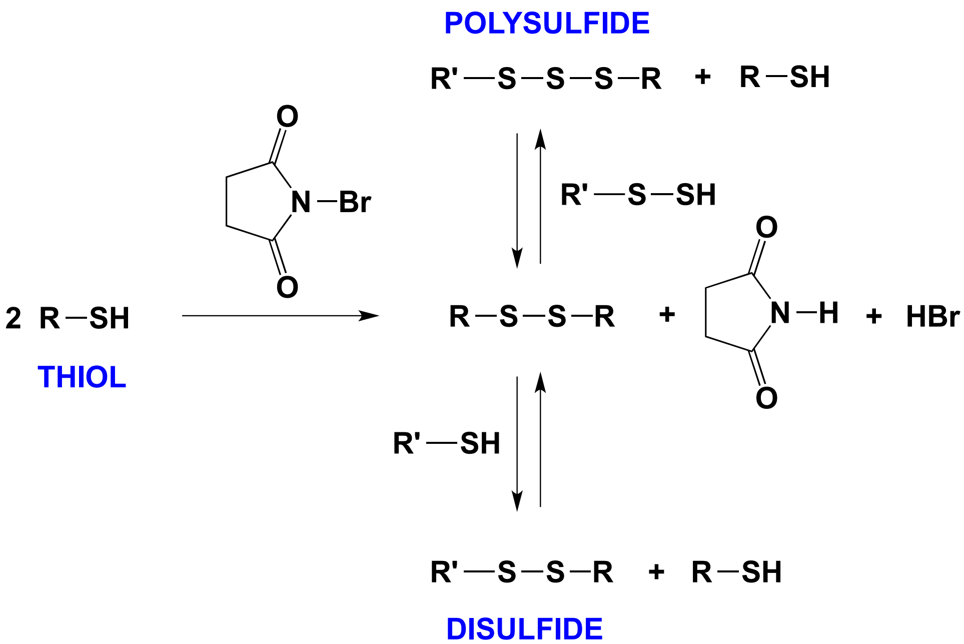
ii. Use in Ozonolysis



iii. Electrophilic Sulfonium Salts

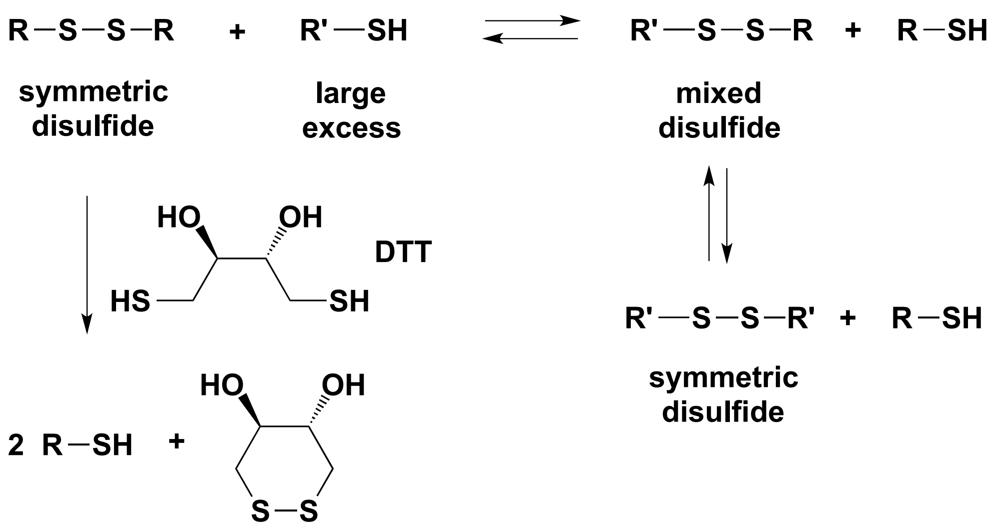


d. Disulfides and Polysulfides



i. Mechanism

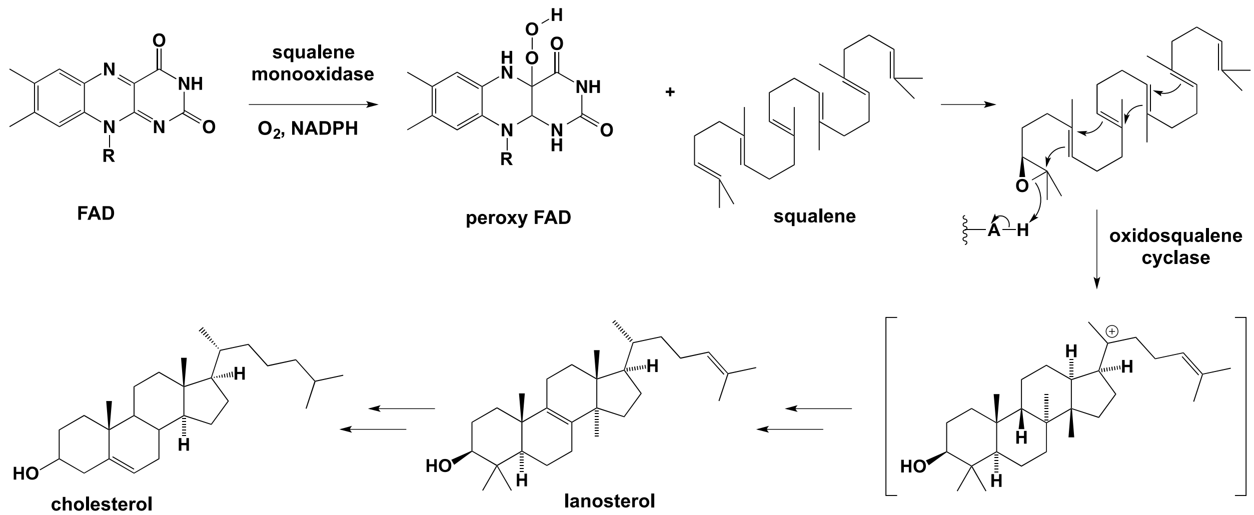
e. Dithiothreitol (DTT; Cleland's Reagent)



