Learning Tips for Students of Organic Chemistry

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From the Outside Looking In...

Every year, I am more and more on the outside looking in when it comes to learning the subject of organic chemistry. The reason is simple: As a practicing organic chemist who has been an instructor of this subject for over 30 years, I cannot see organic chemistry the way that a new student sees it. Students see this subject with the eyes of a fresh learner, with one new idea following another with few previous reference points. One of the things I value in my interactions with students is that they bring their unique perspectives as new learners to my course. The fresh eyes of my students are the greatest tool I have to improve my understanding of “learning organic chemistry”, which greatly effects my ability to help others learn it, too.

As a student, I was a chemistry major thinking about a career in science, so I was predisposed to take my chemistry courses seriously. Although most classmates in my own undergraduate courses were not prospective majors, I was still like many of them, as well as my own students today, in some other respects. One purpose (perhaps a motivation) for learning a subject was to get a good grade on exams. I wanted good grades because I took great pride in doing well in my academic studies. I also knew I needed good grades to get into graduate school. But there was something else. Only in retrospect did I realize that some of my college instructors were trying to get me to see learning from the broader perspective of improving myself through higher education. I think that understanding this lesson was difficult for two reasons. First, I did not have any reference points or experiences for this advice to make sense until much later in life (in fact, in some cases, not until I became an instructor myself). Second, as far as I can recall, these broad lessons in improvement never seemed to show up in my science classes, except maybe as a spoken line or two on the first day of class. These ideas never seemed to appear anywhere else. The book, the homework, the class time and the exams were all “just chemistry problems.” Once I became responsible for organizing courses as a faculty member, I found myself wanting to
address these two problems. As an instructor, I cannot do anything about the first difficulty. I cannot provide students with years of experience in four months (although the students in my Honors course might disagree with that statement). Experience being what it is, generally, you have to get it in order to have it. One of the things that motivates me as an instructor, though, is the thought that I (and all instructors) can help out with the second difficulty, that of bringing evidence of a broader perspective to multiple aspects of a subject.

Although I may be on the outside looking in when it comes to learning organic chemistry for the first time, my knowledge continues to increase in two other areas. First, I understand better every year how the nuances of this subject fit together, often because of questions my students ask. Second, I continue to learn how students learn organic chemistry, which answers one of the most common questions students ask their instructors: How can teaching the same old thing year after year be interesting? For me, that is easy: I never do it the same way twice. There is always something new I learn about how students learn that makes me improve what I do the next time.

I wrote the phrase “bringing evidence of a broader perspective to multiple aspects of a subject” to describe an instructional goal. What does this mean?

In order to answer this, I have to start with a summary of all of my goals for students in my courses. Many times, when faced with the question of goals, faculty will drag out a copy of the syllabus and say “Here are my goals: On the first week of class we will cover chapter one, then chapter two....” If such statements are examples of goals, I find them unsatisfactory. Over the years, I have found it useful to categorize the goals that I have for student learning in my courses. I think there is an important hierarchy to goals that has been lost in higher education. At the most immediately obvious level are what I call “professional technical goals.” These are the goals most directly related to the subject matter of the course: The factual understanding and operational skills you are supposed to develop in your studies, and on which examinations are generally based. In calculus this might be learning how to take a derivative; in French this might be learning how to construct the past participles of some regular verbs. In an organic chemistry course, one early goal is for students to be able to translate the drawings used to represent chemical structures into an inventory of the atoms involved and how they are connected to one other. The technical (subject matter) goals usually become more sophisticated as a course proceeds. The skills you are supposed to develop are gauged by the type of problems that you are
supposed to solve. An increasing number of individual skills are combined and balanced into ways for solving new problems. Later in a course, enough specific examples should have been assembled to allow students to make sense of broader categories and concepts. These larger categories and concepts are what define a discipline (“calculus,” “French,” “chemistry”) and identify what I call “professional intellectual goals.” These concepts and generalizations also allow me to understand new and unfamiliar information both by applying the larger ideas to any specific new situation and by creating analogies based on other factual information that I know. Indeed, I want my students to develop the skills that are used by a practicing chemist.

Courses and subjects are filled with professional technical goals. The professional intellectual goals are what keep a subject from becoming just an endless list of things that have to be remembered. There are professional intellectual goals that relate to chemistry, such as explaining and predicting everything from bonding to bonding changes (chemical reactions) on the basis of electrostatic interactions (the attraction between positive, or electron-poor atoms, and negative, or electron-rich atoms). There are also other professional intellectual goals that relate to science and scientific practice, such as understanding the role of reproducibility in experimental science or the significance of the Uncertainty Principle in understanding observations. It is my obligation to demonstrate consistently how and why the specifics of chemistry interact with larger ideas of both chemistry and science. It is my students’ obligation to appreciate the validity and operational importance of these relationships. Finally, there are “general intellectual goals” that are, to a degree, the overriding purpose of an education. These are the skills acquired from the study of a subject that transcend the subject itself, especially new strategies, insights and experiences about the process of learning and understanding new things.

