Chapter 5

Just-in-Time Teaching Organic Chemistry with iPad Tablets

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Just-in-Time Teaching has been used to facilitate in-class problem solving with iPad tablets for six semesters at a small, selective midwestern university. Organic chemistry classes of 18-51 students have effectively used this pedagogy to improve both student learning and success rates. Students prepare for class using detailed reading objectives and online homework. They then use a course management system to inform the instructor of the concepts with which they are struggling the most. These comments are then used to design each class session in which the instructor addresses student comments through short lectures and collaborative problem solving. Each group of students records audiovisual solutions to each problem on an iPad; these audiovisual solutions are then used for in-class discussion and post-class review.

Introduction

Research supporting the effectiveness of active learning in the sciences is diverse, long-standing, and persuasive. Freeman and colleagues' 2014 meta-analysis reported in the *Proceedings of the National Academy of Sciences* showing an average increase of 6% in exam scores and markedly lower DFW rates (*1*) is among the most persuasive for many. Much of these data, including in chemistry, have been available for years, but the data were not what convinced me to adopt active learning methods in my courses. The linchpin for me was a compelling presentation of specific pedagogies that align well with Bloom's taxonomy of learning.

Muzyka and Luker; The Flipped Classroom Volume 2: Results from Practice
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There are a multitude of models by which to understand ways of knowing. Bloom's taxonomy of learning (*2*) and its 2001 revision (*3*) are popular in large part because of their simplicity and ease of application. The revised Bloom's taxonomy lists six key learning tasks (**bold**). These are not verbs commonly used in chemical instruction, so the list below has been augmented with more familiar chemical terms.

- **Remember** – define, identify, describe
- **Understand** – explain, describe, classify
- **Apply** – solve, calculate, provide, name, predict
- **Analyze** – compare, contrast, explain, illustrate, differentiate
- **Evaluate** – choose, predict, rank, explain
- **Create** – plan, retrosynthesize

The most basic level of learning is to *remember* facts. *Understanding* builds upon *recollection* and *application* upon *understanding*. Organic chemistry is difficult for many students because, unlike in most of their prior experience, the majority of the course content is in the upper two-thirds of Bloom's taxonomy of learning. Even nomenclature, which many consider the easiest component of organic chemistry, is *application* of rules. Asking students to *explain* an organic process can be at the level of *understanding*, but is more likely to be *analysis* or even *evaluation*. Retrosynthetic analysis, the heart of organic chemistry, is the very highest order of critical thinking in the revised taxonomy – *creation*.

The students we are asking to operate within these higher domains of critical thinking come from more than a decade of learning, with few exceptions, in the lower half of Bloom's taxonomy of learning. They often struggle with the problem-solving in General Chemistry because even *application* is more advanced than the *remembering* and *understanding* that they have focused on previously. Most of our students are capable of developing these higher-order ways of knowing, but they often require substantial support to do so.

I was finally convinced to abandon lecture when confronted with the reality that students cannot make appreciable progress on higher-order learning objectives while listening to a lecture. Lectures can help students *remember* facts and *understand* their context. Brilliant lectures can also model *application*, *analysis*, *evaluation*, and *creation* in ways that show students how to engage in these critical processes. This modeling is often an essential part of instruction, but it is rarely sufficient to develop new critical thinking skills in our students. Students must actually go through the hard work of *application*, *analysis*, *evaluation*, or *creation* if they are to develop these abilities. The traditional lecture model assumes that students will be able to do this on their own, between class periods. The best students – such as those that go on to receive PhD's in chemistry and then teach in the discipline – may be successful at this, but the rest flounder. Active learning pedagogies are successful in large measure because they allow higher-order learning goals to be addressed in class, where students are surrounded by their peers and an instructor is available to help.

