Teaching Students Organic Chemistry: QEP III Next Generation Course Redesign™

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Abstract:

During the summer of 2009 Dr. Dandekar, and a group of undergraduate researchers, worked to redesign CHEM 2370 - Organic Chemistry I. The learning outcomes for the course were reassessed, and then matched to all exam materials. After determining the student learning outcomes were tested effectively, a proposed analysis of the course was examined. An overview of the redesigned course material, and the philosophy of learning used in the redesign is also discussed.

Introduction:

Many students struggle through their undergraduate organic chemistry experience. Through personal experience, this struggle that students endure is by no means unfamiliar. As a previous student of the course taught by Dr. Dandekar, and knowing what makes this course difficult, helps contribute to bettering the course for future students. The course was taught previously by strictly lecture and book. Students, such as myself, would spend hours reading the book and doing problems to try and understand the material outside of lecture. While the lectures were very informative, the word documents used as supporting material were dry and not always illustrative of the concept. Often material would be detailed, complex, and absent of real world context. This made it very difficult for most students to grasp concepts even with numerous attempts. Success in the course required you to do numerous examples from the text book to ensure that no basic concept was over looked. Improving the first delivery of material by updating lecture handouts, integrating ideas using diagrams and guided problems, bringing in a real life aspect to the course, and providing video media are all ways that we improved the delivery of the course.

The aim of Next Generation (N-Gen) Course Redesign^{TM} is to help students learn and better understand course material through a learning theory, brain-based learning, unique to organic chemistry instruction. Through the development of course materials based on the N-Gen theory, the organic chemistry learning experience is predicted to be improved dramatically. The course material developed throughout the project directly reflects a set of student learning objectives outlined by a group of undergraduate researchers, including myself, which was led by Dr. Sushama Dandekar. Dr. Dandekar's course redesign for Organic Chemistry I (CHEM 2370) at the University of North Texas. The student learning objectives (SLOs), and the success of the redesign in testing those SLOs were examined for curricular alignment to the learning theory. First, an understanding of the philosophy behind the redesign will be considered, followed by a look at the developed course material, and finally a comparison of the developed course material with the SLOs.

Theoretical Basis:

All learning can be traced to neurological changes within our brains. Understanding what makes these changes last, and applying them, has been the focus of the N-Gen course redesigns[1]. The University of North Texas, in response to the SACS evaluation, instituted the Next Generation (N-Gen) redesign program that encouraged professors, in concert with colleagues and/or students, to redesign courses that create opportunities for deeper learning on different levels for more students. The N-Gen course redesign teams assist in developing instructional techniques that help bring brain-based learning to each redesigned course at the University of North Texas.[1] An inherent part of the redesign, based on social tendencies of humans, with a strong emphasis on collaboration to optimize the learning experience. However, the outcome-based assessment of each redesign and a number of innovative instructional techniques is what makes each redesign unique.[1] What follows is an exploration of the learning theory and it's relation to the N-Gen redesign instructional application.

The requirement for building the neurological connections that allow for enhanced learning is based on the seven brain-compatible fundamentals listed in Laura Erlauer's *The Brain-Compatible Classroom: Using what we know about learning to improve teaching*.[2] The seven fundamentals are: emotional wellness and safe environment; the body, movement, and the brain; relevant content and student choices; time, time, and more time; enrichment for the brain; assessment and feedback; and collaboration.[2] These fundamentals are the foundation for "brain-based" learning. The hope for educators is that their application will bring about the best educational practices that lead to the most successful learning for all students[2].

The emotional wellness of students enrolled in the course tends to be on varying levels. It is important for the teacher to recognize when a student seems to be suffering emotionally. In identifying a disturbed student, the teacher can then guide them to improve their emotional state of being. By improving their emotional state, the student can then begin to improve their concentration and focus their energy on learning the material. Also, the safety of the university classroom is important. If student feel insecurities about being on campus this can distract them and hinder the learning process. With a safe classroom, and a teacher that is in tune with the students' emotions, the stage has been set for an excellent opportunity to learn[2].

The body, movement, and the brain is another fundamental that deals with how proper nutrition and exercise is important for healthy brain functioning. With proper nutrition and exercise, students are able to maximize their learning capacity. The instructor can make suggestions to students about how to take care of their health - extra sleep, healthy foods, stay hydrated, and the like.[2] However, it is ultimately on the student to follow through with these tasks.

