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In the Classroom

Structuring the Liberal (Arts) Education in Chemistry

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In principle, learning about learners allows faculty to create a structure in which novice learners may develop their skills more effectively.

Following the tenets of a re-integrative philosophical framework for curriculum design and educational objectives, we provide strategies that describe our effort to change the educational experience of beginning college students in introductory chemistry. We focus on the explicit connection between instructional goals and practices. For instructors and students, whom we view as collaborators in learning, we address how mental models for instruction and information can affect the classroom environment. We also describe a series of classroom, laboratory, and outside-of-class tasks that are intended to promote meaningful engagement by individual students within the context of these recommendations.

Re-integrative Philosophy and Objectives

We have previously described a re-integrative philosophical framework for curriculum design and educational objectives

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[1]. In the second part of this discussion, we will continue with some of the specific ideas that have been meaningful for both instructors and students in our undergraduate chemistry program. Overall, we have returned again and again to the theme of matching articulated instructional goals and objectives with the classroom practices used to accomplish them. The underlying challenge in this view is the interaction between the intellectual content (goals) of instruction and personal behavior (practices). That is, although we initially identified, articulated, and linked our general educational objectives with our syllabus of chemistry topics, we also recognized that this effort was primarily devoted to changes that affected the "first day of class" discussion in our courses. This is literally the beginning, not the end, of where thinking about instruction needs to occur. Starting on the second day of class and then throughout the term, a different challenge emerges: an instructor's need to fulfill the expectations set out on the first day of class, through guidance and by example. Changing or elaborating instructional objectives is not only the beginning, but it is arguably the easier of two difficult changes to make in the current cycle of educational reform, and a great deal of attention has been appropriately given to this aspect of curriculum development. Changes to personal practices or behaviors are more complex, for faculty and students alike. In this paper, we have framed our discussion in terms of recommendations for instructors (...and students) and students (...and instructors) in order to emphasize how important the effective communication of shared expectations between instructors and students has been in addressing our own instructional practices.

Progress in Practice: For Instructors (and Students)

A Diversity of Instructional Goals

We suggest that two tensions underlie the current climate in post-secondary education. First is the diversity of instructional objectives and needs. Institutions of higher education in the United States have had to evolve rapidly: in 1837, when the University of Michigan was established in Ann Arbor, there were two faculty members and five students. The fraction of students who pursued higher education was extremely small. Just over 150 years later, somewhere between 50-70% of eligible 18- to 21-year-olds attend college along with a large number of non-traditional students, making for the greatest heterogeneity of student perspectives and experiences ever. The needs brought by these students span from the *professional technical* (how to turn the key that starts the engine), to the *professional intellectual* (how ignitions and engines work), to the *general intellectual* (application of the design features and strategies to new problems).

Large classrooms of students in introductory courses, most of whom do not often intend to participate professionally in whatever the subject is, bring the greatest need for addressing more general objectives. These general objectives, however, cannot be delivered in the abstract, and are contextualized in the workings of the professional discipline. Some observable consequences of this tension include the conflict over covering content, a tendency to accuse a previous course of inadequately preparing students, and the deference to standardized examinations to direct curricular design.

The second tension is that instructional responsibilities have become unbalanced, emphasizing teaching over learning. Faculty, traditionally, have invested their effort on creating teaching tools (texts, manuals, and software, all of which can be gathered under the non-pejorative heading of “artifacts,” a term which is used by Perkins and others [2] to remind us that tools are intrinsically neutral and produce effects that depend on the user) and classroom strategies that only augment the faculty’s role as trainers. While instructors have assumed this greater teaching function, there has been a concurrent tendency (is it the cause or the effect?) to hear from students one version or another of “I didn’t learn it because you didn’t teach me,” or “I was not supposed to know that because you didn’t cover it.” We have attempted to give faculty and students the ideas with which to catalyze new discussions. One of these ideas has been to shift the perception of instruction as only a teaching activity to that of a learning experience for both faculty and students.

We view the process called “instruction” as a collaboration between mutually interested parties, each of whom have something to contribute to and something to learn from the effort. The defining value for students is to learn about learning, to transform themselves from individuals who need to be taught into intellectuals who are first learners, and then self-learners. Faculty are more expert learners whose understanding about how to learn the subject matter is what students need at least as much as they do the factual information. Every year, students bring their novice perspectives to their instructors. These provide new opportunities for instructors to examine how students learn to learn. In principle, learning about learners allows faculty to create a structure in which novice learners may develop their skills more effectively.

Many of the attendant dimensions of scientific practice (such as philosophy, history, linguistics, ethics, and so on) have been systematically dis-integrated from formal scientific education. We have identified three defining goals for a kind of re-integrative

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instruction that seeks to be more comprehensive in its scope [1, 3]. (1) Course content is used as a medium for students to develop more effective learning skills. If there are skills that can be best obtained through the study of chemistry (the particular fruit of one of Lavoisier's trees [4]), then the factual information, in addition to whatever cultural literacy value it has, is the vehicle by which those skills are developed. (2) The lens on the natural world that is "chemistry" is viewed as no more or less than one model of inquiry among many. Chemistry holds its unique place and uses its unique methods, but its ability to define intellectual pursuit is the same relationship that "oak" has to defining "tree". (3) Faculty need to articulate and understand the unifying instructional objectives, called the "metacurriculum," for students within the context of the specialized course and, more significantly, how these objectives are matched to the instructional and assessment methods used in the course.