i. Mechanism

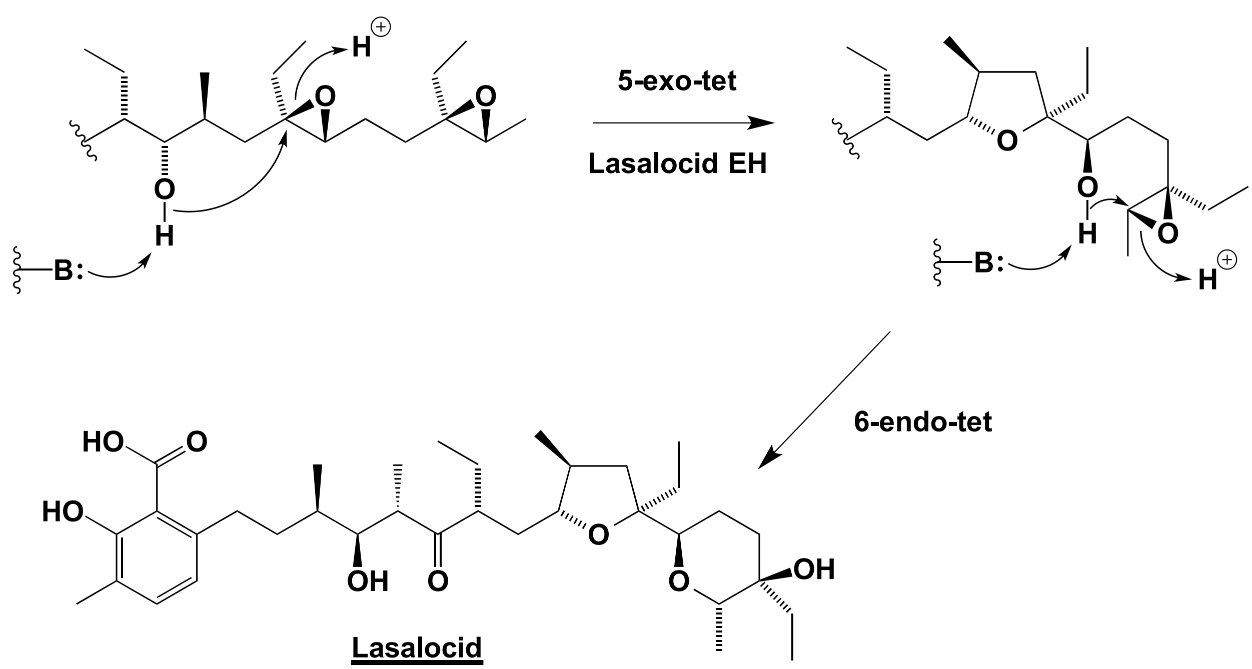
IX. Biological Examples

a. Enzymatic Epoxidation of Olefins



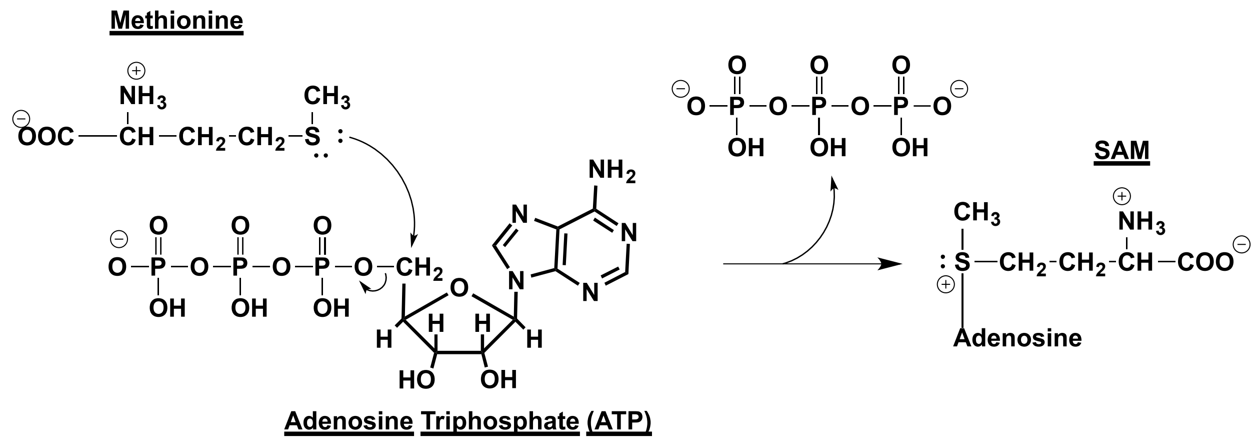
b. Natural Product Biosynthesis

i. Lasalocid – The case of the disappearing epoxides.