Relevant content and student choices are important fundamentals used within the redesign. In the context of this material it is imperative to connect prior knowledge to new information. It is important to recognize the application of relevant content, because it provides a meaningful connection to real life. This real life connection provides enhanced memory. Also, it has been shown that giving students the freedom to design increases their motivation and memory. [2]

The fundamental of time, time and more time is key to being successful in organic chemistry. It is important to emphasize the large amount of work that it takes to master the content of this course. The energy it takes to learn the material, apply it, and then comprehend it is enormous. Setting time aside to achieve mastery is the best way to success in any course, especially this one[2]. It is up to the student to work on this fundamental. Those students who fail to set aside adequate time more often than not, repeat this course.

Much of the developed material for the N-Gen course redesign corresponds with the fundamental of enrichment for the brain. This fundamental is based on the application of a variety of teaching methods. The more ways in which materials can be delivered to students, the greater the potential is for retention. What works best for one student may not work for another, and by creating a variety of media for students to use multiple methods of perceiving and processing information, more styles can be addressed, . [2] Videos, elaborate handouts, color detailed diagrams, and flow charts are some examples of enriched material composed for the redesign. . In doing this, we intended to provide a learning environment for students that addressed multiple styles. Often students, who are labeled gifted, are the only ones provided with enriched activities; however, it has been demonstrated that these kinds of activities enrich learning for all students.[2]

Collaboration is the next to last fundamental for brain-compatible or brain-based learning. People are social creatures and learn best through and with each other[2]. Through enriched group activities and semester long project, we included in a collaborative aspect to learning organic chemistry. The course redesign provided students with opportunities to seek and share thoughts on complex concepts.

Lastly, in order to test the outcome of all learning, assessment and feedback are required. To use assessment and feedback to enhance learning, it must contain several varieties, be rapid, and correct. Students need prompt feedback in order to increase retention. If the feedback is too long after the assessment, it is likely students will not remember what they were asked in the first place. If you decrease the assessment turn around, students will better retain the feedback information. It is also important to make sure that the feedback is specific to the question asked. Feedback that is not specific may lead students away from a correct understanding[2].

The fundamentals of relevant content and student choices, enrichment for the brain, collaboration, and assessment and feedback are the primary focus of the redesign for our specific course. The fundamentals of time, time, and more time, emotional wellness and safe environment, and the body, movement, and the brain are also important; however, these fundamentals are largely student dependent. By applying these brain-based fundamentals during the development of the course material, it is likely to help students understand, apply, and remember concepts throughout their journey through organic chemistry. The material developed for the course and the relationships between the fundamentals and the material are examined next.

Redesign Course Materials:

With the foundation for the redesign in place, a close look at course content can now be considered. As with any organic chemistry course the purpose is to teach students the chemistry associated with the element carbon. The hand-outs developed for the course provide tools for many students to use while learning the basic concepts of organic chemistry. Some concepts include the naming of organic molecules (nomenclature), structural changes within molecules (reactions), categorizing of various regions within the molecule (functional groups), and the spatial orientation of functional groups (stereochemistry), just to name a few. Not only do the hand-outs address a variety of concepts, but the video tutorials also show live examples of concepts. Furthermore, given the abundant nature of the element carbon, and its presence in all living systems, the practical applications of this course are endless. A real world collaborative project was introduced as part of the redesign to tie in the various applications of the subject matter. No such project existed during the course prior to the redesign. First, an overview of the real world collaborative project in relation to the fundamental of relevant content and student choices will be examined. Then a look at the hand-outs and a description of the videos will be explored.

The real world collaborative project, also known as Adopt-a-Molecule, consists of designing a data profile for a molecule that the students are assigned randomly. The project lasts a total of ten weeks over the fifteen week semester, and highlights many concepts throughout the semester as they appear in the lecture. Each week, the student was required to submit answers to specified questions that are related to their assigned compound. Figure 1 is a table with the breakdown for the entire project, week-by-week, listing the topics students were responsible for reporting on that given week.

Figure 1. Adopt-A-Molecule Weekly Outline

Weekly Outline :
Week 3
Molecular formula
Molecular weight
Melting point/boiling point
Functional groups
IR signals corresponding to functional groups identified

Week 4
Create 3D model of molecule using Spartan software, submitting the structure with the lowest energy
Week 5
Solubility
Protic Hydrogens
Identify all chiral centers and designate each as R or S
Week 6
Synthetic or natural
Specific application
Associated receptors
Associated enzymes
Bioactivity
Week 7
Create a "friends" section containing other compounds that are structurally or functionally related
Week 8
Interesting facts
Week 9
Interesting Facts
Week 10
Comparative questions
Week 11
Comparative questions
Week 12
Scrutinize the other profiles of the same compound you were assigned
Did you notice any discrepancies in your profile compared to the other profiles?
What did you learn from reading the other profiles?
What references did other people used that you did not?
Final project submitted before class on week 13