Learning Skills. Specific Strategies and Tactics

A few things we know (and a few we do not) about learning organic chemistry

You should expect that learning organic chemistry, for the reasons outlined above, may be different from other learning experiences that you have had. The myths that surround the subject of chemistry, and especially organic chemistry, do not help at all.
“Organic chemistry is the most difficult course at the University.”

“Organic chemistry is the ‘weeder’ course for medical schools.”

“Memorizing tons of information is the only way to get through.”

“Look to your left in class, then look to your right. One of those people will not be there at the end of the term.”

“Only students with previous college chemistry, a good AP background, and an organic chemistry prep course can do well.”

“I just can’t do science classes.”

Is it any wonder that it is difficult to concentrate on the course with all of these anxieties lurking around? These statements are simply not true.

*Structure and Reactivity* is the large introductory course based on organic chemistry and taken by first-year students at the University of Michigan. Since 1989, the University of Michigan faculty have presumed that the precollege chemistry background of our students is adequate to the task of learning organic chemistry. One of the most gratifying aspects of teaching this course has been feedback that we are fulfilling one of the unstated expectations of new university students, that their academic program will be different and challenging and not a repeat of their high school experience (something that is certainly true in the non-academic portion of a student’s experience in attending college).

We have looked carefully at what characterizes students who are successful in our *Structure and Reactivity* courses. Here is what we know:

1. *The amount and type of previous chemistry does not make a difference, but learning skills do.*

   - The fact that students did not take an AP Chemistry course does not matter. On average, the 35-40% of 1000-1200 students in our first-term Structure and Reactivity course who took AP Chemistry perform at the same level as the non-AP students do. We have strong indications that it is not the background in chemistry content that matters, but rather the learning skills of the student.
• A second thing that points to learning skills is the fact that the Math SAT score is the only other background factor that predicts anything significant about student performance in the first-term *Structure and Reactivity* course, even though the course is 100% narrative, or descriptive, and primarily non-mathematical in nature. Historically, the Math SAT score is thought to be representative of general learning skills.

• Students in *Structure and Reactivity* courses tend to develop their deeper learning skills more than their counterparts in a General Chemistry course, therefore the willingness to make these sorts of changes is an important characteristic of those who succeed in the course.

(2) *Psychological motivation plays an important role.*

• We also have observed that students’ beliefs in their own abilities play as large a role in predicting success as the Math SAT score. A person who believes that he or she has developed a degree of control over learning (or over any task), tends to develop better understanding. Part of this is a feedback cycle, where those who do well to begin with get the message that what they were doing was the right thing. On the other hand, we also know from our course that the first exam does a relatively poor job of predicting course outcome. This means that many students who end up doing well develop their successful strategies later, after some less satisfactory experiences have motivated them to make a change. It is important for students to be patient and persistent, and not to let the first discouragement drag them down.

• Student responsibility is also significant. If students find themselves thinking “I did not learn because the instructor did not teach me well enough,” then they are requiring far too much of the instructor and not enough of themselves. Similarly, if students conclude that “This course just did not match the way I learn,” then they are missing the point about building new skills on the foundation of old ones. I think that becoming a more flexible learner has no down side. Why just reward the same old skills?

*Learning skills*
Learning skills include memorization, but memorization alone is not enough.

The subject matter of organic chemistry is particularly well suited to encouraging students to develop deeper learning skills. This is because you spend an entire year with one specific subject that builds upon itself in a meaningful way. Many times, introductory courses are called surveys, where one topic follows another without much linkage. There can be advantages to this approach. For instance, each new topic becomes a fresh start without the immediate need to master a previous topic. On the other hand, you never spend long enough with any one topic to make deep connections that truly challenge your learning skills. Organic chemistry begins with a relatively few general principles for which you can develop a ever deepening understanding as the year goes on. At least, that’s the plan! On the other hand, no one can force you to do anything, including learning differently. All an instructor can do is to create a situation where you will come to realize that your old skills are inadequate.

My instructional goal for students is to use chemistry as a way to encourage them to develop new learning skills. To accomplish this goal, students must be faced with learning situations where their old skills are inadequate but not abandoned. The skills with which students begin a course are their strengths, their point of reference. For the most part, students begin a course with what are called “surface skills.” Surface skills include the ability to memorize, to organize, to recall and connect one set of symbols or representations with another. A concrete example of such skills is the multiplication tables. You can connect the symbols “2 x 2” with “4” without ever understanding the multiplication relationship. This is also your level of understanding when you learn to do multiplication with an electronic calculator. The multiplication tables or a calculator are just starting points. Your current understanding of multiplication has not replaced the times table or a calculator. Rather it has become broadened and deepened with alternative ways to think about multiplication. Notice that you have not abandoned your fluency with the multiplication tables or calculators because you now have a mastery of multiplication. Rather this fluency is inadequate when faced with a problem that is not on the table you have memorized. Without using a calculator to solve “345.8 x 45.5,” a problem that you probably have not seen before but nonetheless can solve easily, you use your more general knowledge of multiplication as well as your specific recollection of the multiplication tables. Even when you use a calculator, your general understanding of multiplication combined with estimation skills would allow you to
reject an answer such as “157.339” if it showed up on the display. The additional skills you need to combine with surface skills in order to solve this problem are called “deep processing skills.” To solve this unfamiliar problem, the deeper skills interact with your surface skills in ways that allow you to judge whether you are adequately performing the task at hand.