Resolving the Conflict Over Content

These defining goals point to a common point of controversy: content versus process. Many faculty conclude that in order to devote precious class time to issues of process, then, by definition, students will end up "not knowing as much." This conclusion results from a mental model of the content–process relationship that is a *false dichotomy*. Content is not the opposite of process, and does not sit at the other end of a bipolar (dualistic) model. In an authentic bipolar model, simply not teaching the factual content of a subject would define teaching process. This is plainly wrong. Process is contextualized by the content—you cannot just teach "thinking" without also having something to think about! False dichotomies have often hindered progress in understanding parts of the world. For example, the dualistic male–female dichotomy gave rise to a more useful quadrapolar (or synergistic) model where maleness and femaleness are independent attributes, with masculinity, femininity, androgyny, and neutrality comprising the quadrants [5, 6]. We posit that the content–process debate is flawed because it represents another false dichotomy, and that content and process are independent attributes of intellectual development. A non-dualistic view creates four quadrants [3], one of which fits Wandersee's [7] notion of the "intellectual amnesiac" (Figure 1), a wonderful term that describes anyone who, having become a more experienced learner, then wander's into an unfamiliar content area. The process of analogical reasoning allows a student who has not seen every example, but who does have access to a critical subset, to make sense of many new and unfamiliar examples. We have evidence [8] that such students can deal with much greater amounts of content than those from content-obsessed instruction because they have an appropriate

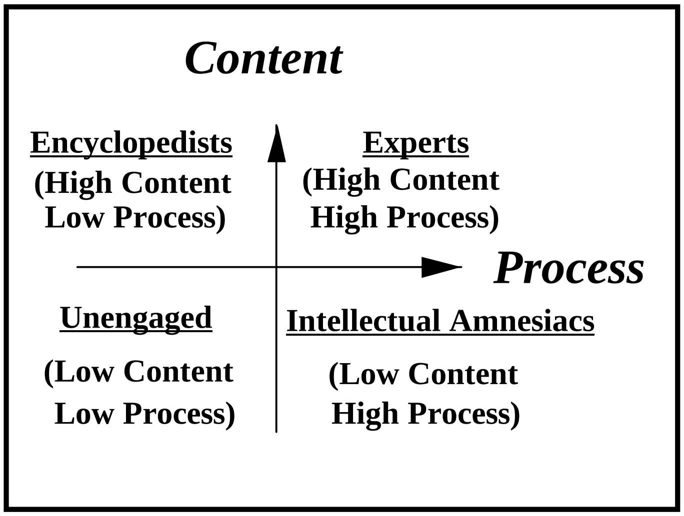

FIGURE 1. A SYNERGISTIC CONTENT-PROCESS MODEL.

framework in which to work. Instructors act on the reality of the zero-sum game implied by a dualistic content-process model: in a 40-hour semester, everything, from standardized examinations to the need to “cover” more pages in denser chapters of thicker textbooks. Operating within this structure, there is simply no time to include elaborate, time-consuming pedagogy that does not result in the transfer of factual information. Novak’s [9] pioneering work on explicitly addressing the “learning how to learn” question provides a compelling antecedent for our analysis of synergistic relationships in education derived from dualistic sources. Dawkins [10] provides a useful, complementary perspective in the relative allocation of resources (in this case: time) that, by analogy, also speaks to the resolution of the false content–process dichotomy. As practiced by faculty in their professional lives, content and process are synergistic in that the learning of one facilitates the learning of the other. When instructional goals require attention to the interaction between process skills and content, then achieving these goals is important, even at the expense of time taken from the content goal.

The debate surrounding collaborative and cooperative learning can also be resolved by looking at them as distinctive attributes for group inquiry. The level of the debate [11] is already at a point where collaborative issues (knowledge, organization, goal setting, and so on) are distinguished from cooperative strategies (group dynamics, selection, and organization), so we argue that it is only a short move to accept that collaboration and cooperation are not mutually exclusive alternatives in a dualistic system.