There are many proven active learning pedagogies described in the educational research literature. The pedagogy described in this chapter uses the framework of Just-in-Time Teaching (JiTT) (*4–6*) to guide both students' and the instructor's preparation for class. Physicists developed JiTT in the mid-1990's to better support and structure students' pre-class reading. They used the then-newly developed Internet to ask their students 2-4 questions before each class session. Open-ended questions that address common misconceptions were the most effective. Many JiTT instructors have also found it useful to ask muddiest point questions that ask students to comment upon the topic they find most challenging. Students direct their reading to answer these questions and instructors use student answers to structure the subsequent class session. The class sessions necessarily focus upon addressing student misconceptions. This can be accomplished through a series of mini-lectures, but many JiTT instructors have incorporated problem-solving and other active-learning approaches.

The pedagogy described in this chapter structures pre-class work with detailed reading guides, publisher-supplied online homework, and a single muddiest-point question completed 6-8 hours before each class session. The instructor then uses these reflections to develop in-class mini-lectures and activities that address student misconceptions and difficulties. The in-class problem solving activities place students in teams of 3-4 to collaboratively create audio-visual solutions on iPad tablets. These solutions are reviewed both collectively in class and individually after class. Students consolidate their learning further after class with individual problem solving.

This pedagogy builds upon decades of education research showing that collaborative learning and metacognition can promote students' ability to construct and retain understanding (*7*). It also develops skills essential for success in the 21st century through both scaffolding and daily repetition. Reading assignments from the textbook improve students' ability to read informational text. Well-structured team problem solving builds the skills most sought-after by employers: leadership, ability to work in a team, written communication skills, problem-solving skills, and oral communication skills (*8*). These themes will be further delineated once the pedagogy has been more thoroughly described.

Methods

Effective implementation of active learning pedagogies requires more than replacing lectures with activities. Providing appropriate incentive and assistance for students to address learning objectives outside of class is also essential. This pedagogy uses three primary resources to effect student learning: the textbook, Just-in-Time Teaching (JiTT), and collaborative learning. The pedagogy described in this chapter has been used to teach Organic Chemistry at a Midwestern liberal arts university with class sizes ranging from 18 - 51 students.

The textbook is an essential resource for students with the pedagogy described in this chapter. Students are expected to read relevant sections and attain lower-order learning objectives before coming to class. Many, if not most, students enter Organic Chemistry completely unprepared to effectively read the textbook, so a guide for reading the textbook and detailed lists of learning objectives are provided for each class period (Figure 1). These lists are arranged by section of the textbook and contain only the learning objectives that students are expected to make progress on *before* class.These lists also direct students to 5-10 minute mini-lectures on challenging or important topics that they are to watch before class (underlined text). These pre-class lists of learning objectives don't contain some of the more challenging learning objectives, such as stereoselectivity and synthesis for the material in Figure 1, so a separate list of learning objectives is provided for each exam (Figure 2). Students find it helpful to have this second list broken down into reactions that they can just memorize (Reactivity), reactions they need to know the mechanisms for (Mechanism), and reactions they need to be able to use in synthesis (Synthesis). Organization of material is a substantial challenge for many students in active learning classrooms. This difficulty is at least partially ameliorated by continual referral to relevant sections of the textbook and the detailed study guides.

Prior to Class
Read Sections 19.1-3, 7, and 11

1) Introduction – watch mini-lecture
2) **[19.1]** Naming
    a) What are the parent names for aldehydes and ketones?
    b) Which has a higher priority?
3) **[19.2-3]** Oxidation reactions – watch mini-lecture
    a) See also 17.7
    b) Methods to prepare aldehydes and ketones from alcohols
    c) Oxidation of aldehydes
4) **[19.7]** Irreversible reactions of aldehydes and ketones
    a) See also 17.4 and 17.5
    b) Understand mechanism(s)
    c) Be able to predict products
    d) Be able to provide reagents that would form given alcohol
5) **[19.11]** The Wittig Reaction
    a) Phosphorous ylides – synthesis, structure, and reactivity
    b) Mechanism and synthetic utility of the Wittig reaction

Figure 1. Lists of learning objectives provided to prepare for a 90-minute class session.

