Learning and Teaching Strategies

Roald Hoffmann and Saundra Y. McGuire

Learning and teaching science challenges many students as well as instructors.

We have been teaching and helping others to teach chemistry at every level—from high school teachers to undergraduate and graduate students to university faculty—for over four decades. From that experience have come a number of teaching and learning tactics that we find effective in facilitating student learning. Initially improvised, these strategies are more than gimmicks, for they have proven themselves in practice.

We've also sought out recent advances in cognitive psychology that give insight into why these approaches work. We've thought through why they are of use in any subject, not just chemistry. And we've also identified potential problems.

A potential injustice in our account is that credit may not be given to the real innovators. Frankly, we do not know where some of these strategies originated—in examples by others, or out of our own improvisations as we struggled to become better teachers. Many people have independently come to similar practices.

Some of what we write is addressed to teachers, some to students. This is deliberate. Cognizance of learning strategies benefits teachers, and awareness of teaching strategies can help learners understand the motives of teachers. Teaching and learning are a double flame.

Six Learning Strategies

The first learning strategy is to take notes by hand, even if the class notes are provided. Preferably no later than the evening of the class day, rewrite your notes, by hand, amplifying their content. During the rewriting stage, it is important that you not just recopy your notes, but rather both condense and extend them where appropriate, paraphrasing them so that you make the meaning your own. The question of whether taking notes on a laptop or by hand is more effective is a contentious one. We think taking notes by hand works best, largely because it is difficult to type in chemical structures, graphs and equations on a computer.

From personal experience and research comes advice on what works and why

It is now well established that active engagement in the process is imperative for learning to occur. When students take their own notes, they are engaged, in real time, and their minds focus on the task. For kinesthetic learners (those who learn best when moving, activating large or small muscles), the movement involved in taking notes facilitates learning.

The process of paraphrasing and rewriting the notes shortly after a lecture helps to transfer information from short-term to long-term memory. If the rewriting is delayed longer than 24 hours, much of the information needed to flesh out the notes taken in class will have disappeared from accessible memory. And it is so much better that gaps in understanding surface in the engaged rewriting of notes, rather than in the frantic cramming the night before an exam. Students need to be convinced that it is important to take the time to rewrite their notes, even if they felt they have understood the material the first time.

Missed classes provide the second learning strategy. If you must miss a class, rather than simply download the notes from a Web page, get the notes from a fellow student. This strategy is another way into group discussion and learning. It is important to develop relationships with other class members and to form study groups early in the course. During discussion of the class notes, much learning takes place. A typical scenario: Student A (the one who missed lecture and is borrowing the notes) says "I don't understand this part of what you wrote," to student B, the note taker. Because B is a fellow student, A is comfortable asking her the question, whereas A might be reluctant to ask it of the course instructor. B explains, and is thus engaged in the most salutary of learning actions, teaching. The only potential problems are that the note taker may not understand, or may propagate a misconception. Additionally, some people are just too shy to ask another human being.

A third strategy makes the best use of a course's textbook. Most students do their homework in solitude (or as much of that as a residence hall room allows) by trying to follow text examples of similar problems. But often the text examples are not exploited for the learning opportunities they provide. First do the obvious; study the text and lecture information relevant to the problems. But then treat the examples in the text and in lecture notes as if they were homework problems—work out the example before looking at the answer, and compare your *approach* to the text's, not just your answer. There are often several ways to do a problem,

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but try to understand the text's method. If the homework answers provided do not include a way of working out each problem, the instructors should be encouraged (that's putting it mildly) to provide complete solutions. The ability to work a problem without using a model is the essential skill tested by all exams (which is obvious to instructors, but not to most students). This approach to homework focuses on *methods* rather than final *answers*. Furthermore, exploring alternative methods will help you to learn to be an agile, flexible thinker.