**Specific Strategies**

Why should students develop new learning skills? I hope that the answer is self-evident: Such development is one of the objectives of higher education. In order to end up with an intellectually rewarding career, you have to be able to walk into a new and unfamiliar situation with the confidence that your skills will see you through. All people who are truly successful at what they do bring these kinds of skills to new problems, and new problems are the interesting ones! Experiences in (and out) of college classes are meant to model these situations. The behaviors and habits students develop during these years define their character for the future, long after the details of specific courses have faded away. I am deeply committed to the idea that we are all life-long learners, and that a necessary goal in education is to encourage the habits of the life-long learner. What does this mean? Mainly, it means that you become more and more responsible for your own education. Rather than having your interests defined by a course or curriculum, you begin to identify what you want to learn, including how to learn it, because it serves some greater, self-defined goal.

What does a deeper or higher order learning skill mean? The skills that more experienced learners bring to a task are complex, and vary from challenge to challenge. The process of making appropriate selections from a menu of existing strategies, or knowing when to invent new ones, is a skill unto itself, analogous to matching the right tool to a mechanical job. For an introductory course, I encourage students to master the following skills:

- **Restatement**

  Restatement is more than just putting it in your own words. It is the process of making new ideas make sense in terms of what you know. As you encounter a new concept, try to imagine having to give a short lesson to another beginning student to get them to understand it. Do not just rehearse the words of the text over and over, and do not just say
them to yourself, in your head. If you have to, say your lesson out loud to yourself. If you can, find another classmate to talk to. More will be said on this in the section on “The role of teaching in learning.”

• **Connections**
  One hallmark of the best learners I have known is their belief that everything is connected. What you learn in one place can help you understand something else. When I face new and unfamiliar information, one of my first reactions is to find an appropriate analogy. Rather than answering the question “What is this like...?” I start with the certainty of “This *is* like...”

• **Review and reconnect**
  Connections are not enough. As you develop the map that is your understanding, it is also important to review what you once knew in terms of what you now know. New information should give you a new perspective on old information. Another version of this is the idea that your understanding should be sketched out rather than defined too specifically too early. When dealing with a new chapter in your text, for example, you can elect to move very linearly and deliberately through the book, one page at a time, digesting each adverb before you permit yourself to turn the page. Unfortunately, this approach minimizes opportunities to make connections. Another approach is to think of your understanding as a painting. First you start by making a sketch, which is a process filled with erasure and correction, a time when what once seemed right is now out of place, and a time to get a look at the whole canvas and try to see the big picture, even if it is a bit blurry. After this comes a time of refinement and elaboration, where self-consistency across the canvas allows the newly defined parts to complement one another.

• **Self-constructed summaries and aids**
  As you build towards self-reliance, you must begin to solve problems with no information other than what will be available at your exams. Any amount of time you spend “getting little hints” or using anything other than the information in the problem to help solve it is wasted. If you tie your skills to an answer key, your notes, or where you are in the text, then you will be practicing skills that are useless for the exam. At some point, you must be willing to look at an unfamiliar problem and say “I don’t know how to do that, yet.”
and move on to the things you can do with the knowledge you have. If you do construct aids, such as mnemonics, lists, or other associations, make sure they are the kinds of things you have actually used to solve problems.

- **Self-constructed assessments**
  Whatever your course of study, the object of your study will be ideas and how people deal with information. One way to test your own proficiency is to create your own problems. This can be done many ways for many different subjects. In my chemistry courses, I usually recommend two things for everyone. First, take any general subject heading in the course (“resonance forms,” “Brønsted acid-base reactions,” and so on) and write it on a blank piece of paper. Now create (do not look up or recall) 10-20 examples of that phenomenon based on the general principle. One of the best uses students can make of their instructors is to share these creations. Other versions of this exercise might be to see if two or more of the general ideas can be combined, or to get together with others and use these problems as the basis for testing one another. The other advice I have is related to creating exam questions. Instead of creating examples under the topic heading, students can do what the faculty do: Go to chemistry journals. In my course, nearly all of the exam questions have a citation because it is very convenient to thumb through the journals and use simple sorting skills to look for specific examples of general phenomena. You can do this, too.