/ now WileyPLUS

An online homework system (*9*, *10*) (currently OWLv2) associated with the textbook is also essential both in student preparation for class and consolidation of material after class. Explanatory / tutorial assignments are due prior to each class period. These assignments assess lower-order learning objectives and, sometimes, introduce higher-order learning objectives. They are graded primarily for completion, typically requiring less than 30 minutes. Online post-class homework is also assigned weekly to help students review and consolidate their understanding of the material. The homework assignments are mastery-oriented in that the emphasis is upon whether students can answer items correctly within ten attempts.

Brief Study Guide for Exam 3

1) **Structure**
    a) **[19.4-5]** Understand the factors that favor hydrate formation
    b) **[19.10]** Understand the factors that favor acetal formation
2) **Naming**
    a) **[19.1]** Be able to name most simple aldehydes and ketones
3) **Reactivity**
    a) **[17.4]** Reduction of carboxylic acids with $LiAlH_4$
4) **Mechanism**
    a) **[19.2-3]** Preparation of aldehydes and ketones from oxidation of alcohols
    b) **[19.7]** Reduction with hydride and Grignard reagents
        i) Be able to use Cram's rule to predict/explain stereoselectivity
    c) **[19.11]** Wittig reaction
    d) **[19.4-5]** Hydration - Acid and base mechanisms, factors effecting equilibrium
    e) **[19.10]** Reactions of aldehydes and ketones with alcohols, factors affecting equilibrium
    f) **[19.6]** Reaction with HCN
    g) **[19.8]** Imine and enamine formation
    h) **[19.9]** Wolff-Kishner Reduction
    i) **[24.6]** Reductive amination
    j) **[19.13]** Conjugate addition reactions – when irreversible, when reversible?
5) **Synthesis**
    a) **[19.2-3]** Synthesis of aldehydes and ketones from alcohols
    b) **[19.7]** Synthesis of alcohols from aldehydes and ketones
    c) **[19.11]** Synthesis of alkenes using the Wittig reaction
    d) **[19.6]** Reaction with HCN
    e) **[19.10]** Use of acetals in synthesis
    f) **[19.8]** Imine and enamine formation
    g) **[19.9]** Wolff-Kishner Reduction
    h) **[24.6]** Reductive amination

Figure 2. Lists of learning objectives provided to prepare for an exam.

Just-in-Time Teaching (JiTT) provides the course structure. Students' preparation for class culminates in their electronic response to a JiTT prompt by 12:30 am before each class session. This is occasionally a topic-specific prompt, but is more often simply a muddiest point question. Topic-specific prompts ask students to explain an observation in complete sentences whereas muddiest point questions ask them to specify clearly what material from the reading they struggled to understand. The strength of the muddiest point questions is that they force students to reflect upon their own learning, an important metacognitive task. The necessary effort is incentivized in two ways. First, JiTT responses, worth 5% of the course grade, are graded on a 0-5 scale with fairly high criteria (Table 1). Students receive prompt feedback (within 8 hours) on the quality of their JiTT responses. Second, clear and concise responses are more likely to be used in class where the heading of most PowerPoint slides is a JiTT response. Students often comment that they value seeing their own responses shaping in-class activities.

Students now ask/answer questions on Perusall

Table 1. Rubric used to assess JiTT responses.

5 – Clear articulation of which content was challenging and demonstration of a serious attempt to grapple with it
3 – Explanation of which content was challenging, but little explanation of how or why
1 – Response demonstrates little effort

Each 90-minute class period is organized around the JiTT responses that students submit before 12:30 am. There are typically 3-4 response clusters addressed in a given class period (Figure 3). Several student responses are displayed via PowerPoint. Some questions are addressed directly with short (3-5 minute) mini-lectures and others are addressed via collaborative problem solving. The audio-visual solutions created by two or three of the teams are then reviewed as a class before the next cluster of JiTT responses is addressed. This structure ensures that class time is used to address the material that students are actually finding difficult and helps students to establish ownership of their learning.