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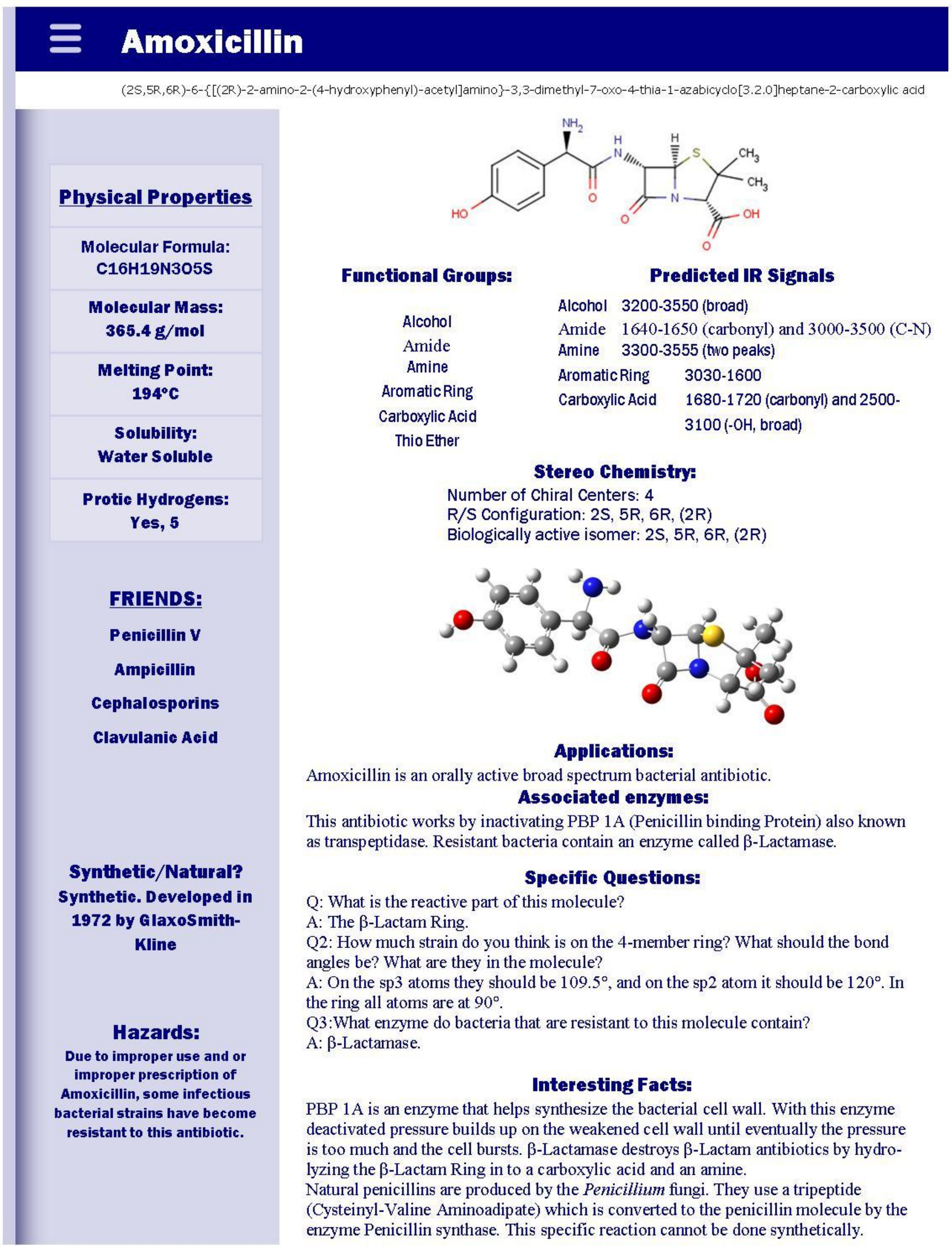
This project is composed of twenty nine various compounds that were selected for their relevance to everyday life. Some examples of the compounds include amoxicillin and ciprofloxacin (antibiotics), aflatoxin B1 (carcinogen), cholesterol (cell membrane component), and other organic molecules encountered in pharmacies (morphine – painkiller) or in foods (capsaicin – responsible for spiciness of some foods). The everyday application of them brings a real life aspect to the course that organic chemistry classes can lack. This real life aspect presents students with the opportunity to apply the course to their environment – an example of the relevant content fundamental. Also, the tasks are related to the order the material is taught. With the students being free to design their profile to their liking, there is no limit to their creativity. This allows the fundamental of student choices to come into effect. By not limiting the students creativity in designing a molecular profile, it enables them to take in the information and process it in a way that supports their learning style. See figure 2 for example molecular profile.