- **Information and meaning**
  A theme that links the five skills listed above is the distinction between “information” and “meaning.” When I write “cat” or “table,” these words are just collections of symbols that are meant to represent the idea of a cat or a table. Without prior knowledge about these symbols, it is not possible to extract the meaning of “cat” from the letters c-a-t. The word “cat” is not a cat! Similarly, the symbolic representation “H\textsubscript{2}O” is not water, but it is meant to represent all that water is and how it behaves and interacts. One of the things that make organic chemistry so interesting is that once you learn the basics of the structure/reactivity relationships, you will be able to predict the behavior of substances the structures of which you have never seen before, much the way a very complete knowledge of Greek, Latin, and word origins might allow you to understand words you
had never seen. Information collects all of the surface features, while meaning gathers all of the inferences. One of the common mistakes made by instructors is to advise students that learning organic chemistry is like learning a foreign language; not so. When you learn any second (or third, etc.) language, you do so with an idea of what the objects that need to be described are. In other words, there is a great deal of translation. If you already know what a cat is, and you have a word for it in your first language (“cat”), then learning that “chat” is how this idea is represented in French benefits from your preconception of what a cat is. Now imagine that some other animal (or maybe you are not even sure it is an animal; it is like nothing you have ever seen before, actually) is not only named in a language with which you are unfamiliar, but that the descriptions of this thing are also only available in this unfamiliar language. Learning organic chemistry is not like learning a second language at all; it is more like learning your first language.

• Diagnosis and treatment

Diagnosis. Solving problems follows a medical metaphor quite well. There are two parts to the problem-solving process: Diagnosis and treatment. Diagnosis is the part where general classifications are made, and perhaps a general strategy is developed. On a chemistry exam, it simply means deciding which of 6 or 7 major ideas is represented by the problem. If you have created such a list before the exam, and practiced using it, then you can use it as a guide while taking the exam. The exam problems must represent the ideas from the chapters in question. This raises an interesting idea to keep in mind about textbooks. Textbooks themselves can allow you to under-develop or avoid using your skills in diagnosis. For example:

(1) Problems within the chapter are diagnosed for you before you get there! Not surprisingly, the problems relate to the preceding section. One way to demonstrate that diagnosis is a real skill is to take photocopies of the in-chapter problems after you have done them, cut them apart from identifying markers, randomize them, and then try to answer the question, “What kind of problem is this?” The same problems that were so easy before are now difficult. Ready to learn diagnosis?
(2) **Problems at the end of chapters are still mostly associated with the chapter,** and are sometimes drill-like (Problem 23 had parts a, b, c, d...w). Once you struggle with 23a and 23b, all of a sudden 23c is easy. You are not actually getting any better at diagnosis because you can do 23c; you are just anticipating what the problem is about. It is being done for you. Any time you know what a problem is about before you have read any part of the problem, you probably should not do it. Skip it and come back later and see if you can still tell what it is about.

(3) **Keep book-reading and note-reading time separate from problem-solving time.** Try the problems in a new chapter before you read the chapter, just to see that you cannot do any of them. Even by reviewing the problems, you may begin to get a sense of the ideas that you will need to pay attention to. If something is unclear after a respectable effort, move on. Try to treat chapters as whole entities, as stories where all the parts are interwoven. As you make your initial fast pass through the text, see if any of the problems make more sense. If so, try them out. If you can’t solve them, you will come back to them again. If you recognize that you do not know how to do a problem with the understanding that you have at that point, that is an important thing to know. Concentrate your efforts on learning what you can do with what you know, and work from there as you reread (and reread and reread). If you do not spend overly long with parts of the chapter that are not clicking, you will free up time for future readings. No knowledge can be presented so linearly that you can’t learn from page 54 without getting page 53. And many times, what you learn on page 54 can help you understand page 53. Give yourself permission to turn the page!

The bottom line in learning to do diagnosis correctly is quite compelling: If you don’t get this part right, it doesn’t matter how well you do the next part, because it will be wrong. The correct answer to the wrong question never gets any points. After all, a physician may know how to treat two different diseases perfectly well, so the most important thing is first to make the diagnosis correctly! A physician does not get “partial credit” for prescribing the right medication for the wrong disease.

**Treatments** The following suggestions are, by definition, incomplete. These ideas are meant to inspire you to think about learning in ways you might not have before.
(1) *Practice useful skills.* Always ask yourself, “Am I doing this work honestly? Am I just rationalizing someone else’s answer in the *Study Guide?* Am I using a resource that I will not have at an exam? Did I know what this problem was about before I did it?” You can learn how to do the wrong thing very well. It feels as though you are making progress, but it is in the wrong direction, or simply allowing you to generate incorrect answers more efficiently. It is fine to get the advice that you must spend a little time studying the subject every day, but this is the beginning of the story, not the end. How you spend your time matters too. Many high school and beginning university students equate time spent with effort when what is needed is productive effort. The only way to know whether what you are doing is productive is to examine it honestly. Can you do problems when they are out of context, can you explain your ideas in writing, and can you explain them out loud?

(2) *Concentrate on your strengths.* Build on what you know and learn to identify the problems you can do with what you know. Learn to admit when you do not know something as well as when you do. Sketch out your understanding by trying to keep the broad arguments in mind when you are concentrating on the details. Work back and forth as you master new ideas, asking, “How does this fit into the overall picture?”