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Representing the Relationship Between Information and Meaning

One skill that defines expertise is the fluid movement between (surface) information and (deeper) meaning. Another attribute of the expert learner is persistence, which is a key concept in theories of human motivation [12, 13]. We concur with the idea that learners are always constructing their understanding by seeking and creating larger patterns (the "big picture") by grouping, ungrouping, and regrouping the interconnections between individual ideas. There is a great deal of intellectual risk, at the cost of ego, in backing away from a perceived or imagined pattern, even when all of the pieces do not quite fit. Or worse, students sometimes believe that they are simply incapable of seeing any pattern at all because of a fundamental inadequacy. A person might make the conscious decision not to invest the energy to persist, but that is a different situation. We have observed very capable students who seem to lack the awareness that they must actively move back and forth between the smaller and larger concepts, constantly checking and rechecking the internal consistency of the picture they are constructing. One of the important themes that appears in our instruction, then, is to provide the kind of language and examples that students can draw from in order to persist, even when the immediate feedback is discouraging. The typical advice that faculty give based on their own experiences is naive ("stick with it," "wrestle with the problems") and draws from their own (un)naturally high persistence as learners in chemistry. Individuals do not persist because of their satisfaction with the fight; individuals persist because of their ability to envision and believe in a goal that cannot yet been seen [14].

Describing the goals outlined above to a group of first-year college students is difficult to do in the abstract. These students lack the necessary experiences from which to create appropriate analogies when it comes to the level of intellectual effort to which we are alluding. Visual puzzles can serve as metaphors for the kind of persistent grouping and regrouping of data that are necessary for successful problem solving or analysis. We use a series of images (Figures 2-5), taken from the area of visual perception and cognition, to represent some of the more abstract instructional goals that we associate with our courses. It is mindful of the Gestalt notion of closure (that is, the human tendency to fill in gaps in order to construct understanding, analogous to our ability to perceive motion from 60 frame-per-second film [15, 16]) where we posit that the individual facts of an argument are represented by the isolated shapes of the closure examples. In order to see an animal represented by the shapes of Figure 2 [15], an observer needs to consider the relationships between the individual pieces of

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information in the context of prior knowledge and experience. Of course, Figure 2 is not a metaphor for a very sophisticated discipline, with its few, well-defined "facts" (shapes), but it gets the "big picture" idea across to students. We discuss the value of expressing viewpoint and shared assumptions by using Figure 3 [15]. Even though it is as unsophisticated as Figure 2, the implied message for Figure 3 is indecipherable until we, as instructors in this metaphorical discipline, share an important viewpoint in order to make our discussion of the subject matter (the spots) meaningful. Numerous alternative interpretations can be inferred, on the other hand, as viewers persist in their belief that there is actually something they will eventually be able to understand. Although the significance of this point can be made with any discipline's jargon, it is chemists, perhaps more than any other group, that base their intellectual work on a representational system (namely, molecular structure) that is meant to connote physical objects that cannot actually be seen. We are simply more comfortable with the notion that "H-O-H is water" than we are with "T-A-B-L-E is a table." Of course, we chemists understand that letters are used to represent atoms and that lines have been used to represent chemical affinity since before the discovery of electrons, but these are clearly learned associations and not at all imbedded in the use of letters and lines. Bransford and Stein [17] use textual passages to make this same point. In the case of Figure 3, knowing that it has been printed upside down is critical to understanding what was implied by its author. In chemistry classes, it is purposeful to write "HI" on the board and to explore the real distinctions between questions such as "What does HI mean?," "What could HI mean?," and "What could HI represent?." Inference and implication play significant roles in understanding all communication. The validity of "hydroiodic acid" relative to "a greeting" or "the middle of 'ship'" as responses to the HI questions depends not only on context, but also on the how well an ascribed meaning has been learned.

Figure 4 is usually the first figure we show an audience, with two objectives in mind. After collecting different interpretations of the shape in response to the question "What is this?," we describe the role of inference, representation, and the observer's prior knowledge in suggesting anything other than "projected blotch(es) of light." The importance of contextualization is illustrated after showing Figure 2 and asking an audience to suggest what is represented by the topmost fragment. A remarkably unanimous and loud reply of "a cat's head" contrast nicely with the debate and uncertainty surrounding Figure 4, even though Figure 4 is simply the "cat's head," isolated and rotated. Figure 5 [18] is a better metaphor for a sophisticated

