Using Just-in-Time Teaching in the Organic Classroom

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Outline

Introduction

Organic chemistry plays many roles in the undergraduate curriculum. Certainly a few of the students in the class have a genuine interest in the subject and someday hope to become organic chemists. A few more are chemistry majors, and generally these students are motivated to gain a solid understanding of the subject even if they are primarily interested in one of the other chemistry fields. These are not the majority of the students. At least in the author's case, the majority of the students in the two-semester sequence are biology majors and/or premedical students. These students tend to view organic chemistry as a hurdle and often view it as a memorization course. The challenge to the professor is to engage these students and to help them move beyond memorization. Just-in-Time Teaching offers tools that instructors can use to meet these challenges.

Just-in-Time-Teaching, commonly referred to as JiTT, combines web-based activities with a student-centered classroom environment. The method was developed in the physics community by Gregor Novak, Evelyn Patterson, Andrew Gavrin, and Wolfgang Christian(1). While physicists remain a major force in the JiTT community, there is nothing inherent in the model that limits its utility to physics, and many scientists in other disciplines are also adopting these methods(2). In the author's case, the techniques have been applied to a two-semester organic chemistry sequence with strong results.

Just-in-Time Teaching will take on as many forms as there are instructors, but all JiTT classes will share certain characteristics. The web component of the course will include pre-class assignments typically know as warm-ups. Some web sites will also include supplemental information designed to help students find connections between the classroom material and topics in the news. The purpose of the web component is to improve student-faculty interactions, and it should not serve as a barrier between the two. The JiTT classroom builds off of the web component and continues to build student-faculty interactions.

Warm-up Activities

The center of JiTT is the warm-up activity (also known as pre-flights at the USAFA). These short assignments are typically due two hours before class, and allow the instructor to assess student understanding and misconceptions before entering the classroom. A typical warm-up activity consists of three questions, two short-answer and one multiple-choice(1). One of the short-answer questions is designed to get students to learn the principles of organic chemistry and apply them to new situations. These problems emphasize both knowing concepts and thinking analytically. The second-type of warm-up question is called an estimation questions by Novak et al. (1). In this question, students are asked to come up with an answer without having all the information they need, and uses critical thinking skills. The multiple-choice question should provide a direct measure of student mastery of a concept.

Before they attempt the warm-up questions, students are supposed to have read the assigned reading, but they won't have seen the material in lecture. The questions are designed to get students to think about what they are reading before they come to class. Their answers serve as an assessment for the instructor so that the classroom presentations can reflect actual student needs and misconceptions.

The following is a short list of warm-up questions used in the author's Organic Chemistry courses.

Application questions:

1. Some reactions are said to be spontaneous yet they won't normally occur in a human lifespan. How can this be so?

2. Acetals are often used as protecting groups for ketones and aldehydes when strongly basic conditions are going to be used. [For example, if a starting material has both an aldehyde functional group and an epoxide functional group, and you wish to open the epoxide with a Grignard reagent, you would first protect the aldehyde then use the Grignard.] While acetals are excellent protecting groups in strongly basic conditions, they fail under acidic conditions. Why?

3. Your book talks about three different mechanisms for elimination reactions (E1, E2, and E1cB). How do these mechanisms differ from each other, and what controls which mechanism is followed?

Estimation questions:

1. Use the Merck Index, Ref 615.103 Mer, to look up ibuprofen, ketoprofen, and naproxen. Which parts of the molecules are related to their function as NSAIDs?

2. ^{13}C NMR spectroscopy is used to explore the carbon skeletons of molecules. The position of the signal is dependent on the electron density around the carbon. In organic chemistry we indicate electron density using delta+ and delta-. The larger the dipole, the larger the change in electron density. Signals for carbons attached to silicon usually come at 0 ppm. Those attached to other carbons usually come at 15 ppm. When a carbon is attached to an oxygen, the signal is usually at 50 ppm. Where would a carbon attached to a nitrogen come. Explain your answer.

3. Biological systems often use thioesters to transfer acyl groups from one molecule to another. Why is a thioester more effective in these systems than a simple ester or an acyl chloride?