Figure 2: Example Molecular Profile of Amoxicillin



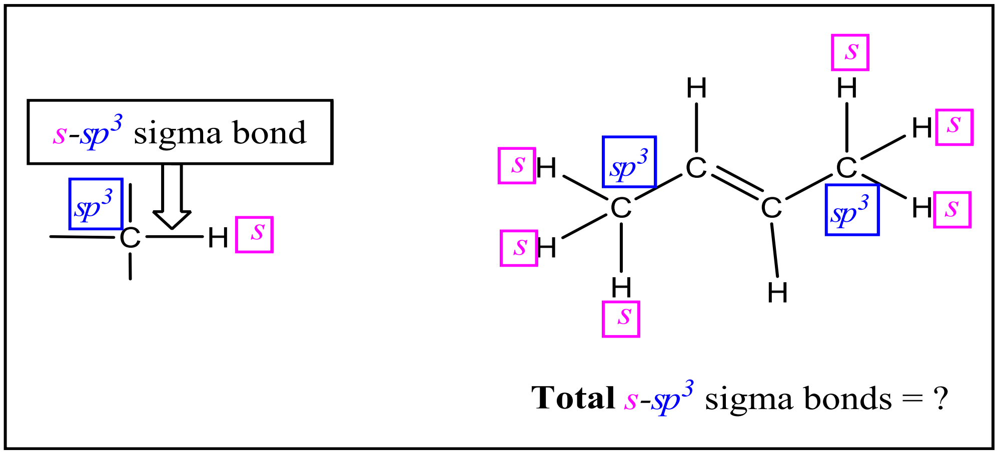
This is another way that the project enhances student learning. Moreover, part of the Adopt-A-Molecule can be considered collaborative. Collaborative learning is another applied fundamental of brain-base learning to this project. The last part involves looking at other student's molecular profiles and answering questions about the different molecules. If other students provide incomplete or inaccurate information on their project, it may be noticed by peers and corrected. It is a form of peer feedback that provides better understanding of subject matter. Also, although not explicitly linked to the brain-based fundamentals, several points are highlighted by Dr. Dandekar that help explain the importance of this project: it teaches students to research literature for primary and secondary sources; students learn to apply classroom learning to "real-world" issues; the context of the material contributes to motivation for becoming aware of its significance; the motivation and curiosity developed through awareness aids memory; and it promotes critical thinking about information presented to the student.

The course content that is related to the fundamental of enrichment for the brain includes class hand-outs, guided problem, and the tutorial videos. These are forms of enrichment because it provides a variety of learning tools for students to use. If limited by learning one way, students are less likely to make new connections. By providing various means for understanding, students are not limited to one learning style.[2] The tools were designed to improve comprehension.

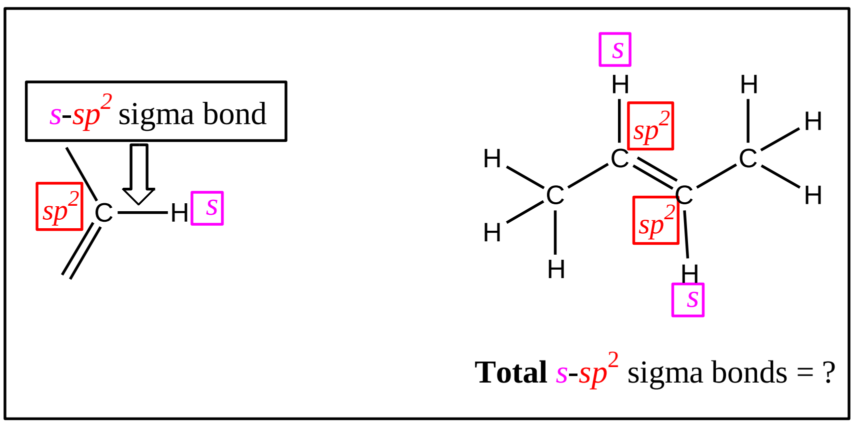
Many of the concepts within the course are animated through molecular structures and diagrams. These concepts are brought to life through the use of elaborate hand outs available online. Also, guided problems are used to integrate material for better understanding. Another way the redesign enriched the learning experience is through the creation of tutorial videos. These videos provide the students with examples of concepts, not by the instructor, but by students who had previously taken the course. The videos, being made by students, provided current students with a peer perspective, with the intent to lessen the intimidation by the "professor". A total of sixteen videos were created for the course. These include a variety of topics: Identifying Hybridization Patterns in Organic Molecules, Drawing Structural Formulas From Molecular Formulas, Steps for Solving Acid-Base Reaction Problems, Solvent Selection for Acid-Base Reactions, Identifying Functional Groups from IR Spectra, Building Molecular Models, Building Functional Groups with a Model Kit, Newman Projection Formulas and Energy Diagrams: Bromoethane, Newman Projection Formulas and Energy Diagrams: Butane, Structural considerations for Cycloalkanes, Preferred Conformations for Cyclohexanes, Identifying Chiral Centers, Stereoisomers: Enantiomers, Determining R and S configurations, 13C NMR: Number of Signals. The topics selected are fundamental to understanding a variety of concepts presented throughout the semester. If students are able to access these videos at their convenience, it was our hope that this will motivate them to watch them until the concepts are well understood. Also, if well understood, provide a foundation for more complex concepts based off of those presented in the tutorials.