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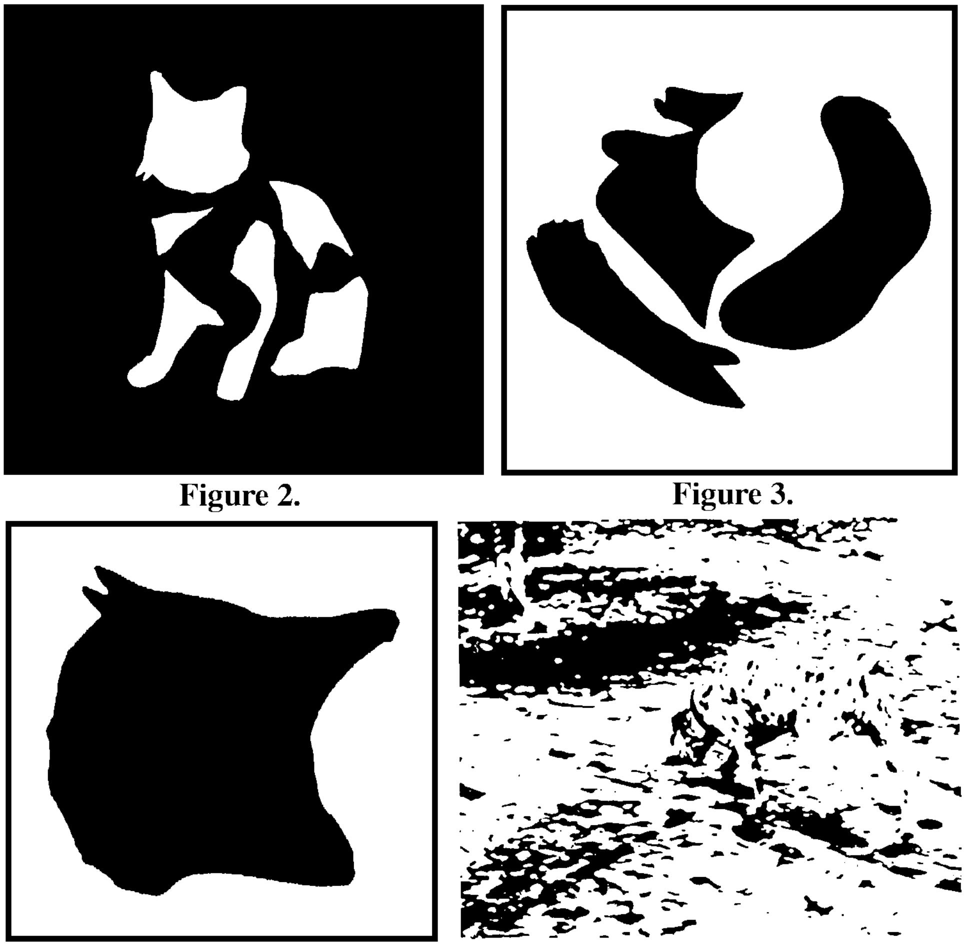

Figure 2. **Figure 3.**

Figure 4. **Figure 5.**

FIGURES 2-5. GESTALT IMAGES USED TO METAPHORICALY REPRESENT CONCEPTUAL DEVELOPMENT.

discipline. In most groups of 30 or more, 1 to 3 will immediately perceive the image originally captured by this high contrast photograph. Like the students in our classes who "connect" with us right away, any subsequent discussion of details will serve to reinforce the picture we now collectively share. By using Figure 5, we hope that the other students begin to understand why we are constantly returning to the "big picture" in class, since much of the well-intended discussion about the details will be lost without this shared understanding. Figure 5 has been especially effective with a faculty audience, especially when you congratulate the few who have seen the image and their neighbors whom they have instructed, and then whisk away the overhead while exhorting a need to get on to the next topic on the syllabus *because there are a lot of topics we are supposed to cover!* With students, we linger with Figure 5, informing our persistent observers that they have all the facts they need, and that for the most part they are

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engaged in grouping, ungrouping, and regrouping against their prior knowledge. A good fraction of them are helped by mentioning the Dalmatian dog in the center right-hand side. The lesson that sticks is simple: when you run into difficult or challenging material, add an alternative to throwing up your arms, resigned to your inability or the inadequacy of your situation; instead, consider that you need to change your viewpoint, to group things differently, perhaps to develop new strategies and alternative viewpoints. Every year, a subset of students connects with this pictorial metaphor for persistence. “I just haven’t seen the dog, yet” becomes the way these students describe their perspective on a difficult topic.

We use images like Figures 2–5, then, as powerful pictorial metaphors for the notion that literal, surface representations do not carry intrinsic meaning with them. We have been able to mine a number of rich lessons from these images, including (a) systems of representation (Figure 2 is not a cat, it is a set of ink splotches that represent a cat), (b) the role of context, (c) the big picture perceived by teachers as they begin their lessons and the instructional objective, as well as the factual content that constructs the picture, (d) the role of persistence (“I haven’t seen the big picture, yet, but I am still looking” versus “I can’t do chemistry”), and (e) the idea that understanding a more abstract image (such as Figure 2 or “H_2O”, which is no more water than W-A-T-E-R) probably requires less of a Gestalt “closure” compared with a more sophisticated or photographic one (such as Figure 5 or perhaps a two-dimensional projection of a calculated three dimensional molecular model for water), which relies on a greater depth of experience and background to more completely decode. Just because a greater meaning can be attached to a particular representation or model does not mean it is the one that will be most accessible by a new learner. As we say in chemistry: don’t confuse thermodynamics (the “deeper” well) and kinetics (the more accessible place).