Multiple-choice questions:

1. The reaction of (S)-3-chlorocyclohexene with potassium hydrogen sulfide yields which product?
a. (S) 2-cyclohexenethiol
b. (R) 2-cyclohexenethiol
c. (S) 3-cyclohexenethiol
d. (R) 3-cyclohexenethiol

2. An unknown compound shows five signals in its ^{13}C-NMR spectrum. One of the signals is between delta? 165 and delta ?180. Its ^{1}H NMR spectrum includes a singlet which is NOT in the delta 10 - delta 13 region. Which of the following structures is that of the unknown?
a. pentanoic acid
b. propyl ethanoate

c. ethyl propanoate
d. pentanal
Other examples of warm-up activities can be found off the assignment pages at
http://home.hiram.edu/www/chemistry/organic/.

The application questions should call on students to do more than copy an appropriate passage from their text or other resource packet. At the very least they are being asked to use their own words to discuss a technical topic. This allows the professor to assess the depth of understanding for each student specifically and the class in general. For example, the last application question will provide information on how well the class understands elimination reactions and whether or not they are likely to be able to distinguish these reactions on an exam. While a set of predict the products questions may provide the instructor with the same information, it may not reveal what misconceptions led to any incorrect answers.

In other application questions, the author has asked the students to "write" a mechanism in English. This should force students to move beyond just trying to memorize the pattern of arrows and intermediates in the mechanisms they "have to know." These written statements explaining reaction mechanisms quickly reveal student misconceptions. For instance, if several students produce a verbal mechanism for the reaction of 2-methylpropene with HBr that fails to mention the reaction proceeds to form the most stable intermediate, the instructor can spend extra time on that concept in class. If the students were asked to write a conventional mechanism and had some of the arrows wrong, it is impossible to determine whether the error was a case of the student trying to track a proton instead of the electrons or if the student truly could not locate the electron-rich area and the electron-poor area. It also seems to be the case that the students arrive at a deeper understanding of the mechanism if they have to describe it in their own words rather than using symbols they are mimicking from a text example.

The estimation questions are designed to help students deal with questions where they don't have all of the information (1). In a general chemistry course this might take the form of the following: The NaCl concentration in the Great Salt Lake is x M. Estimate how many grams of salt are present. In order to answer the question, students must not only know how to relate the concentration in molarity to a number of grams, but somehow estimate the volume of the Great Salt Lake. These problems force students to solve the problem on several different levels and to use critical thinking. The form an estimation question might take in organic chemistry isn't all that obvious. In the author's classes, these are typically designed to get students to apply their knowledge in new ways and to problems to which they can't readily find the answer. For example, the ^{13}C-NMR question above is given for the second day of class, when the language of chemical shifts, deltas, and ppm is hasn't entered the student's vocabulary, and they don't know where to begin to find the answer. Instead, they must answer the question based on what they are beginning to learn or review - the idea of bond polarity and electronegativity. As an added bonus to this question, the author finds that a review of this question later in the semester serves as an excellent introduction to NMR spectroscopy. At that point, the professor can talk about the role electron density plays in creating the effective magnetic field experienced by a given nuclei.

Both the application and the estimation questions are writing exercises, and they fit with the goals of most writing-across-the-curriculum programs. In these programs, writing is used to help students construct their own knowledge. By having to visualize an appropriate answer and work to put that answer into words arranged in complete sentences the students are gaining a more complete understanding of the underlying concepts of organic chemistry.

The multiple-choice questions are typically a straight-forward measure of the students understanding of a concept. It is important that the possible answers try to get at as many of the common misconceptions as possible.

In order for the warm-up activity to be as meaningful as possible, students must actually do them. In the author's experience, assigning points which are part of the overall course grade works well. Because the answers are also being used to help define the day's activities and to look for patterns of misconceptions that need to be addressed, it is important that students feel they don't have to get the "right answer" to receive a good grade. The goal of the warm-up activities is to promote thinking and to provide feedback to the instructor. In order to make these activities valuable to both the student and the instructor, the emphasis needs to be placed on the reasoning process. The author uses the following grading rubric.