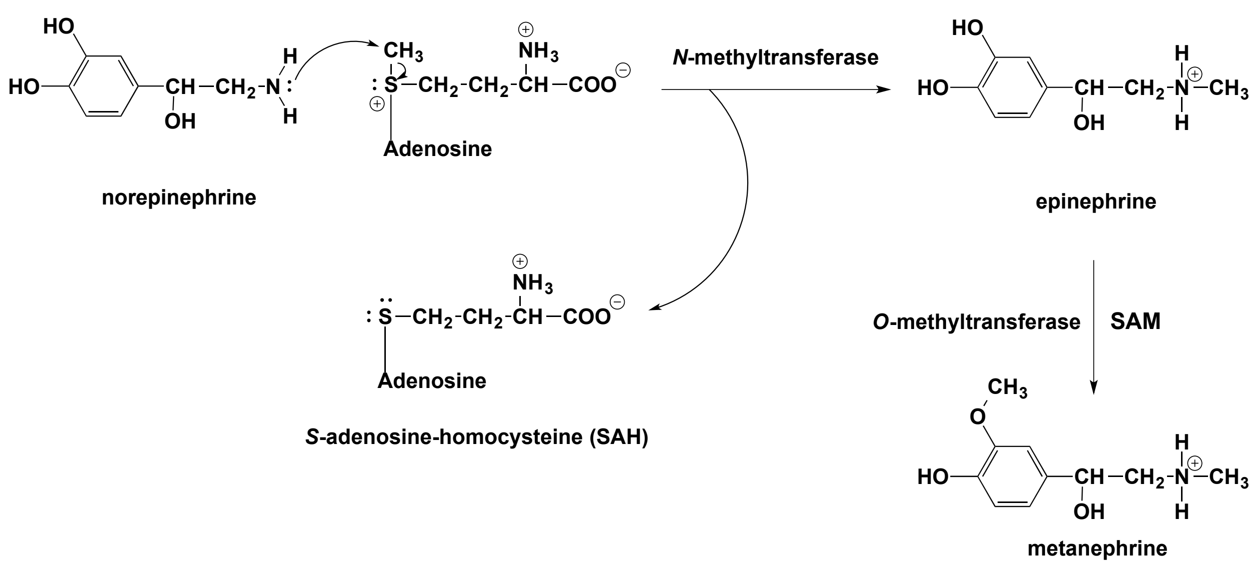


c. SAM as Biological Methyl Donor

i. Biosynthesis of SAM

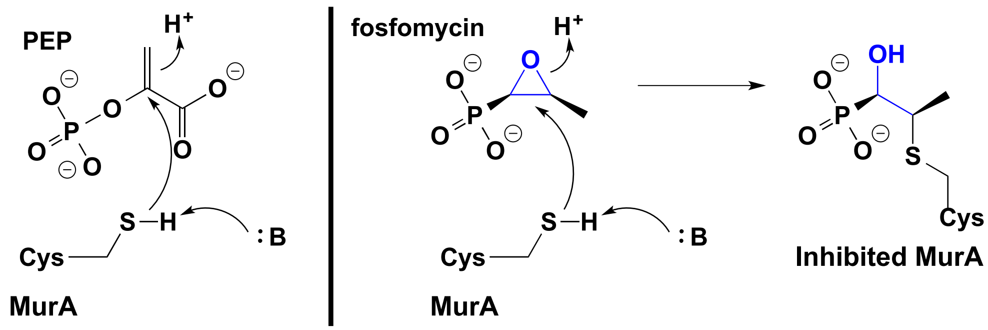


ii. Methylation of Epinephrine (Adrenaline)