Progress in Practice: For Students (and Instructors)

Teaching is an Implicit Part of Learning and also in all Other Forms of Expression

For all that has been written and said about examination methods, we think it is useful for instructors to realize that we ask our students to teach us on our exams. In all cases, whether an exam is in written or oral format, an instructor takes on the student role as questioner and learner, while the student is the one who provides answers. Yet honest opportunities for students to build the skills for this role-reversal are not provided except at the exams themselves, and faculty tend to adopt the role of arbiters who judge

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rightness and wrongness. By pointing out to students that during examinations they are assuming the teacher's role, it allows them to confront the need to learn how to express their understanding before the inevitable examination. In order to emphasize the role that teaching, as well as preparing to teach, can have in the learning process, we have actively promoted ways for students to practice their teaching skills before the examination. Another aspect to effective teaching is to look at a student's work in greater depth than simply making an inventory of "correct" and "incorrect." An effective teacher can look at a student's work from the student's perspective as well as his or her own, thereby using an expert perspective to analyze the kinds of assumptions that could lead to the observed errors. The intellectual challenge that arises from this viewpoint is thinking about how to reconcile inconsistencies between student and teacher perspectives, and also how to construct a bridge between them that requires effort from both directions.

Our colleagues in disciplines that more openly acknowledge their reliance on developing skills for expression (literature, art, dance, theater) all rely on the performance studio in their instructional design. The studio is a place where the desired skills can be displayed to a peer group of learners, usually under the guidance of a more experienced individual who critiques as well as organizes peer review, and generally after some amount of solitary preparation has occurred outside of the studio (wrote a story, filled a canvas, or learned the lines). A great deal of high-value learning takes place in the studio because every participant has done something about a common task (write a story, fill a canvas) that carries the results of their individual efforts. Where is the comparable "performance studio" for chemistry learners? Laboratories should fulfill this role, but there are many reasons why this is not true in practice. In any event, regardless of the design of laboratory courses, skill-building with those activities would be too far from the expected mode of expression on an examination. In Progress in Practice 1 we describe a performance studio option for introductory science students that draws from the principles outlined above.

Progress in Practice 1: Structured Study Groups

In our structured study group program, a cohort of 120 First-Year Honors students participate within their 1200-student course for their standard coursework and examinations, earning their Honors credit by participating in extra weekly 2-hour sessions that are shaped, metaphorically, along the lines of a "performance studio" in

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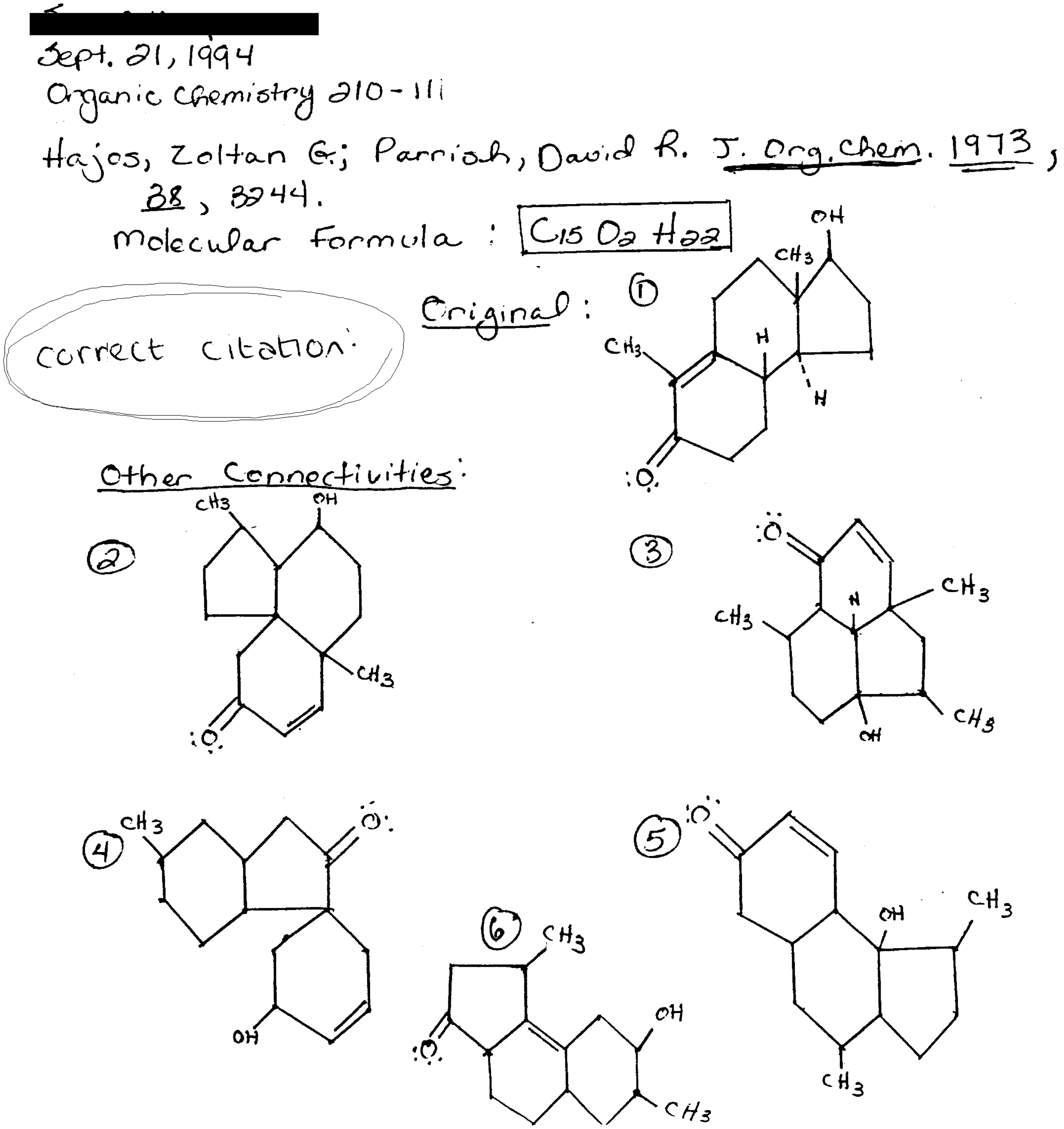
the Arts. Assignments, in the form of common (not identical!) tasks, are subjected to peer presentation and peer critique facilitated by upper-level undergraduate leaders. Unlike simply directing students to work in groups or only providing them with problem sets, both of which are productive and engaging [19], students in the structured study groups follow a detailed curriculum that helps them to develop the kind of skills that we believe are attached to a deep mastery of the subject matter in a format that encourages the students to also develop their more general learning skills.