All warm-ups will be graded on a 10 point scale. Assignments will be mainly graded on your reasoning process, but part of the score may relate to the correctness of some of your answers. To receive a 10 on an assignment, you must provide excellent clarification of your reasoning. A 9 will be awarded for all good efforts, with solid explanations. You do not need to have the correct answer to receive either a 10 or a 9, but you do need to display strong reasoning skills. Students will receive a 7 on any assignment with sketchy explanations. Assignments with correct answers, but weak explanations will receive a 5, and correct answers with no explanations will receive a 4. Late warm-ups will receive a grade of 0.

The author has found that from time to time she needs to reiterate in class that the most important part of the warm-up activity is for students to use their reasoning skills. This is where the misconceptions will come out and most student learning will occur. As many readers will likely realize, students enter organic chemistry wanting to memorize the right answers. Since most instructors are more concerned with students learning the concepts and being able to apply them in new settings, it is important that we strive to help students make the switch from memorization to analysis and critical thinking. The warm-up activities, with an emphasis on completeness and thoughtful reasoning help to promote better problem-solving skills and less reliance on memorization.

Classroom Component

Developing excellent warm-up questions is a process much like writing the best exam questions. The primary step a faculty member should take is to change her/his focus from what needs to be covered for a specified unit to what students should master (including content, process, application) during that unit. The author has found that shifting her focus from coverage to student learning has positively impacted the classroom environment and student success.

Consider the topic of electrophilic addition to alkenes. A standard approach might be for the professor to assemble a list of reactions and concepts that should be covered. Along with covering the reactions and their predicted products, an instructor may spend some time on designing syntheses using these reactions. Pausing to reflect on what students should walk away from in the unit, one might wish that they would understand the basic reaction mechanism, be able to pick out the electrophile and the nucleophile in the reaction, and predict the regiochemistry of the products. This type of mastery does not require the professor to cover every reaction in the book, what it requires is a thoughtful presentation of main concepts with plenty of instruction and examples helping students to master the ideas. The authors has found that once a few reactions have been covered thoroughly in this manner, the students are quite capable of reviewing the other reactions on their own, and even making sense of reactions found in the primary literature.

As stated previously, the web components of JiTT are used to create better faculty-student interactions. In order to maximize the utility of the method, the professor must be willing to work closely with students in the classroom, and continue the dialogue started in the warm-up activity.

Warm-up activities are typically due two hours before class time. The two-hour lead time gives the instructor a chance to adjust the day's activities to address student needs. Most professors who have taught any course for a few years can identify the common student misconceptions. Still not every group of students shares the same misconceptions, and a tool to help an instructor determine specific misconceptions before class time improves instructional efficiency. Class time can be organized so that more time is spent on the problem areas of a specific class and less time on the concepts the students understand.

Once in the classroom, the professor typically presents selected student answers and helps students assess the strengths and weaknesses of each. During this exercise, the instructor should make sure that the specific students' misconceptions are covered. It is also important that care be taken to provide positive feedback on all answers. The goal is to help students feel comfortable sharing ideas even before they "know" the correct answers. It should also be to help students learn to evaluate their own answers, and learn to build on ideas. Professor handling of the warm-up discussions can help set up an environment where all students feel comfortable talking in class.

The author has found that her classes are more dynamic and students are much more willing to participate in discussion and to share their ideas in the class. Student participation helps to quickly uncover misconceptions and helps every student gain a better grasp of the material.

Puzzles

As originally conceived by Novak and company, puzzles are a comprehensive problem involving most if not all of the concepts in a given chapter or unit (1). In the author's class, puzzles are used as in-class assignments at the end of a chapter or unit. A sample puzzle the author has used at the end of the section on electrophilic aromatic substitution follows.

Puzzle: A chemistry 320 student ran a series of four reactions starting with benzene. Unfortunately the student was a poor record keeper, and wasn't using an appropriate laboratory notebook. As a result, the student has four sets of notes, but doesn't know the order in which the experiments were run. The four sets of notes, arranged alphabetically, include a bromination reaction using bromine and iron(III) bromide; a two-part Grignard reaction starting with magnesium turnings in diethyl ether followed by treatment of the Grignard reagent with butanal in ether; a nitration reaction using nitric acid and sulfuric acid; and an oxidation reaction using pyridinium chlorochromate (PCC) in methylene chloride. The student did obtain spectral data for the final product including a ^{13}C-NMR, ^{1}H-NMR, and an IR. The ^{13}C-NMR of the product showed four signals in the aromatic region, one signal in the carbonyl region, and three signals in the aliphatic region. ^{1}H-NMR of the compound showed two doublets in the region between 7-8 ppm each integrating to 2, a triplet at 2.1 ppm integrating to 2, a sextet at 1.2 ppm integrating to 2, and a triplet at 0.9 ppm integrating to 3. The IR indicates the presence of both a nitro group and a carbonyl group in the final product.