(3) *On an exam, you are the teacher.* Like it or not, instructors demand performance of one kind or another. If you always keep in mind that you need to express your ideas as well as learn them, you will be ahead of the game. You do not necessarily need to work with another person, but it is generally easier to develop such skills if you do. Self-examination and quizzing your study partners is a chance to practice those skills before the exam. During the examination, your role is that of the instructor, and your instructor is the student to whom you are explaining the ideas. If you have practiced this skill before the exam, you will not be forced to learn it there.

(4) *Constant, daily building of ideas.* If you play catch-up, you will be caught. Listen and think in class. Respond to questions. Create your own tools for solving problems, and do not wait until just before the exam. If you are allowed an index card of information, it should be created and refined throughout your study of the chapter.
Even if you are not allowed to bring it to the exam, you can still think about developing a card’s worth of information that is useful for solving problems. Look at the general statements and topic headings and conclusions from the lecture and ask yourself, “Do I believe these? Do I believe that the examples support the ideas?” Even if you wait until the last minute, at least give yourself a few days for the longer-term connections to begin to form. If your exam is Tuesday night, then pretend it is really on Saturday or Sunday and use the intervening days to review and allow the ideas to percolate. Whatever your time frame for study, push it back a few days, even if all you intend to do is cram for the exam.

(5) *Exams transmit expectations.* More than anything, the exam is where you really learn what the course is about. You must pick up your graded exam and analyze why you made errors. The “correct answer” simply does not count for that much compared with correcting the process by which you made the error. If you think an exam question was written poorly, then one thing to do is try to rewrite it yourself. Write out in words the thought process you used to create an answer and look for where you went wrong. Having this process written out also is a good way to engage your instructor. Avoid avoidance; when the exam is taken and graded, pick it up and look at it. If you do not pick it up, you are only making things worse, not better. The old exam is a place where you can inspect your real errors, the ones pertaining to how you were learning.

*The role of teaching in learning*

**Learning to be a critical listener**

I started with a discussion of how teaching impacts my learning. A phrase familiar to all instructors is based on their first teaching experiences: “I never really learned this subject until I had to teach it.” Most instructors understand that the most important advice to give is that students should work together in their learning. The reason for this is that you develop teaching skills when you work with others. Developing teaching skills is relevant to all students who take exams, write papers and give presentations, which includes everyone. All of these events are
fundamentally teaching events, that is, situations that call for explanations to be given. When a learner is consciously aware as a goal of the need to explain things to others (in other words, teaching), then learning is improved.

One useful teaching skill is to become a critical listener. When you work with others, don’t decide only whether what they are saying is right or wrong according to your rules and ideas. Try to understand the rules and ideas being used by the other person in what they say or do. Let me use a specific example outside of chemistry. If you were helping a grade school student to learn multiplication, asking him or her to create 10 or 20 new problems, and their solutions, would be a good idea. Your expertise at multiplication would allow you to scan all 20 problems in a very short amount of time, and give that student some valuable feedback. The interesting thing is that understanding is hardly ever completely correct or completely incorrect. Usually, understanding is incomplete, adequate in some places, inadequate in others. The challenge in monitoring your own learning is to put yourself in situations where you can distinguish between adequate and inadequate understanding. For example, this young learner might come to you with 20 examples, and the first few you see are:

   (a) $1.1 \times 11 = 12.1$  (b) $2 \times 2 = 4$  (c) $3.5 \times 1.4 = 4.9$  (d) $2 \times 4 = 6$

As an instructor, you can react in many ways to these examples. The worst thing to do is to say: “Letter (d) is wrong, you need to study more.” In my experience, I have always noticed that I can learn about the way students understand something by assuming that what I see is the result of a consistent application of some set of rules. This is an example of critical listening. I am less concerned about only getting across my perspective and more concerned about understanding the perspective of the person I am with. The reason that I like the multiplication example is that it demonstrates something I see often; a student’s inadequate rules and my generally more adequate rules can overlap. This means that we can both come to the same factual conclusion for different reasons. If I want to probe the deeper understanding of my students, so that I can better know that they are using the correct process to obtain their answers, then I must try to push the edge of understanding. By learning only how to produce (and evaluate) answers with surface strategies, students can end up learning how to do the wrong thing very well; that is, they master inadequate rules that just happen to produce the same answer as the better rules do. It is easy to make this mistake in teaching: Just because another person’s interpretation or answer looks correct does not
mean it was obtained by the same pathway as yours or that it means the same thing as it does to
you. I do not mean to imply that multiple interpretations are not possible; I mean that better
communication depends on double-checking that I understand the connection between the
process and the product of a student’s effort before I build what I do on incorrect assumptions.
For example, the cases of “multiplication” presented by your student were in fact created by the
consistent application of the rules of addition, instead of those of multiplication. To tell the
student that he or she was doing something inconsistently would have been very bad advice.

There are a number of different ways to practice your teaching skills as a way to improve
your learning. The one prerequisite is that you learn how to open yourself up for interactions with
other students: Good communication (speaking and listening) skills, mutual trust, and a
willingness to be publicly incorrect and to be corrected are all necessary. You must examine the
conditions under which an answer is provided in addition to the answer itself, and you need
problems that are both difficult and for which you cannot easily obtain solutions. Better learning
through teaching is a fact. It has worked for me, as I described at the beginning of this essay, and
it can work for you, too.