Available to the students are thirty four handouts and four guided problems. Handouts are designed to be used an instructional tool during lecture time that students could access before every class. These documents have design elements that present information in a more descriptive way than before the redesign. Prior to redesign, lecture material was solely presented in a text document that lacked a pictorial aspect needed to visually understand concepts within the course. Colors are used to easily differentiate between the specifics of various molecular structures, flow charts connect information in new ways, and sample problems show methods for problem solving based on the building of concepts. Figure 3 and 4 are examples that use colors to help students see the hybridization of different atoms and the types of bonds made between them.

Figure 3. Hybridization of Tetrahedral Carbons in 2-Butene



: Figure 4. Hybridization of Trigonal Planar Carbons in 2-Butene



Colors were also used in nomenclature examples. Figure 5 contains examples of complex nomenclature, figure 6 is an example of common problems that students face doing nomenclature, and figure 7 contains examples of nomenclature for bicyclic compounds.

Figure 5: Complex Nomenclature

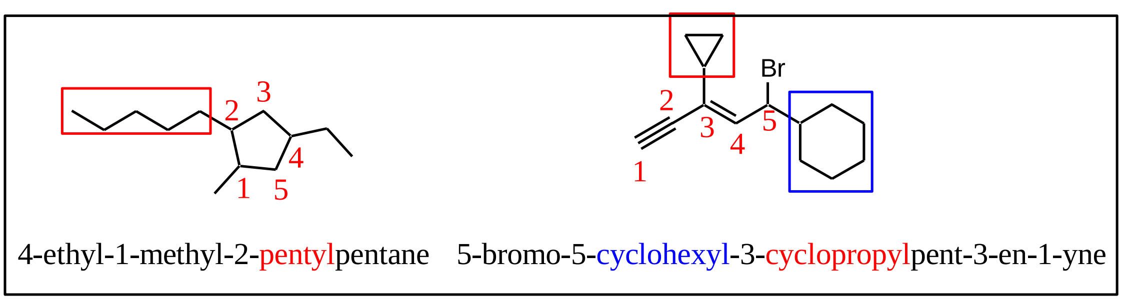
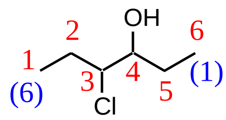
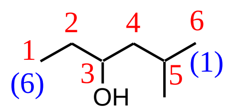
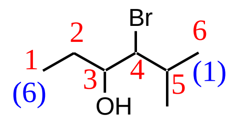


Figure 6. Nomenclature Numbering: Common Errors

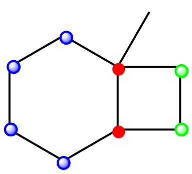




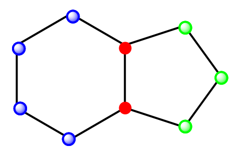


3-chloro-4-hexanol	5-methyl-3-hexanol	4-bromo-5-methyl-3-hexanol
4-chloro-3-hexanol	2-methyl-4-hexanol	5-methyl-4-bromo-3-hexanol
		3-bromo-2-methyl-4-hexanol

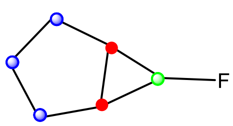
Figure 7. Bicyclic Nomenclature



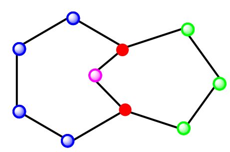
1-Methylbicyclo[4.2.0]octane



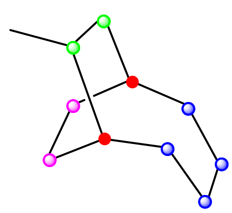
bicyclo[4.3.0]nonane



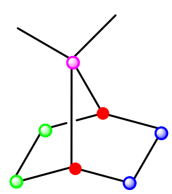
6-fluorobicyclo[3.1.0]hexane



bicyclo[4.3.1]decane



7-methylbicyclo[4.2.2]decane



7,7-dimethylbicyclo[2.2.1]heptane

Part of the redesign theory is that grouping material is an effective way to improve learning and memory[1]. The flow charts include the use of colors to further clarify every aspect of the topic, hence making the content relevant, as suggested by the brain-based theoretical premise. Figure 8 is an example of a flow chart describing how to transition from a Newman projection to a fisher projection. Figure 9 is an example of blank templates for chiral, or stereo, centers, and

Figure 10 is an example of a blank template Newman projection and the associated energy diagram.