During each session, the meeting time is typically divided between a number of activities. Each participant brings a duplicate set of his or her written assignment from the previous week. These assignments generally involve the creation of examples within a given context. In the very first assignment, they pick a C_{10}–C_{13} molecule from a chemistry journal (after learning, in their session, how to decode line formulas, what journals are, where they are found, and what proper citation format looks like) and are directed to construct five rational examples of molecules with the same formula. They then propose rankings for their created molecules based on three of six properties, including, for example, magnitude of dipole moment, boiling point, and solubility. Later, a typical assignment might be to find an example of an SN_2 reaction in a chemistry journal and format it as a quiz problem appropriate to the level of the class. The students are always directed to provide a brief statement that puts the reaction in context, a copy of the journal pages from which the example is derived, and a properly formatted citation. At the beginning of the session, the students submit one copy of their work to their leader, and the other copies are redistributed to the class. One or two rounds of peer review follow. The reviewer does not correct the other student’s paper, but rather answers a set of factual questions about the others’ work: does the molecule or reaction fit the prescribed criteria (yes or no?); is the format and information appropriate to the level of the class (yes or no?); is the citation formatted correctly (yes or no?). During this time, the discussion within the group is free-wheeling, and it is the time of greatest learning for the students. Although the only duty is to mark off a “yes” or “no,” the first round of peer review can take up to an hour. Only when faced with reviewing another’s work can the student deal with issues that were either incorrectly understood or that simply did not occur to them. These students have a structured opportunity to make, recognize, and correct their errors before they get to an examination. After the reviewing is completed, the reviews and the unmarked papers are returned to the originator, and he or she has a chance to decide if any corrections are needed. This second set of assignments and the reviews are collected, and they form part of the basis for the leader's evaluation of the student's performance that day. Strands of advanced topics also comprise part of the class period. For example, in the first term, part of four or five class periods are devoted to discussion and in-class exercises involving Frontier Molecular Orbital theory. In the second term, spectroscopy, bioorganic chemistry, and more FMO-related work (electrocyclic, sigmatropic and cycloaddition chemistry) are alternatively introduced over the course of the meetings. Finally, the next week's assignment is presented, along with any supporting discussion, examples, or software (ChemDraw, Chem3D, and CAChe) training needed to clarify the expectations. We also use a scanner-computer-projection system in class so that a student's hand-drawn or on-disk answers can be used as the basis of a group discussion, if it is appropriate. Figure 6 is an example of a student's first assignment, and Figure 7 is an example from the second term of the year-long "Structure and Reactivity" course. Each of the two terms of the course in which structured study groups are used has ended the semester with a project that lasted a few weeks. In the first term course, the students receive copies of two to three journal articles, usually short communications, in which chemistry appropriate to the experience of the students can be found. The author of the articles has been one of the faculty in our department, although in principle it could also be an upcoming seminar speaker. For three weeks, along with their last sets of assignments, the students create and edit a set of questions that might be asked of the author. From each student's contribution of three questions per article, the group selects and refines three questions from their entire section. During the last week of classes, the entire group of study-group students meet with the author who then fields the questions asked by student representatives. We have once again taken a page from our colleagues in English, for example, who routinely arrange meetings between students and the author of a piece that the class has been studying. To end the second semester course, the students spend the last three weeks creating, refining, and peer editing their own case studies in scientific and professional ethics (analyzing ethics cases is one of the tasks in both terms).

The Honors students are graded for their participation in the weekly groups within the context of the larger 1200 student course. Every week during the term, the seven group leaders and a faculty member meet to discuss the upcoming and previous assignments, the grading criteria, and the classroom challenges faced by the leaders themselves. The leaders are then responsible for assigning to their students' performance a grade based on a U (unsatisfactory) - S (satisfactory) - O (outstanding) scale. In electing to participate in the Honors groups, students agreed to have their course grades based on a



[redacted]

Sept. 21, 1994
Organic Chemistry 210-111

Hajos, Zoltan G.; Parrish, David R. J. Org. Chem. 1973, 38, 3244.