**Working with others is more than a social occasion**

There are additional good reasons for having conversations about things you are trying to
learn. Sitting by yourself alone somewhere, you can convince yourself of just about anything.
Time on your own is a good beginning, but sooner or later you need to see if you can share what
you know. Certainly, as discussed earlier, this is what happens at an exam! When you have the
opportunity to say what you are learning out loud, you must consider organizing the ideas for
someone else. In fact, when you know you are going to be in the situation of describing what you
understand to someone else, you actually learn it differently. If you naturally learn by having
discussions, that is fortunate. It probably means you are thinking appropriately about the exam
situation. Anticipating the need to make explanations is at the core of this advice. A person does
not necessarily have to work with someone else to achieve these benefits. On the other hand, in
my experience, students do not seem to take this need enough into account. Editing your own
ideas is a difficult task. An external editor, or proofreader, for your ideas, makes sense. Whether
you like it or not, the exam will put you in the position of explaining ideas. If you wait until then
to develop and practice that skill, you are overburdening the exam time with things that you could have practiced ahead of time.

Learning to use vocabulary actively and accurately

Ideas are represented by words and other symbols. In order to work with ideas, you must also work with words and symbols. As you test your ideas, speak out loud without the safety net of your books nearby. While you are walking across campus, talk chemistry with a friend. While you are out at dinner, get out a napkin and draw out chemical ideas. These are the only ways to build the proper confidence that you can actually communicate using chemistry. When I work with students, I am intolerant (in a nice way) about imprecise language. I will stop students who use phrases such as “that thing over there” or “you know, the one from class” and encourage them to think about the proper terminology and phraseology for communicating ideas in chemistry. These are important skills to practice before examinations. During your exams, you have no choice but to represent your ideas correctly. Your answers will be incorrect if the wrong symbols are used, or if a structure is drawn the wrong way, if the wrong words are used...even if you “knew it.” Incorrect representation is an error. “I know I didn’t write it that way, but I meant...” never ever works. Does the importance of vocabulary also apply to courses where multiple-choice problems are used on examinations? Yes and, unfortunately, no. There are many strategies that rely on recognition and recall that can be used in preparing for these kinds of exams (which I have never given, by the way). This does not mean that students cannot develop a good idea about chemistry in courses with multiple-choice exams, but I do think that there is less reason to do so. Learning strategies based only on memorization are familiar and well-practiced by students, so they feel quite comfortable with them. As you can probably tell by now, I think that this degree of comfort is exactly why moving away from those strategies is a good idea!

Examinations

Exams are the real curriculum, not the syllabus. Think about that one more time. Nothing I say about learning in this course matters if a student does not see clearly how it relates to the examinations. Like it or not, the structure and expectations of higher education include grading, and grading results, for the most part, from examinations. Students learn about my expectations
at examinations, not from what I say in class. It is therefore quite important to ensure that there is congruence between (a) the stated goals in a course, (b) the instructional method, (c) the instructional tasks, and (d) the examinations and how they are evaluated.

I believe that nothing I say will matter, and that nothing I do in class will matter if the examinations do not fulfill the expectations created by the classwork. If I do not want memorization to be the only tool students develop, then my exams must ensure that this strategy alone will not work. In addition, I must think about instruction in a way that encourages the development of new learning strategies. To that end, nearly all of the examination questions in my course are derived from examples taken from current chemistry journals. There is no better way to demonstrate two important ideas. First, simply becoming familiar with the textbook examples cannot lead to success. Students must develop the skill to identify major ideas and themes and then use these concepts as their basis for drawing analogies. Second, we demonstrate that the subject is vital. The major ideas still appear and reappear in current research month after month. All the learning strategies previously discussed can apply to courses that use multiple-choice exams. In my view, however, this style of exam does not obviously require this way of learning and can cause students to default to more familiar and comfortable strategies. Many educators debate whether a student’s choice to use lower level learning skills should have any bearing on the decisions made by an instructor in choosing a testing strategy. After all, almost any exam will create a distribution of students in the class, and “good students” will probably learn well in any situation. This last sentence highlights my reason for giving the kind of course that I do: I do not see it as my professional responsibility to find the “good students” who are already sitting in my course on the first day of class. My responsibility is to provide an opportunity for improvement by all the students in my class (including me, by the way).

The course packs for the *Structure and Reactivity* courses at the University of Michigan have two parts: Essays such as this one, which constitute one way of transmitting the course goals to students, and actual pages from the last 4-5 years worth of old examinations, with no solutions provided. Sometimes no matter what I say or do, only an inspection of these exams will convince students that my words mean what they say.