Figure 8: Fischer Projections

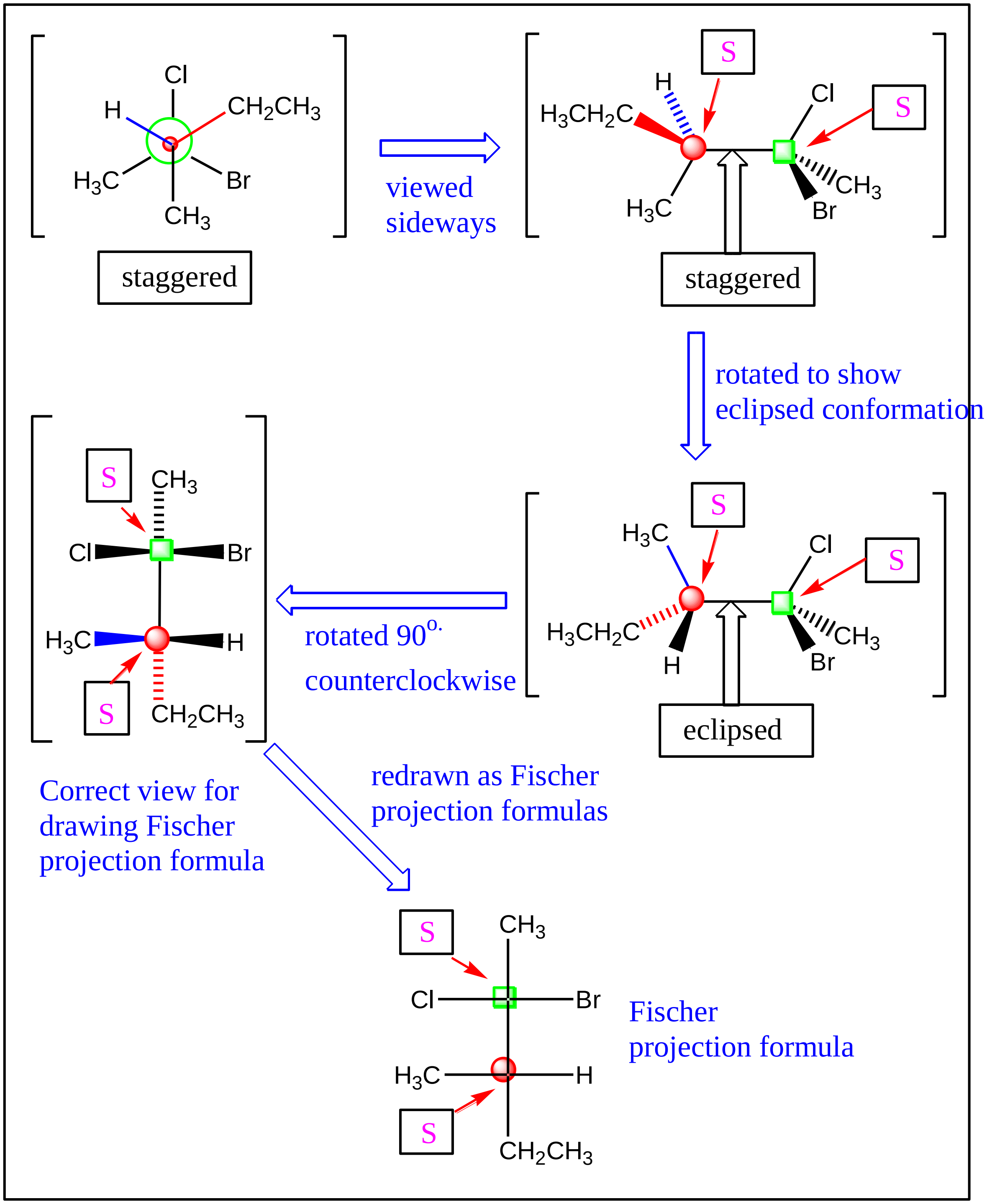
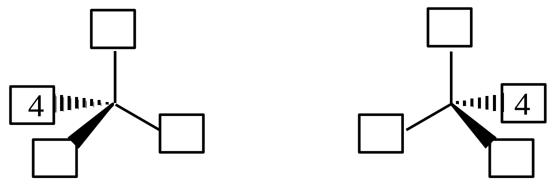