Molecular Formula : $\boxed{C_{15} O_2 H_{22}}$

correct citation:

Original: ①

Other Connectivities:

② ③ ④ ⑤ ⑥

FIGURE 6. A REPRESENTATIVE STUDY GROUP ASSIGNMENT FROM THE FIRST TERM COURSE

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[redacted]

Section 213
Chem 215H
Winter Term 1993

Topic Enol/Enolate Substitution

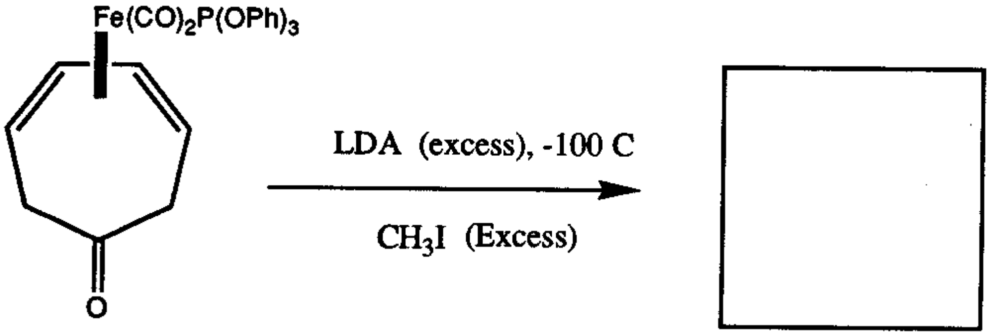
I. Reference

Pearson, A. J.; Chang K. *J. Org. Chem.* **1993**, *58*, 1228-1237.

II. Context

Methodology for the stereocontrolled functionalization of cycloheptadiene via sequesntial nucleophile additions to a cycloheptadieneiron complex and a derived alkyl-substituted dienyl complex has been developed. The following reaction is only one reaction in a sequence.

III. Problem and Solution



What product is obtained in this substitution reaction?

Solution:

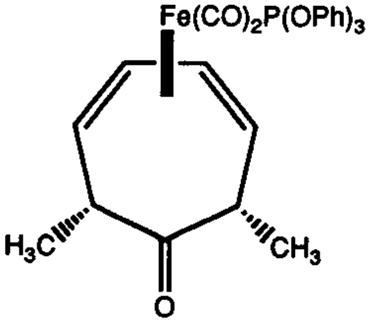


FIGURE 7. A REPRESENTATIVE STUDY GROUP ASSIGNMENT FROM THE SECOND TERM COURSE.

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two-part scheme. First, the entire class of Honors and non-Honors students have their grades determined as usual, based on their four examinations. In order for an Honors student to maintain this grade with an "H" designation, he or she needs to have achieved an "S" average or greater from their group leader, with an "O" counterbalancing a "U." A less than "S" average results in a proportional reduction of the student's grade, with an all "U" average reduces the student's course point total by 10% along with whatever grade change might accompany that reduction.

The educational experience for the seven undergraduate group leaders has been profound. They also, in effect, participate in an informal course in classroom practice and pedagogy every week during their regular leaders' meeting. The level of engagement and excitement that has been generated in this group of students, who are themselves in the process of making career decisions about graduate and professional schools, is quite extraordinary, and may be one of the most important outcomes of this process. Instructors at any level of experience will appreciate the most common reaction of our leaders during the first few weeks: "Boy, this is really hard!" About half-way through the term, the group leaders also developed the ethic of what they called "active non-participation." Their comments revealed that the teaching abilities of these student leaders evolved rapidly: moving the center of classroom activity from themselves, "teaching to" their students, to becoming authentic discussion facilitators in a group classroom. In large part, the tasks and the structure of the peer-evaluation component encouraged the leaders to shift into a more collaborative learning mode. Walters, and others, have reported similar outcomes for student leaders who assume authentic roles in the design and delivery of instruction to beginning students [20].

Finally, students in the course participate in an "ice-breaker" activity during their first group meeting that allows each of them to experience why we want them to think carefully about the teaching and expression aspect of learning. The class is divided into two groups. One half of the class simply observes the activity of the others (before reversing roles, later). The other half divides into pairs of students who sit back-to-back. Each of the paired-off students receives 10 wooden match sticks. One of the students in the pair is the "teacher", and creates a figure on the tabletop with the match sticks (only horizontal or vertical placement, touching at least one other match at only one of its two ends). After creating the 10-match stick array, the "teacher" must provide verbal instructions to his or her "student" (the other partner in the pair) without any feedback from the student and without looking at what the student is constructing. A

You have assigned a student the task of creating some multiplication problems, and these examples are presented:

2 x 2 = 4 -1 x 0.5 = -0.5 1.1 x 11 = 12.1

3.5 x 1.4 = 4.9 2 x 4 = 6 -3 x 0.75 = -2.25

What advice do you give?