Interestingly enough, every year all students think that their exam is more difficult than the one given the year before. This is just not true. There is also an aspect to taking examinations that
is characteristic of any situation where performance is called for known as “performance anxiety” (or, in this case, “test anxiety”). Test anxiety is not attached to the subject, even though many students would like to think so. Test anxiety is like stage fright for acting or a musical recital, or like the tension at a sporting event when you are at the starting line for the race that counts. It does not matter how smoothly things have gone before. You are human, and human beings become anxious at the event that matters. There are many different strategies to use to combat this kind of anxiety, including what your teacher, mentor, or coach has to say to you prior to the event. What you need is confidence from two sources: Yourself and the people you respect. Clearly, the more practice you have that allows you to develop skills you can use during the event, the better off you are. An examination, at its core, is an event that requires you to make an explanation about things you have not necessarily thought about before. The more you have practiced this, the better off you will be. The more you have avoided it, the less prepared you will be.

We do not provide solutions to the old exams because we want students to work together. Although it is frustrating not to have an answer key, there are plenty of problems with solutions in the Study Guide associated with the textbook. In addition to encouraging students to work together, the old exams can help individuals to regulate their learning. Every day, after class or after studying, a student can go to this set of problems and use them to answer two questions:

1. What can I do with the knowledge I have now?
2. Can I identify the kind of knowledge I need to solve the problems I cannot now do?

One of the more sophisticated skills of the expert problem-solver is learning how to develop a sense about whether their solutions “seem reasonable” or “make sense.” This is an intuition that only comes through solving problems in a way where problem-solvers are honest with themselves about the confidence they have in their abilities.

Getting the “A” grade

The techniques outlined in the section on specific learning strategies are meant to give you an alternative to simply “doing problems” and constantly re-working them. These techniques should
become second nature to you. They will serve you in all courses, including organic chemistry. Working on these skills is like taking an art class. You must take some time to sketch out your ideas and practice your skills nearly every day. You need to show your creations to other people so that errors in your technique can be corrected. Learn how to share your chemistry ideas – especially your incomplete ones – with your peers and with your instructor. Remember, you cannot simply persist in old study practices if they are not working for you and expect to see different results no matter how much time you invest.

You want to get a good grade in your courses, and I want you to learn something about how to learn along with your mastery of chemistry. I want you to do well on your exams because I believe that if you do, there is a good chance you also will have done the following:

1. **You will have learned how to be successful at something very new to you.**

2. **You will understand that science operates as a narrative, where sophisticated stories are told by people just like you by using their common sense and reasoning skills.**

3. **You will realize that information or facts, alone, are not terribly interesting, but they can point to a fascinating understanding or meaning of the world.**

4. **Best of all, you will develop confidence that your new learning skills will be something you can carry into other parts of your academic life.**

For your part, I would like you to begin to attach a more meaningful value to getting good grades. Your introductory classes can be a valuable learning experience in being with a group of students who have been as successful in their previous work as you have, and in developing the kinds of skills you will need for more challenging courses in the future. “Getting an ‘A’” is really not a goal; making sure you have learned how to do new things, including how to double-check yourself in those new abilities, is a goal. I am perfectly comfortable knowing that the majority of students who take chemistry classes will not become chemists who use the information from this course on a routine basis; therefore there must be some other value that goes beyond a grade for your transcript. I do hope students will exit a course like this understanding why some people find a career in chemistry an interesting place to spend their professional lives.
The Bottom Line

Go back to the first few pages in this course pack. The 6 ideas stated might be restated this way:

1. We have designed a course that, for want of a better term, “forces” the issue of learning to apply general ideas to new settings by always taking our problems from new settings. It is a strategic error to think that these problems will be trivially reconstructed to make your examinations.

2. There is more about the grading policy in the next section, but keep in mind that 1 out of every 2 students can solve at least 6 out of 10 of these pages completely correctly, without accessing any other resource except having studied, and 1 out of every 4 students can solve at least 8 of 10 correctly. This is the historical result from 16 years of teaching Chemistry 210 with these examinations. It is a strategic error to think that these are textbook exercises where 100% is the expectation; on the other hand, it is equally problematic to think that students can only do these problems by looking up answers and consulting answer keys – these are pages from actual exams, and we know for a fact that students performed according to the statistics given above.

3. The textbook, and the lectures, are designed to help you prepare to be able to handle complex problems, but in order to do so you must engage actively and learn to assess if you are actually learning something or merely going through the motions. It is a mistake not to follow the program.

4. Yeah, you hate it that there is no answer key for the course pack for you to check your solutions. Our experience in those same 20 years, and most of your 30,000 peers who have taken this course, MOSTLY all agree that this is the right thing. Accessing others’ answers and pretending that mean you understand how to do the problem is a form of self-deception.

5. …besides, in the real world of science, there can often be many acceptable answers to a given set of data, depending on what someone knows. You can only answer these problems in the context of your own course, not the course you did not take.

6. "The most important thing I got out of this class was the idea of teaching others. When you study with the idea that you have to tell someone what you're thinking, you just learn it differently."
CHEM 210 COURSEPACK - FAQ

Learning organic chemistry is different from most things you have needed to learn in school. Mainly, this is because it is not a “general” or “survey” class, in which lots of areas are covered in little depth. Organic chemistry is one topic area, and it is presented in a specific sequence, it continuously builds on itself, and it is covered in depth. If you treat the Course Pack as just one of many resources, and do not ignore the book problems, you will have a better chance of learning this subject in the way that the department intends.