Study groups are important in learning, but it seems to work best to alternate group work with individual effort. First, you should try to do a homework problem or prepare for an exam on your own. Then, the collective wisdom of a study group can be enlisted. Three to six fellow students who have each done their best to digest and absorb difficult material are powerful resources for each other. Social constructivist learning theorists have shown that meaningful learning results from small study groups with two crucial features: discussion and problem-solving activities. Several websites provide excellent tips on forming and running successful study groups. But finally, you must return to solving the problem set or facing the exam preparation on your own.

Not all instructors are comfortable with homework done in groups, but our experience is that groups are very effective. Do-it-yourself is the primary principle of active learning, though groups can help resolve the occasional blind spot. Some social dynamics may limit group value—for instance, passive personalities are likely to merely listen.

Groups can also be useful study aids if students make up practice quizzes and tests for each other, thereby thinking from the teacher's perspective. One of us (Hoffmann) tells his students: "The only way you will get into my mind about the exam is… to try to get into my mind. That means to do what I do, and make up an exam." Creating a practice exam involves not only selecting and organizing all the material (including choosing what is representative and what is important) but also discussing the exam in a group setting.

Another way to enter the tester's mind is by teaching the material, one student to another. When one of us (McGuire) asks instructors attending faculty-development workshops when they began to develop a deep understanding of the conceptual structure of their discipline, most say that it did not happen until they began teaching. Helping a fellow student not only accelerates one's learning but moves one past disappointment about not getting things right oneself. Usually, if you can help someone else get going, the gratification is motivating for both parties.

Finally, we encourage students to set attainable goals. If you are spinning your wheels and studying does not lead to learning, the process can share some symptoms with depression—feeling unable to act, for instance. For this reason, it is important to tackle small, achievable tasks.

In working problems and taking tests, move slowly, from simple problems to more complicated, integrative ones. Success, self-achieved, builds confidence, and so is a very powerful motivator. When you attempt to reach a goal that is within your grasp, a wonderful cycle of initial success, more effort, and additional success is put into motion.

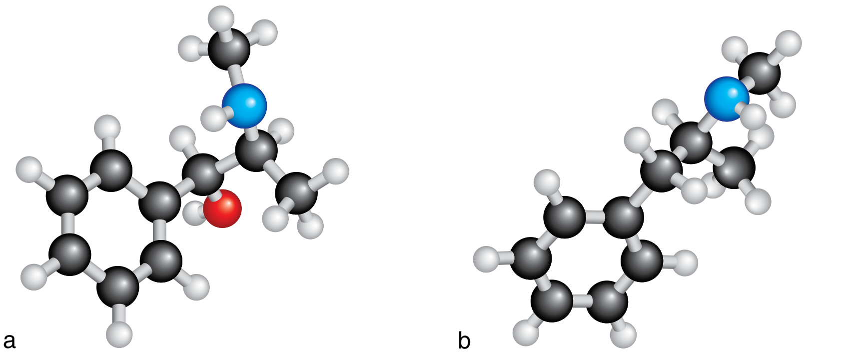
It is important for students to realize that everyone learns differently; an attainable goal for one student may be trivial for another. It is most relevant to develop the learning skills necessary to perform more cognitively demanding tasks.

Students learn better when they have more interaction with their professors and other students, and when they ask questions freely. Teachers can help to facilitate the learning process through individual discussions, classroom demonstrations and encouraging students to work in groups. (Photograph courtesy of Jim Zietz, LSU University Relations.)

Six Teaching Tactics

Moving to the teacher's side of the classroom, we recommend instructors grade on a contract with the students, whereby grades are based on a combination of a major, absolute performance component (examinations and quizzes) and a minor "curved" part of the course (such as labs and other multisection pieces). The only reason for curving should be fairness—if several graders are involved, for instance. The grading criteria—the percentage mastery equivalent to an A, B, etc.—must be explained to the students at the beginning of the course, along with a promise that the borderlines between grades will not be raised. Students are empowered when they see that the outcome of their course grade is dependent on their work, rather than on a comparison with the work of others. Young people react very positively to fairness; a contract boosts confidence.