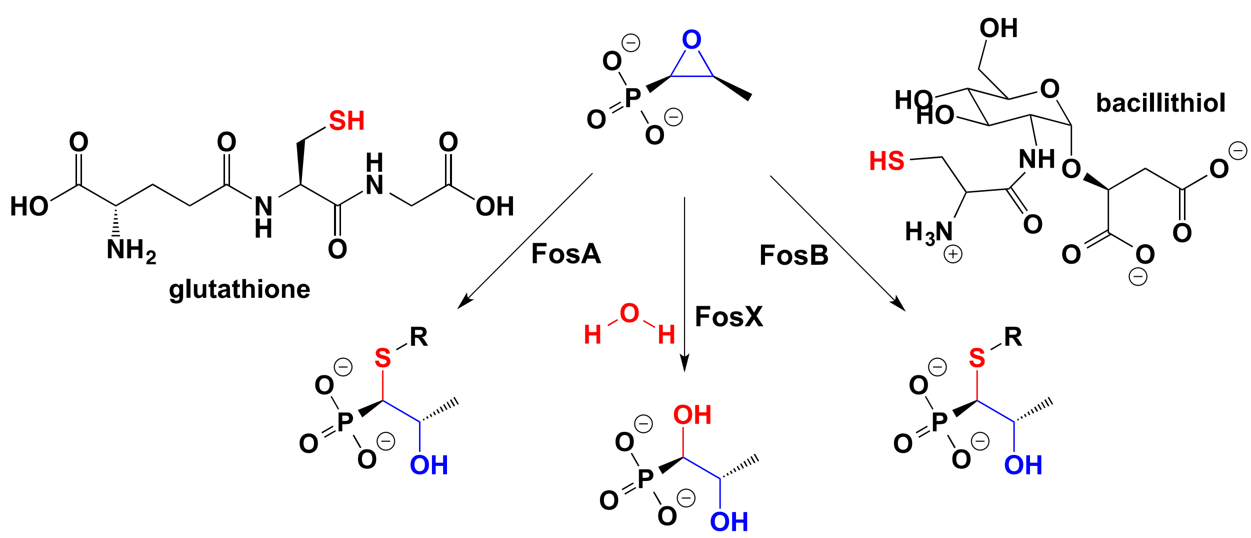


d. Suicide Enzyme Inhibitors

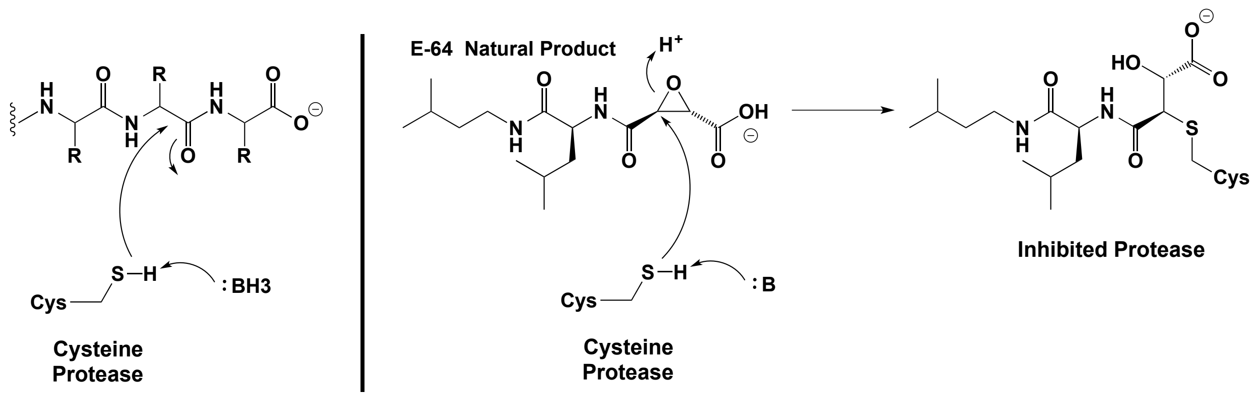
i. Fosfomycin Inhibition of MurA



ii. Fosfomycin Inactivating Enzymes: Antibiotic Resistance



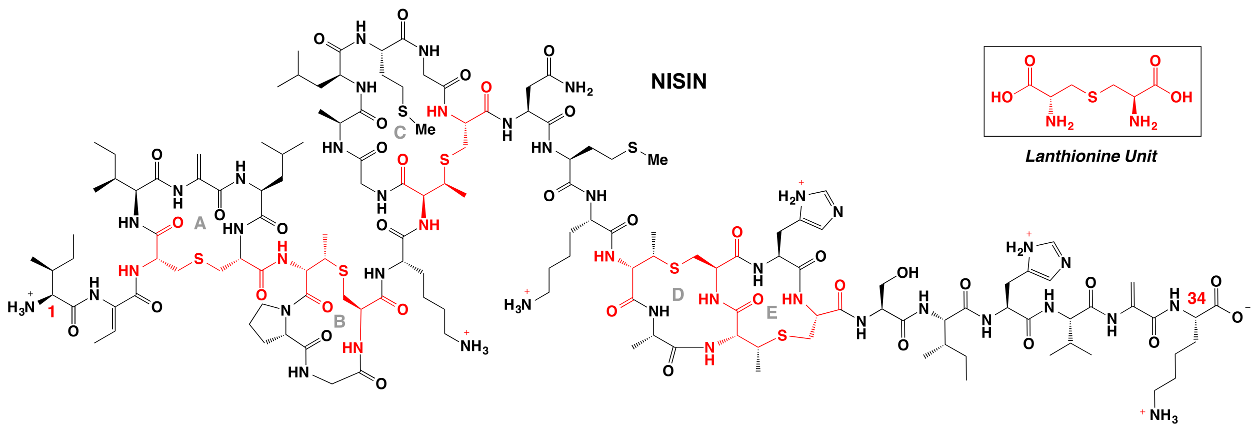
iii. Epoxysuccinates