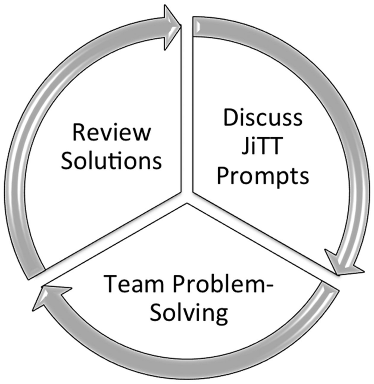


Figure 3. The classroom learning cycle is repeated 3-4 times per 90-minute meeting.

Collaborative learning is the central component of this pedagogy. The textbook and JiTT are valuable, but only in-as-much as they enable students to engage in collaborative learning. Approximately two-thirds of each class period is spent with students working in teams of three or four. Teams of two tend to have difficulty gaining the collective understanding to solve problems and teams larger than four have difficulty keeping all members engaged. This is consistent with observations in other disciplines (*11*). Students organize their teams on the first day of the semester and then reorganize after each exam. Students are required to form teams containing at least one person that have not previously been grouped with. This periodic, forced reorganization helps the class become a single community of learning rather than several isolated teams. It also increases the likelihood that each student will have the experience of being in at least one high functioning team and one that requires effort.

Class time is spent throughout the semester discussing expectations and characteristics of good teamwork. Students are directed to:

- Work individually on their assigned problem for 1-2 minutes,
- Work as a team on their assigned problem until a solution is understood by all,
- Ask one another questions and offer explanations to ensure mutual understanding,
- Discuss challenges within their teams or with the instructor,
- Take turns recording audio-visual solutions on the iPad tablets with no student recording a second solution before each has recorded one,
- Work on additional questions as time allows.

now use 2x3' whiteboards

During problem solving periods the instructor circulates through the teams to ensure that they are working well together and arriving at reasonable understandings of the material. Students evaluate themselves and their teammates at the conclusion of each unit of material for 15% of their course grade. Initially students completed a table on each exam using the rubric shown in Table 2.

Table 2. The teamwork grading rubric is used by students to assess their own and their teammates' contributions.

Descriptor	*Every Day*	*Typically*	*Rarely*
Prepared for class and engaged in activities	5	3	1
Asks helpful questions and answers others' clearly	5	3	1
Both contributes to solutions and allows others to do so	5	3	1

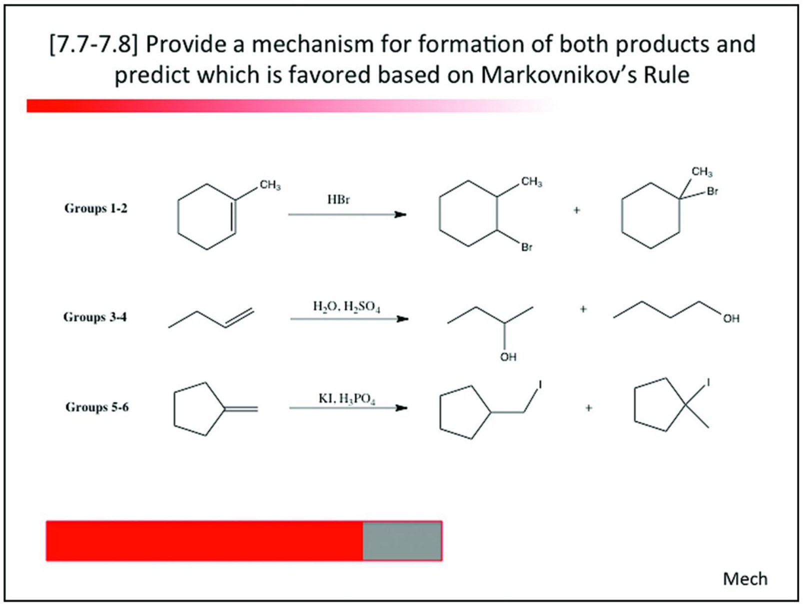
Rubric now generated from "Qualities of a good teammate" norming activity