However, the professor will need to construct exams such that the level of mastery of the material is accurately reflected by the grade that students achieve on the test. In psychometrics, this is referred to as *content validity.* In particular, one has to watch for misjudgments of mastery in multiple-choice exams of the type where the simplest arithmetic mistake will yield an incorrect answer.



In teaching chemistry, a professor can use events in the news to reinforce concepts. For example, the cold medication pseudoephedrine *(a)* is extremely similar in structure to the illegal drug methamphetamine *(b)*, also known as crystal meth.

The kind of contract we recommend is very scary to some department administrators, who may insist that each course has a predetermined median grade. Such worries, amusingly, reflect a lack of confidence in faculty members' ability to assess mastery levels.

A second teaching strategy is to bring "real life" into the classroom. News, crises and everyday life open the mind. Devote five minutes of each class to a discussion of science in current affairs. Every minute spent this way is worth it.

Newspapers (print or online editions) sadly carry little science; what they do carry is often health-related. The stories rarely give chemical structures but sometimes name the molecules or drugs. But the structure of a molecule can be shown in class, along with a copy of the story.

From a stream of such short stories from the real world comes appreciation of the relevance of what is taught. In chemistry, students begin to see that small differences in the structures of molecules may determine whether a substance will hurt or heal, or both. For example, they may begin to understand that not all cholesterol is bad, or that the drug methamphetamine (crystal meth) and the decongestant it's illegally made from in home laboratories differ by just one atom.

But the discussion of newsworthy topics may not be the most important part of this strategy. Ultimately, bringing real life into the classroom day in, day out builds a bond between teacher and student. Students begin to feel that the instructor has gone to the trouble of searching the media that very day and cares that students learn.

Here's a strategy on which the two of us disagree: Allow each student to bring into a test or final examination an 8½-by-11-inch page on which anything in the world can be written.

One of us (Hoffmann) feels strongly that as we move from print to digital textbooks, and as it becomes increasingly more difficult to forbid a student to use a computer or fancy calculator in an exam situation, we are moving toward open-book exams anyway, like it or not.

The other co-author (McGuire) feels that this is not a good strategy because she has observed its negative consequences. In her experience, most students think that if they can bring in a "cheat sheet" to the test, they need not know anything because everything relevant can be written on the sheet, information of which they have no conceptual understanding. She feels that professors should provide information (such as constants) that students need, but are not expected to memorize. She stresses to students that they can only think critically using information safely stored in their minds—information that they *own*.

On the up side, the sheet serves as a security blanket for scared students. But its true purpose is to make the student review the material, to make judgments about what is essential and what isn't, and to organize the material. The sheets can become a prime learning tool. With progress in the course, one of us has observed that students realize this, saying after an exam "I didn't even look at the sheet."

Getting students to think on their own is the primary objective of teaching, and care must be used to make students see multiple paths to an answer. Suppose a teacher in an introductory chemistry course has just gotten through discussing, say, the mass relationships in a combustion reaction: Octane (C_8H_{18}) is burned with unlimited oxygen to give water and carbon dioxide. He or she then continues: "Here we've seen how to figure out that if you burn 114 grams of octane with an unlimited amount of oxygen you will get 352 grams of carbon dioxide. But wait, the same ideas can be put to work in many more problems. For instance, I don't have an unlimited amount of oxygen (the air intake on my car is clogged), I have 200 grams of O_2. How much carbon dioxide would I get then from my 114 grams of octane? This is a so-called limiting reactant problem; seemingly different and tougher. Yet the same ideas are at work.

Here's another problem: My Volvo travels 8,000 miles a year, at an average fuel consumption of 22 miles per gallon. How much CO_2 am I putting into the atmosphere each year?"