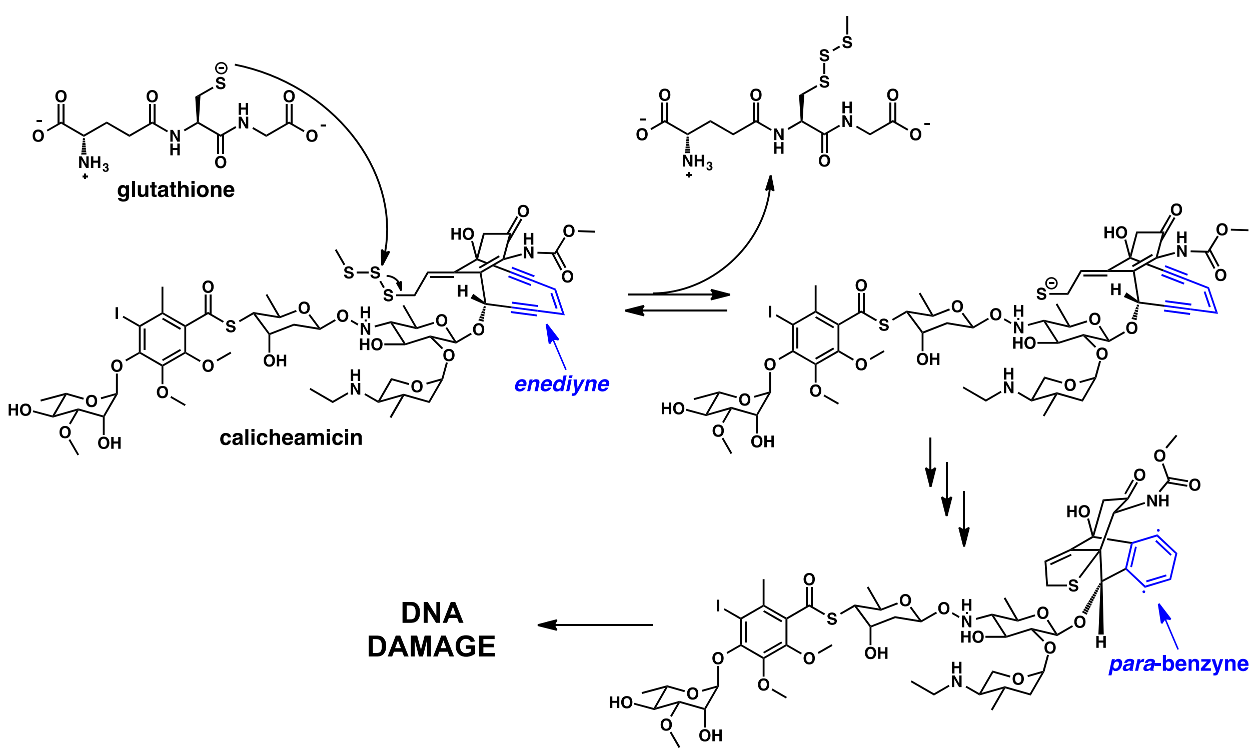
e. Catalase

$$\mathrm{H{-}O{-}O{-}H} \xrightarrow[\mathrm{Fe(II)}]{\text{catalase}} 2\ \mathrm{H{-}O{-}H} + \mathrm{O_2}$$

f. Structure Stabilization by Thioethers and Disulfides

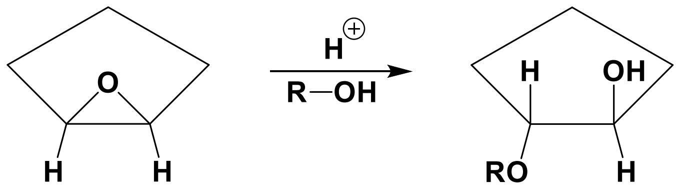


g. Biological Reduction of Calicheamicin