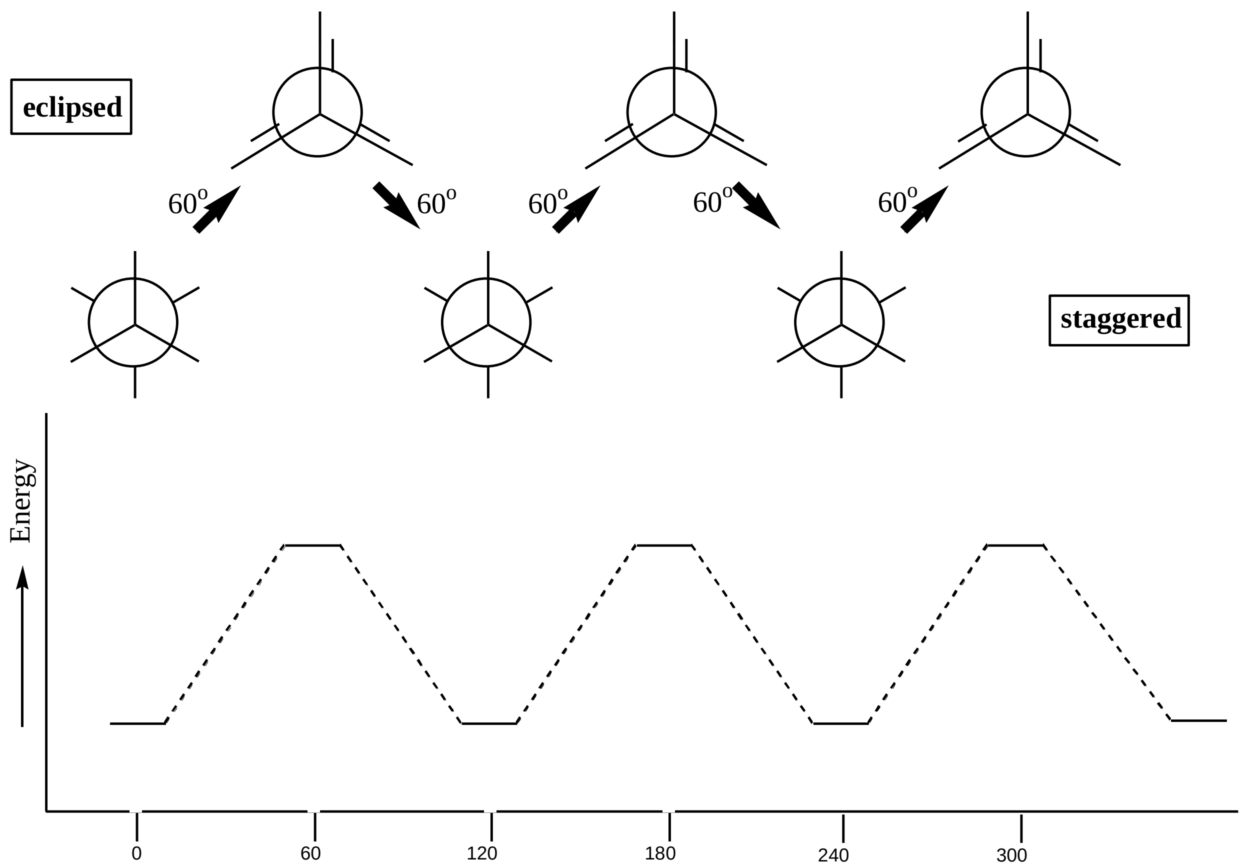
Figure 9. Blank Template for Dash Wedge Formula and Fischer Projections of Stereocenters

Dash Wedge Template for Stereocenter



Fischer Projection Template for Stereocenter

Figure 10: Newman Projections and Energy Diagrams

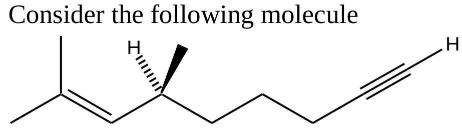


The examples here include blank spaces for students to write in. This will help students learn problem solving strategies in a systematic way. It is important to include a kinesthetic exercise like writing or drawing because it helps to solidify connections through repetition[3]. Writing is required to perform problem solving in this course. The fundamental of "time on task" shows that time spent doing problem solving is the best way for success[3]. By designing the hand-outs to allow students to fill in diagrams instead of writing out all the details of the diagram, lecture time can be used on more examples, or on further explanation of examples. This is one of the ways that the fundamental of time, time, and more time was incorporated within the redesign.