Turning around the problem reinforces mastery of the underlying concept. There is nothing more convincing of a concept's value than the feeling that it can be used for not just the problem that occasioned it, but for many other problems. And turning things around has an element of surprise to it. Repeating the same type of question in different permutations may seem repetitive to the teacher; we think it is rarely so to the student.

Surprise and humor can help bridge the gap between teachers and students. When one of us (McGuire) asked a group of Louisiana State University students to explain the difference between studying and learning, most replied that studying involves forcing yourself to memorize uninteresting stuff (as they put it), whereas learning means gaining insight into things you actually care about. How can we build into the travails of most study some of the psychological fun of learning—that tremendous empowering sensation of understanding after not understanding?

Judicious doses of humor help a lot. Few chemical stoichiometry problems or lists of the names of the foot bones could be imagined to evoke raucous laughter. But lapsing into a fragment of "Dry Bones" (the thighbone is connected to the hipbone…), or playing Tom Lehrer's "Element Song," or Blackalicious' "Chemical Calisthenics," or Diego Carrasco's "Química" breaks tedium, giving the feeling of fun.

Humor is also a smile, or a surprise, or turning things around and looking from a different perspective. All of these things are part of what made the Marx brothers so good. Work in that direction, work to achieve surprise. Look in the course material for mistakes that lead to weird contradictions or unphysical results. These are the intellectual equivalent of pratfalls. Humorous situations, in moderation, are attention grabbing, emotionally satisfying and can create an environment that promotes long-term retention and learning. Humor also reduces stress, allowing students to enjoy the learning experience. Humor humanizes the instructor and builds a bond.

A final teaching strategy is to do still more demonstrations, even if you already do some. Although not every subject lends itself to doing demonstrations, chemistry certainly does. Mind you, demonstrations did not come easily to one of us, a theoretical chemist (Hoffmann). But he took to it and, in fact, learned how to turn white wine into red (and back again) from his coauthor. Demonstrations are somewhere between magic and science, somewhere between gripping theater and chemistry.

We know of no deeper silence in a classroom than during the first seconds of a demonstration. Theater directors and nervous concert-hall managers envy us those natural moments of rapt attention. The auditorium is hushed, awaiting change. The demonstrator does not fail to provide it, with color, flame, smoke or explosion. There ensues catharsis for the lecturer, a catering to all the senses of the audience, and, sometimes the only thing the students remember from a course.

Yet a demonstration is also a shifting of gears, from lecture to action. It is an intellectual alarm clock—"time to wake up, something is going to happen!" The act may be staged, but it is tangible. And it may invoke in the minds of a few students the essential question: "What is happening?"

A potential problem with this approach is that at times the link between demonstrations and what is being taught is weak. Moreover, a course overloaded with demonstrations could sacrifice learning for entertainment. But, perhaps in the lecture room it is as Daryle Singletary sings: "I ain't never had too much fun."