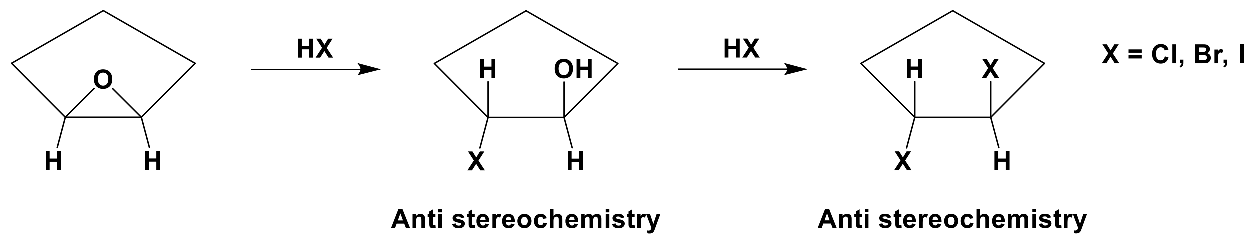
X. Problems

1. Draw an arrow pushing mechanism for the reaction given below.

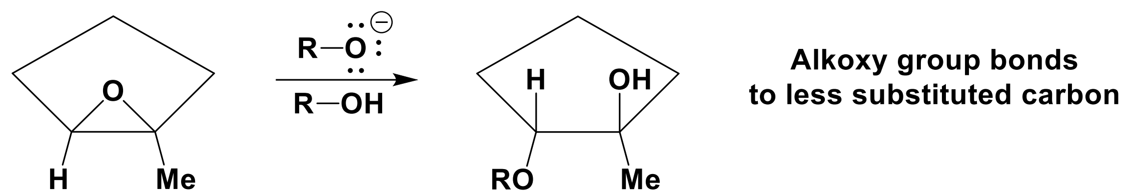


Anti stereochemistry

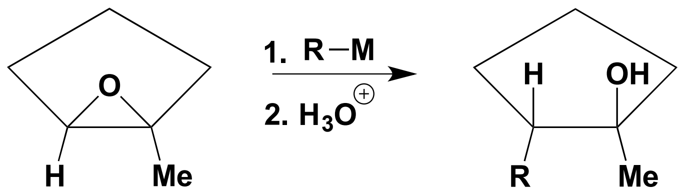
2. Draw an arrow pushing mechanism for the reaction given below.