The sample guided problems developed by Dr. Dandekar are a way for students to take a self-assessment of their understanding. They provide a guided example of a multistep problem that uses multiple concepts to connect material. Grouping is used here in a more traditional testing style that provides instant feedback for students. Figure 11 is an example of one part of a guided problem.

Figure 11. Guided Problem

Consider the following molecule



1. What is the molecular formula of this molecule?
    a. C_9H_{14}
    b. $C_{10}H_{16}$
    c. $C_{11}H_{18}$
2. How many *s*-sp^3 carbon-hydrogen bonds are present in this molecule?
    a. 16
    b. 18
    c. 14

Do you need help? ☐Yes ☐ No

If <u>Yes</u>:

First, label each carbon as *sp*, sp^2, sp^3

Can you answer Q2 now? ☐Yes ☐ No

If <u>No:</u>

What orbital is always used by hydrogen to bond with any atom?

☐ *s* ☐ *p* ☐ *sp* ☐sp^2 ☐ sp^3

Can you answer Q2 now? ☐Yes ☐ No

If <u>No:</u>

Count the total number of hydrogen atoms attached to all the sp^3 carbons atoms.

Now you should be able to answer Q2 correctly.

As part of the N-Gen redesign, we provided feedback for all online and in-class assessments, such as quizzes, tests, and group assignments. The assessment part of the redesign was driven by a rigorous list of Student Learning Objectives (SLOs). Based on the content of the course, each topic was categorized in a systematic way to manage student learning. The SLOs consisted of broad General Learning Outcomes (GLOs), with more specific outcomes being the SLOs, and more defined objectives called Specific Learning Outcomes. Grouped under four main goals, all of the SLOs were matched to the assessments made for the course and are compared later. The comparison, of SLOs versus assessments, will be an indicator of the effectiveness of the redesign.

Analysis:

As part of the assessment and feedback fundamental of brain-based learning, it is important to test students over all of the SLOs. Through the duration of the semester, there were three exams and a final exam administered to the students. The SLOs for the course redesign were matched to all test items. Looking at how many of the test items match up to an SLO, compared to the entire list of SLOs, provided a look at how well the tested material aligned with the SLOs for this course.

Overall there are 143 SLOs, which include the 34 general learning objectives. Figure 10 is a breakdown of the total number of SLOs tested on each exam.

Figure 12. SLOs Tested

	Exam 1	Exam 2	Exam 3	Final Exam	Total SLOs Tested
Number SLOs per exam / Total number of SLOs	(39/143)	(35/143)	(56/143)	(106/143)	(141/143)

There were only two SLOs that could not be matched to test questions. The test questions that are needed to match these last two SLOs were created and inserted into one of the three exams or the final. The students taking the course this semester were tested on over 98% of the SLOs. This shows that the students were effectively tested over the learning objectives. The tests and SLOs were a key part of redesign and correlate to the fundamental of assessment and redesign. Providing the students with the expected learning outcomes allowed them to assess their own understanding of what was expected of them throughout the course, and the tests provided feedback as to whether or not they truly mastered those learning objectives. . It is important to note that some of the test items covered several SLOs. Therefore, the number of SLOs don't equal the number of test questions. While it is important to test students over all the learning objectives, this does not tell us whether or not the redesign improved the performance of the students.

Conclusion:

The seven fundamentals of learning are applied to the content of this course. However, the effectiveness of these fundamentals have not yet been examined. To assess the course for improved student performance, a more comprehensive study must be conducted. A review of student performance in the redesigned course versus the course prior to redesign would be needed to evaluate the effectiveness of the redesign. During the study it would be important to retest the same SLOs. If the study was designed to have questions match up with SLOs in both courses, the information obtained by assessing the students will indicate which SLOs are tough to comprehend, and if the redesign helped in assisting students comprehension of the course content. Knowing what students have difficulty understanding can give insight into improving teaching methods. Although this proposed analysis is not included here, it should prove invaluable for a complete and effective redesign.

Based on the seven fundamentals of brain-based learning[2] our foundation for the redesign shows potential for improvement of CHEM 2370, Organic Chemistry I. Through changing the method and delivery of the material to incorporate the fundamentals of brain-based learning this potential for improvement can be seen. Instead of teaching off of text documents and only drawing figures on a chalk board, the redesigned material allows for a variety of instructional tools to better present the material and engage students. Also, having matched testing material with the SLOs the effectiveness of teaching certain subject matter can be more easily measured. This will allow for a better understanding of how to increase the overall comprehension of subject matter by students. Here the redesigned course content and how it correlates to the fundamentals of brain-based learning has been examined, and the results of matching developed test material to the SLOs has been accomplished. However, an examination of student performance must be carried out to determine the overall effectiveness of the redesign based on the premise that the fundamentals of brain-based learning can improve student learning of the subject matter

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