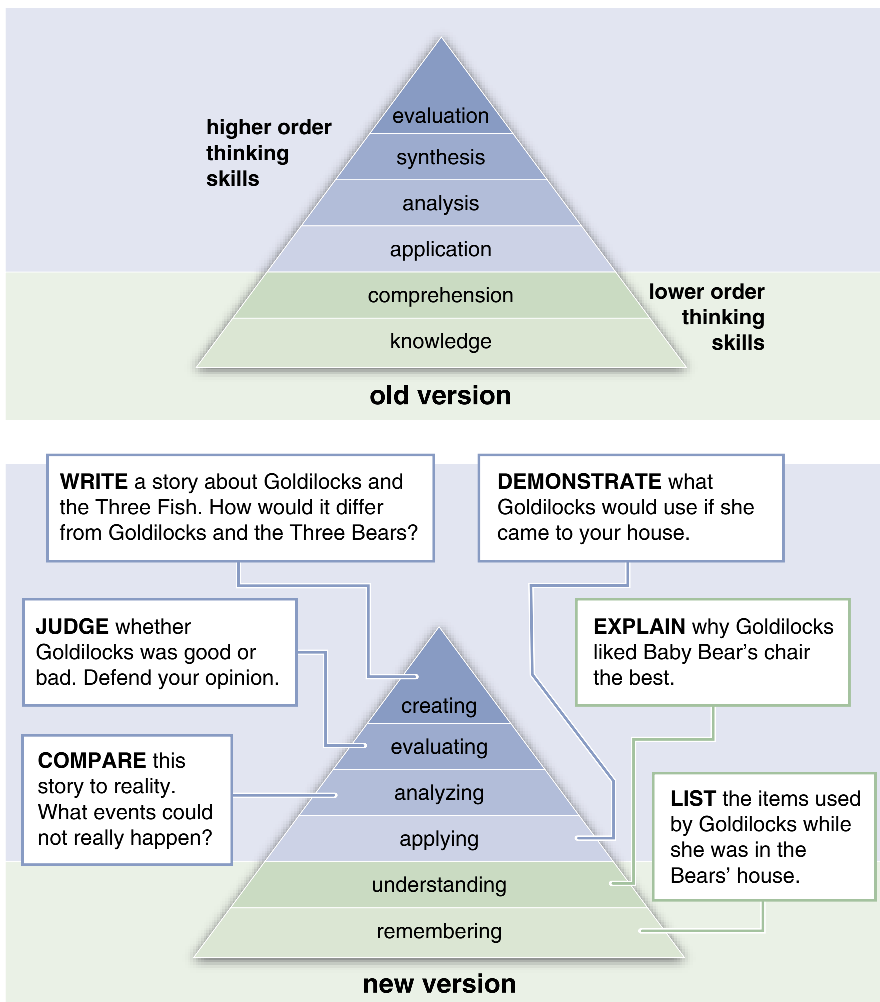
Three Transforming Motivators

So far, we have presented quite specific strategies. We now turn to some general observations about the education process, awareness of which can greatly enhance learning. These are directed toward both the learner and the teacher.

A student's learning style impacts the way she or he prefers to take in and process information, and to interact with others. Some students prefer to memorize discrete facts and specific formulas and then apply them, whereas other students prefer to use broader concepts and organizing principles to derive the discrete facts and formulas themselves. Learning style can also refer to a person's preferred modality—visual, auditory, read/write or kinesthetic. It is important for students to become aware of their learning styles and for teachers to know that there are different ways to learn, that more roads than one lead to this Rome. Why impose your way (and get frustrated when people don't use it) when you can encourage students to learn in their own, optimum ways? When students become aware of their learning preferences, they learn more efficiently by, for example, converting lecture notes or a course manual or a text into their preferred format.

A potential difficulty is that when students determine their preferred learning style, they may be tempted to think they can learn only in that way. It is important to stress that the various learning styles can be learned; just being aware that something may be learned in a variety of ways helps. When students investigate a spectrum of strategies, consistent with the gamut of learning styles, they broaden their learning preferences and become better thinkers.

Most students think that learning selected terms, definitions and solutions to specific problems is the way to perform well in courses. Few of them realize that learning is a process, and that there are



Bloom's Taxonomy attempts to break down learning into its levels. In its older version from the 1950s *(top)*, the steps were labeled from rote-memorization knowledge at the bottom through to evaluation at learning's highest levels. Recently the taxonomy has been revised and verbs are used to describe the levels, with the top two steps being reversed *(bottom)*. Using a simple example of how the taxonomy can be applied to "Goldilocks and the Three Bears" *(white boxes)*, students are able to understand the distinction between the levels and how to apply the taxonomy to their own learning.

various stages of learning. Learning how to learn, through examples, is the key. In 1956 Benjamin Bloom and colleagues identified levels of learning proceeding from rote memorization through comprehension, application, analysis and synthesis, finally to evaluation. Recently, this taxonomy has been revised and verbs used to describe the levels. Additionally, the top two levels have been reversed. In the new taxonomy the levels proceed from remembering through understanding, applying, analyzing and evaluating to creating. *(See the figure on the previous page.)*

We have found that teaching students how to learn has transformed many of them from rote memorizers and regurgitators into independent, self-directed learners. Showing students how Bloom's Taxonomy is applied to "Goldilocks and the Three Bears" helps them understand the distinctions between the levels.