3. Draw an arrow pushing mechanism for the reaction given below.

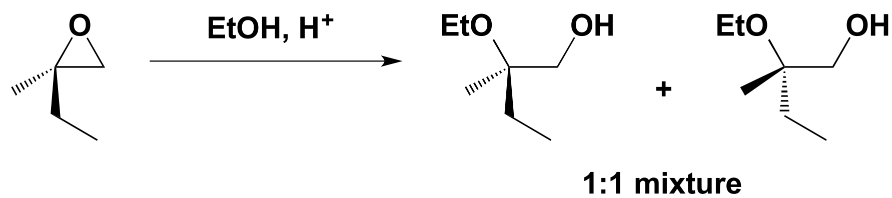


4. Draw an arrow pushing mechanism for the reaction given below.

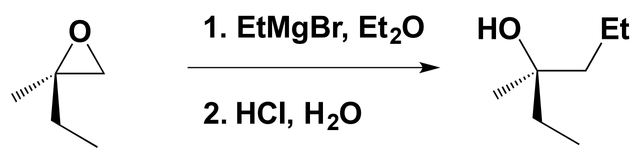


R bonds to less substituted carbon (M = Li or MgX)

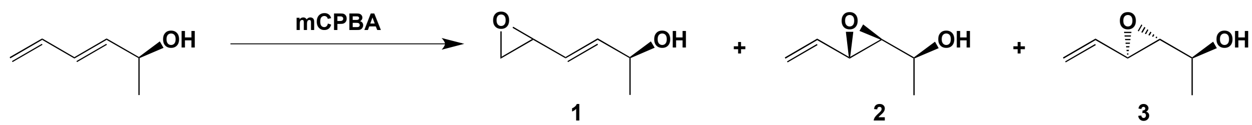
5. Rationalize the regiochemistry and stereochemistry for the reaction given below. Draw arrow pushing mechanisms and frontier molecular orbitals to support your answer.



6. Rationalize the regiochemistry and stereochemistry for step #1 of the reaction given below. Draw arrow pushing mechanisms and frontier molecular orbitals to support your answer.