6 Frequently Asked Questions about the Chem 210 Course Pack.

Are these really the old exam pages?

(1) Yes, these are actual pages from past exams – you will see how diverse this subject is. We have provided these problems so that you can appreciate their style, not memorize the specific examples… because these particular molecules will never re-appear. As you will see, we generally use the most recent professional chemistry journals to inspire our questions because they illustrate one of our main purposes, namely: learning how to apply your knowledge to new and unfamiliar situations. Since these examinations are often different from your past experience, the course pack gives you a chance to see what real questions look like. Please note: the emphasis in any course can vary depending on the interests of the faculty who are teaching, so these problems are not a contract of topics.

Am I expected to be able to do all of these problems?

(2) Frankly, no. This course pack is not a set of textbook exercises, where the author believes that you can do all of them. A simple and sobering fact based on 21 years of experience with over 35,000 Chem 210 students: an average student in this course scores 60-65%... being able to solve 100% of these exercises is not actually a realistic goal – but if you use them honestly, you can identify the topics you are having difficulties with. These problems do not replace the ones in your text or at the CTools site. Be sure to work through the textbook carefully and thoroughly. Use these course pack problems as a measure of where you have learned to identify the concepts behind a problem as well as how to solve it (and if you cannot do it honestly on these problems, you will not be able to do it at the exam, right?). Think of the 60% value the following...
way: 1 in 2 students in the course, during an examination setting, were able to do at least 6 out of every 10 pages without consulting any other resource… 1 in 4 students could do at least 8 out of every 10 pages under an examination setting.

If I focus on the Course Pack, can I forget about the textbook problems?

(3) No. Read the textbook. Do the problems in the textbook. Read this carefully: the problems in the textbook are nearly all derived from old exam problems!!! The difference is: a textbook is structured to provide practice with hints. When you read a section about, for instance, how to assign a molecular dipole moment, it is not too surprising that the problems at the end of that section have to do with … assigning dipole moments! Solving the problem only has one part: get the answer. The author decides that it is time for some direct practice, and that is when the author inserts a problem set inside the chapter. At the end of the chapter, the problems a bit more out of context, because now solving the problem has two parts: categorize and/or identify the type of question (“oh, this is a dipole moment question”) and then solve the problem. If you access the chapter or the answer key to give yourself little harmless hints, you are going to fool yourself into thinking that you have done both parts (identify and solve) when you have only done the “solve” part… having cheated a little bit to get to the identification. The task of identification is crucial, because on an examination is will not say “Hi, I’m problem 3(a) and I am a dipole moment problem!” If you cannot identify with confidence what kind of problem you are looking at, you are not ready to do the problems in the course pack.

Why don’t you provide an answer key – that is just so freaking unfair!

(4) We do not provide a single reliable answer key for these old exams for a good reason: you want to have practice problems that mimic the exam situation. From the student perspective, this is probably the most controversial stand we take in this course. Each year, we hear reasoned and passionate arguments about why it would be so important to know (“to know”) what the authoritative answers should be “so we can check our answers.” Solutions are not provided for a good reason: namely, when you take an exam, you do not have the safety of an answer key to check while you are taking the exams. You have plenty of problems with answers if you remember to do the ones in your text. “But the textbook problems are not like the course pack problems…” is the next passionate argument. Not true.
Most of the problems in your text come from old UM exams – the author was a UM professor in the department of chemistry.

**Why do my GSI, my instructor, and my peers all disagree on some answers?**

(5) There is no single source of ultimate authority for “the correct answers” … different instructors have different expectations. Chemistry is not a mathematics class – there are usually many answers that could be considered correct in the context of the course any given semester. These problems are open-ended, and the group of faculty who created the exam is the only group that decided what was a correct answer and how it was to be graded. The question is not “what is the right answer” as much as “what are the answers that make sense in the context of this semester’s class?” … Because the mix of faculty is different every year, your current faculty instructors probably do not know how these pages were graded. But they can answer the important question: in the context of the course you are taking now, what would be the reasonable answer(s). Your peers do not know how it was originally graded; upper-level students do not know; and your GSI does not know. Answering this question is your focus: “What is a reasonable answer, and how can I be confident enough to know that it is reasonable?”

**When I am using this the right way, what will it look like?**

(6) Use every opportunity to have "chemistry conversations" with your peers: what is the answer in the context of your course, this semester. If you can explain your ideas to them, and respond critically to their explanations, you'll be better able to explain your ideas while you are answering exam questions. Study together productively. Set up a group through the Science Learning Center – or just do it on your own. Our campus is filled with empty classrooms in the evenings – take turns standing at the board and teaching each other. You have not learned it well enough to take an exam if you cannot teach it to someone else – that’s what you do on a good exam, after all. Or, as a student wrote in an e-mail message a few years ago: "The most important thing I got out of this class was the idea of teaching others. When you study with the idea that you have to tell someone what you're thinking, you just learn it differently."