More recently this function has been completed electronically using the CATME website (*12*, *13*). The CATME domains used are: Contributing to the Team's Work; Interacting with Teammates; Having Related Knowledge, Skills, and Abilities. The training / calibration, prompts, and analysis offered by CATME have led to better student comments and results more consistent with instructor observations. CATME has many additional functions which have not yet been exploited.

Now use CMS (Moodle)

Students' JiTT responses determine the problems that teams are assigned during class. Each cluster of responses typically generates 3-4 problems that are assigned based upon the randomly distributed iPad tablets (one iPad per team, 5-8 teams per class, Figure 4). Students work individually for 1-2 minutes before discussing the problem in their teams and recording an audio-visual solution on now use LMS

an iPad using the *Explain Everything* app (*14*). It is important for both learning and Americans with Disabilities Act (ADA) compliance that the audio and visual portions of the solutions be comprehensible in isolation from one another. Solutions are placed in a Dropbox folder (as .xpl files) to which each iPad is linked. Students are encouraged to work on one of the other team's problems as time allows once their own is uploaded to Dropbox. Each cycle of teamwork lasts five to fifteen minutes.



[7.7-7.8] Provide a mechanism for formation of both products and predict which is favored based on Markovnikov's Rule

Groups 1-2 — HBr

Groups 3-4 — H_2O, H_2SO_4

Groups 5-6 — KI, H_3PO_4

Mech

Figure 4. A typical PowerPoint slide that assigns problems for teamwork. The bracketed numbers indicate the corresponding sections of the textbook. The text in the lower right corner indicates the Dropbox folder in which solutions are to be saved. The red/grey bar is a ten-minute countdown timer.

The uploaded audio-visual solutions are reviewed as a class once time has expired and at least half of the teams have uploaded their solution. The class is then prompted to comment upon both strengths and weaknesses of the solution before another is viewed. Typically two or three of the solutions are reviewed before the next learning cycle is initiated with new JiTT responses (Figure 3).

The .xpl audio-visual solutions are converted to .mp4 files using the *Explain Everything Compressor* and uploaded to the course management system (*15*) after class so that they can be reviewed by students on a variety of platforms. It is technically possible for this step to be completed by students during class, but it introduces too much delay (*Explain Everything* on an iPad takes 1-3 times longer to compress a .xpl file than the recording). It has also been necessary for the instructor to review each solution and briefly comment upon their accuracy to increase student perception of their value.

N/A

Results

This pedagogy has improved student performance relative to the teacher-centered instruction previously employed. This improvement has been most readily observed in the population most difficult to reach – the weaker students. Seven years of trying every teacher-centered intervention possible had failed to alter a persistent 26% (± 3%) DFW rate (the percent of students receiving a D, F, or withdrawing from the course) in Organic 1. The first year using this active-learning approach saw the DFW rate decrease to 6%. The average DFW rate over the first three years of this approach was 12% (± 8%). Exam scores have, likewise, improved by 1-3%, with the largest increase on the cumulative final exam. Exam scores in Organic 2 have also increased, but are not considered statistically significant due to a high number of confounding variables. These gains have occurred within the context of falling performance in General Chemistry where final exam scores have fallen by 2-8% (depending upon instructor) over the same time frame.

Student response to this pedagogy has been largely positive. There are certainly students that state their desire to “be taught” the material rather than having to “teach it to themselves.” This is increasingly a minority of students, but they have occasionally been quite vocal. There have also, however, been a significant number of students that emphatically express their appreciation for this student-centered approach. The majority of comments on the course evaluations are now strongly in favor of the pedagogy. More gratifying, and important, are the personal messages former students have begun sending to express their gratitude for the experience.