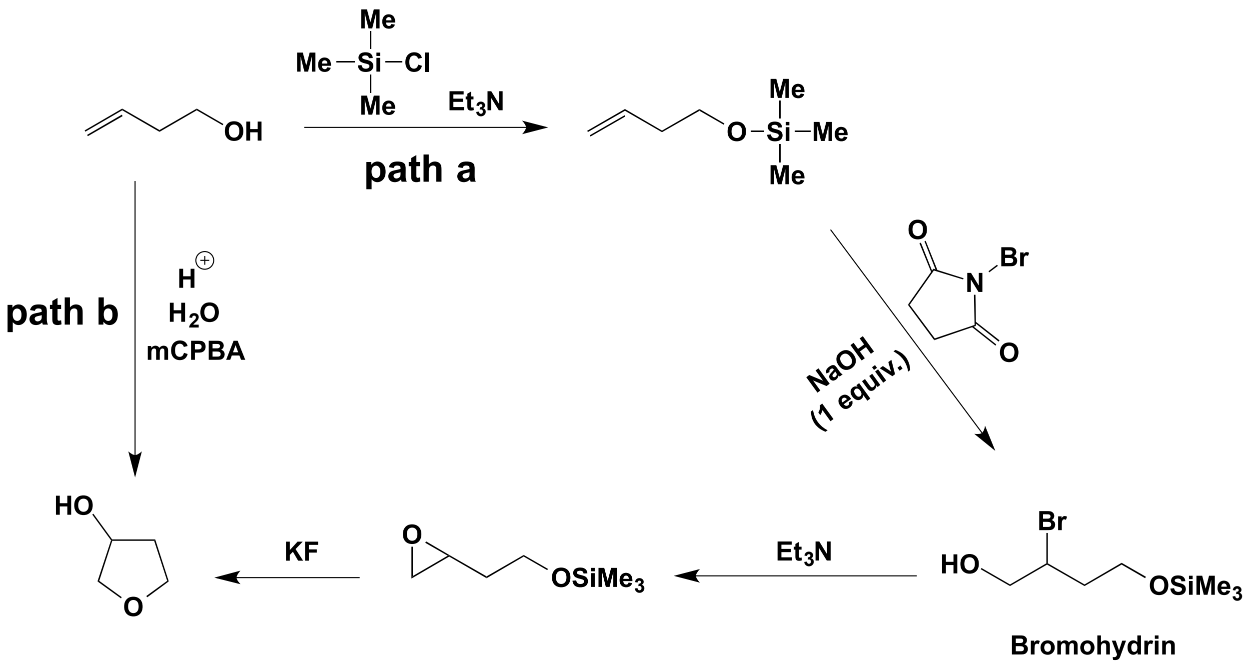


7. Circle the major product (1,2, or 3) for the reaction given below. Justify your answer by drawing the transition state for the reaction. (*Hint:* Consider the Henbest Effect.)



TS ‡

8. Propose mechanisms for each step in the synthetic pathways below leading to the cyclic ether.



XI. Further Reading

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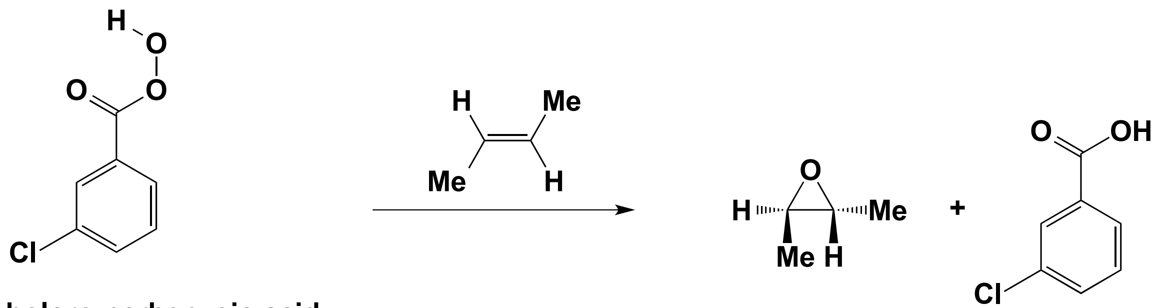
6.6 Example Quiz

CHEM262 – Organic Chemistry II – Spring 2019

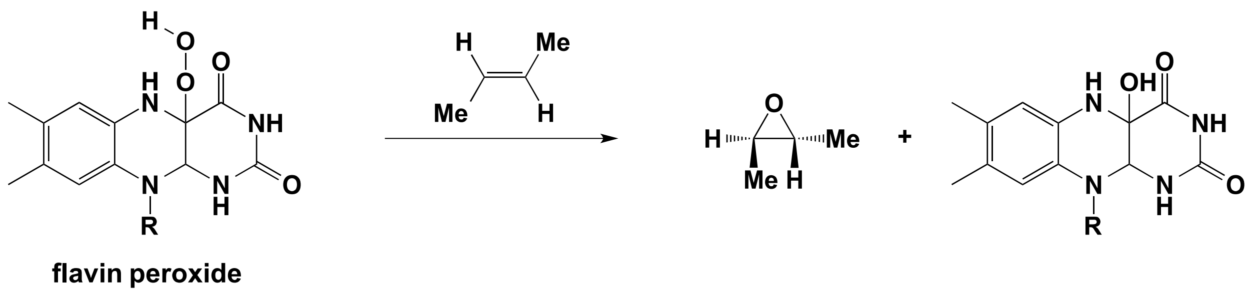
Quiz #1

1. Reaction of alkenes (olefins) with a peracid results in formation of an epoxide with retention of stereochemistry. Draw an arrow pushing mechanism for the olefin epoxidation by mCPBA shown below.



meta-choloro-perbenzoic acid
(mCPBA)

2. Flavin monooxygenase enzymes generate flavin peroxides that can perform olefin epoxidations. Draw an arrow pushing mechanism for the olefin epoxidation by the flavin peroxide shown below. *Be sure to show all proton transfers.*



3. Why do these epoxidation reactions occur with retention of stereochemistry (*trans* olefin gives *anti* epoxide)? Write 1-2 sentences and draw a transition state structure for the olefin epoxidation by mCPBA from question #1.

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