The reactions in this puzzle utilize material from the unit on EAS as well as previous chapters. The students are being asked to analyze information, and to construct a story of what happened. In short they are using critical thinking skills and integrating information from throughout the unit.

The in-class portion of the puzzle activity is split into three sections. Typically students will spend about 5 minutes working on the problem alone. At this point, they will break into small groups and spend another 5-10 minutes collaborating on a final answer to the puzzles. Once the groups have agreed on an answer the whole class has a short discussion of the materials.

The author has found that making students first work on solving the puzzle alone helps to stimulate the conversation and creates a more productive problem- solving session. During this time, the students begin to gather their thoughts and ideas on solving the puzzle. Each student is supposed to make a list of what they know, and what questions they have. Occasionally a student will solve the puzzle while working alone, but not often. Having worked on the problem alone and assembled individual ideas, the group work seems to be more efficient and to involve more students. The author has found that when students begin group work without having individual processing time they often rely on a single leader to provide the answers, and there seems to be less discussion over alternative theories.

While the group work is happening, the author is walking around to the groups answering questions, probing understanding, offering hints, and making sure all of the students are engaged with the process. If it is clear that more than one group is confused about one issue, she can quickly address it with everyone. Once it is clear that all the groups have either solved the puzzle or nearly solved the puzzle, a short classroom discussion can be used to answer any last questions on the unit.

Assessment

The author has found JiTT to be a success in a number of ways. First of all, it helps to quickly develop rapport between students and faculty. Students seem to be more willing to ask and answer questions in the class. They seem to be more comfortable thinking through an answer out loud, and collaborating with the whole class to get to the one best answer. The author has found that students visit her office earlier in the semester and tend to take a more proactive role in dealing with their misconceptions.

Secondly, exams scores have improved dramatically. The author has used the ACS Organic final for the last several years, and the national percentile ranking of the class median climbed substantially once JiTT was implemented (see Table below), and looking at the histograms of grade distributions from the various classes shows a shift in the grades with fewer extremely low grades.

	Year	Median	Average	Low
pre-JiTT	1998	35	35.4	21
	1999	35	36.1	24
	2000	35	35.2	20
post-JiTT	2001	39	37.7	25
	2003	38	38.2	23
	2004	42	39.9	25

*The author was on sabbatical for the 2001/2002 academic year.

For years 1998-2003, all students were given the 1998 ACS Final Examination in Organic Chemistry; the 2004 class received the 2004 ACS Final Examination in Organic Chemistry. The author made no other major changes to the organic sequence during these years. While no statistical analysis of the data has been performed by the author, the results strongly indicate that JiTT strategies have a positive impact on student learning.

Several things may play a role in the student success. First of all, students are pushed to keep up with the material throughout the two semesters. In the author's class, the warm-ups are due every other day throughout the semester. In their classroom evaluations, the majority of students indicate that the warm-up exercises forced them to keep up with the material, and that they were grateful for this prodding. Secondly, the warm-up activities and corresponding classroom activities push students to take charge of their own learning. Finally, the professor is able to assess student learning early and often, and is able to intervene more quickly and directly. In other words, by evaluating their responses to warm-ups and puzzles the faculty member can address exactly what students need.

Conclusions

Just-in-Time Teaching is a versatile tool that can be used in a variety of settings to enhance student learning and to improve educational outcomes. The primary tool is the warm-up activity, which helps students, and professors assess current levels of understanding and address problem areas. Puzzles, another JiTT instrument, give students the opportunity to work on their critical thinking skills, and to apply their knowledge to new areas. In the author's case, the use of these techniques has had an impact on student learning as demonstrated by student scores on the ACS Organic Final Examination. They have also help to create a better environment in the classroom, with students more willing to offer answers and explanations in class. Finally, as an assessment tool, JiTT offers timely evaluation of student understanding and allows the professor to address class needs as they arise.

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