Distinctive Characteristics

Development of technical reading skills is necessary in undergraduate education. Success in the sciences requires the ability to read informational text, yet students entering college appear to have little experience doing so. This pedagogy supports student development of reading skills by requiring that they read and providing instruction on how to do so. The key learning objectives for each section of the textbook are provided so students know what they should learn from their reading. Finally, the pre-class online homework helps students assess whether their reading was effective.

Metacognition, thinking about thinking, has been shown to greatly enhance student learning (*7*, *16*). Students that frequently assess whether they understand a passage of text, whether their problem-solving strategy is working, whether they are ready for an exam, etc. have higher learning outcomes. The pedagogy described in this chapter promotes metacognitive development from the first day of class when the rationale for an active learning approach is presented. This includes improvement in student outcomes, but also a mapping of course learning objectives to Bloom’s taxonomy of learning. This type of approach has been shown to promote metacognition and improved outcomes in general chemistry and more broadly (*7*, *16*).

A 2012 report of the National Research Council lists "defining learning objectives, demanding more student responsibility in mastering content, and using class time for problem solving" as additional means to develop metacognition (*7*). The pedagogy described in this chapter provides learning objectives for which students are responsible each day of class. The muddiest point JiTT question that students answer before each class provides further opportunity for them to engage in metacognitive thought. Brief, frequent opportunities for reflection have been shown to be the type of writing-to-learn exercise most strongly correlated with increased student performance (*17*). Likewise, collaborative problem solving encourages students to reflect upon their own understanding as they work toward a common solution.

Collaborative problem solving is a powerful component of many active-learning pedagogies because it can be highly effective (*7*). It has already been mentioned that collaborative problem solving develops metacognitive skills. It also places students in the active role of co-constructors of knowledge rather than that of passive recipients (*18*).

Collaborative problem solving is more effective when care is taken to ensure that metacognition and co-construction occur. This pedagogy does so in several ways. First, the emphasis during problem solving is on effective teamwork, not obtaining the "right" answer. The ability of teams to work toward a shared understanding is 15% of the course grade. The actual solutions are reviewed and commented upon, but not graded. Second, students spend the first few minutes of each activity working individually so that they each bring something to the collaborative effort. Third, the product of this collaboration is an explanation, not just an answer. Decades of talk-to-learn and writing-to-learn research have shown that students who write and/or talk out their rationale develop stronger metacognitive skills and learn better (*18–20*). This pedagogy requires each team to provide both a complete visual explanation and a complete audio explanation of their solution. Teams have chosen to divide the responsibilities for this differently, but the requirement that each team member contribute once before anyone contributes twice keeps all team members engaged. Finally, when audio-visual solutions are reviewed in class particular attention is paid to elicit student feedback on strengths and weaknesses.

Leadership, the ability to work in teams, problem solving, and communication skills are consistently among the top skills employers seek in college graduates (*8*). Collaborative problem solving with electronic whiteboards provides an excellent opportunity for students to develop and demonstrate each of these skills. As students work in four different teams over the course of a semester they are presented with a variety of interpersonal challenges. Some challenges they overcome easily, others require assistance from the instructor. Regardless, this experience strengthens their ability to work in a team and be an effective leader. Problem solving and communication skills are, likewise, strengthened by practice. Students often resist public speaking, but the use of electronic whiteboards has been well received. Students take recording their audio-visual solutions seriously, but without much of the anxiety and flippancy often seen with live presentations in front of the class.

Future Directions

The basic structure of this pedagogy seems to be working quite well. There is, however, at least one area in which improvement should be possible - the problems assigned for collaborative work. It may be valuable to introduce more real-world problems such as those used in problem-based learning (PBL) (*21*, *22*). Alternatively, students may be more engaged with the existing problems (both in class and afterward) if some of them begin appearing on exams. A synthesis of these options may also further promote student engagement and learning.

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