In addition to teaching students about Bloom's taxonomy, we have found that when students learn about metacognition (thinking about one's own thinking), they transform their attitudes about learning, their methods of study and their grades. Metacognition is a way of standing outside, of willed thinking about the acquisition of knowledge and understanding.

Is there a potential danger of talking too much about the metaworld, at the expense of applying what one has learned to the academic subject at hand? An introductory chemistry course is not a philosophy of education course. We may have another disagreement between the authors here. One of us (McGuire) can't get enough of metacognition because she has seen countless students improve their test scores from below 50 to over 90 in a matter of weeks, just by using metacognitive learning strategies, whereas the other one of us (Hoffmann) tires and wants to grapple with real teaching. We do agree that when students become fluent in the language of chemistry (or any subject) their metacognitive sophistication will increase to the level that they no longer have to consciously think about it.

Our third observation reflects on the relationship between teacher and learner. The feeling that the teacher knows much more than you—knows more ways to transform raw facts into understanding or how to actually make an object or molecule—can intimidate a learner. You might think, "How could I possibly learn to do that?" But when respect for a teacher's mastery accompanies a second feeling, that the teacher cares deeply about transferring understanding to you, a mysterious psychological force is turned on—the mentor/apprentice relationship.

There is nothing about this linkage specific to learning science—it is a constant of human society. The reason the relationship works so well as a learning/teaching strategy is, we believe, twofold: First there is a simple motivating force: The student admires the mentor (admiration does not exclude resentment of a perceived taskmaster) and wants to gain the mentor's ken.

Second, learning is not a process that insists on perfect understanding at every step. That's a caricature of mathematical proof. At its best, learning in science is a nonlinear sequence of observing facts then trying to explain them, and in the process gathering or being confronted with further facts and continuing to augment one's understanding.

In this sequence, confidence that the mentor has wisdom and tools to impart can make the learner accept facts on faith, secure in the psychological confidence that the mentor will explain, in time. To put it another way, the mentor/apprentice relationship can guide the learner through unavoidable boring or tough stages, toward mastery.

Enabling Learning and Teaching

We have called the teaching process magical and mystical; so is learning. People have taught and learned for tens of thousands of years; the biological roots of learning are older still. There is no one way to teach or learn, yet we think there are some identifiable underlying psychological principles that enable good learning:

1. **Empathy:** The teacher must care, and everyone knows it is difficult to do so when there are obstacles such as four classes to teach, inadequate pay, social problems and other distractions. But students have finely tuned emotional antennae that detect care, and a good number respond.

2. **Active learning:** Any teaching strategy that stimulates participatory activity on the part of the student will make learning so much easier.

3. **Judicious interplay of groups and individuals**: Learning is a solitary action, yet it can be enhanced by episodes of group activity. Such interplay is often observed in society, for example, in the way kids master any sport (dribbling practice in soccer, a team scrimmage) or learn music through taking part in a marching band. And the group interplay at a meeting of professionals from any discipline demonstrates learning at its best!

4. **Empowerment:** Students love to feel capable. We have seen countless students get hooked on studying and learning once they saw their abilities growing dramatically, through their own efforts.

We in academia expect students to acquire information, strategies and critical-thinking skills that allow them to learn from our teaching. There should be no less expectation that instructors think critically and seek out specific strategies to improve performance in the classroom or lecture hall.

The suggestions we present here are not prescriptive; we just want to share with you some of the strategies we have improvised and developed over the years to facilitate learning for, rather than to deliver instruction to, the students we have taught. We hope that you will find them to be useful tools in your own teaching and/or learning.

Acknowledgments

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