FIGURE 8. AN EXERCISE FOR DEMONSTRATING THE IMPORTANCE OF ADOPTING THE LEARNER'S PERSPECTIVE.

direction can be asked to be repeated by the student, however. Naturally, we use this same activity during our initial training session with the leaders. The exercise is extraordinarily good in its effect. Meaningful post-activity discussions involve issues like sharing underlying assumptions (what does "up" mean, the fact that the match sticks have heads and tails), sharing the big picture and internal references (most "teachers" will have their "students" attempt to re-create the array, match by match, in the same order that it was built, and without any organizing statement like the fact that a 4x2 rectangle has been constructed). The paired students exchange roles for the second round, and the observing students take their turns after that. The distinction between "teaching" strategies and "learning" strategies becomes blurred, if not imaginary.

"Teaching with Trust" Means Respecting a Student's Point-of-View

When training undergraduate study group leaders or our teaching assistants, we have emphasized the idea that finding ways to help students understand the basis of their errors is more helpful than simply deciding on how incorrect they are. By trusting that students tend to use a set of internally consistent rules with which to make decisions, an instructor can take on the student's perspective and analyze the pathway that led to a given set of correct and incorrect answers. After one of our students gave an interesting

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series of Brønsted acids upon being prompted to list proton donors (she suggested HCl, then HI, then NaOH...), we were inspired to explicitly shift our perspective to the student's point-of-view when analyzing similar student responses. We use the multiplication problem exercise in Figure 8 as part of various training sessions.

These examples demonstrate the importance of trusting that students tend to be internally consistent in their use of strategies, and that even incorrect strategies can

produce he same answers as correct ones some of the time.[1] We now routinely recommend that the best use that a student can make of faculty time is to present their instructors with copies of written examples or discussion <u>created</u> by the students without using other reference materials. Because of the multiplication problem example, our students appreciate how their expertise in multiplication allows them to rapidly evaluate the creations of someone learning to do multiplication. By analogy, our students begin to see how faculty with expertise in chemistry can rapidly evaluate a page full of examples even though they are being seen for the first time. In Progress

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[1] The student who produced this list proton donors (HCl, HI, & NaOH), when prompted to identify the proton, pointed to the H in HCl, the H in HI, and the Na in NaOH. The student explained that "proton" referred to the positively charged partner in a substance. This example inspired us to re-think evaluating lists of student-generated examples from sorting out the incorrect from the correct, according to our rules, to gaining insight by trying to infer the set of rules being used by the student which, when applied consistently, would give the presented list. The more examples that appear on a student's list, the better chance to see the rules being used by the student. Without the NaOH example, we might have been inclined to attribute the suggestions of HCl and HI to knowing what proton donors were just because they appear on our personal lists, also. Instead, none of the examples were truly "correct", given the process by which they were suggested; instead, the same representations (HCl and HI) happen appear on two lists: proton donors as defined by chemists and the misunderstanding that the word proton is a synonym for positive.

Like the example of acids, the lesson from the multiplication problems example points to why just checking for right and wrong answers may not be much help for revealing student's misunderstandings. In the list of student-generated multiplication problems, the most common advice given revolves around identifying the single incorrect example ("2 x 4 = 6") and reinforcing the notion that 5 out of 6 were correct. This could be the worst advice to give. This student may not understand multiplication at all, but has instead generated 6 examples that correctly apply the rules of addition. To suggest that one of them is wrong could add even more confusion to this student's actual misunderstanding. The leading question we have learned to ask ourselves, then, is whether there are conditions or assumptions under which a list of student-generated examples might be consistent.

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in Practice 2, we describe some other classroom strategies for facilitating communication between faculty and students.

Progress in Practice 2: Levels of Socratic Instruction

We are not willing to dismantle the college lecture classroom because it is possible to choose to use the venue ineffectively. Chemistry faculty are the most experienced learners of chemistry, and they should draw on their experience and imagination to tie what needs to be learned in chemistry together with what are the many different strategies to approach learning and how to choose between learning options. Reflective practitioners [21, 22] can successfully step outside the simple presentation of factual material to provide a more “behind the scenes” interpretation of what appears in a text, at a demonstration, or on chalkboard and computer screens.

At the core of bringing together instructors and students are two overriding questions that drive all classroom activities: Am I being understood? and How do I know? In any conversation, we use many interactive cues to decide if our message is comprehensible. There are many different levels of Socratic instruction that can be used in classrooms to gauge the level of student understanding. For example, when our chemistry students are learning how to integrate the details of a topic such as “acylation reactions” with their other knowledge, we suggest that they start with a blank sheet of paper and create new examples of what they think are acylation reactions, using words and pictures. Then, after they have examined their work to the best of their ability, they can present these artifacts of their knowledge to their instructors or their peers for evaluation. Modifications of this technique work as well during a lecture period whether a classroom has 30 or 300 students in it. After creating five examples, pairs or trios of students can take a few minutes to select what appears to be the best example from their collection. Some of these can be gathered by the lecturer and used as the basis for subsequent discussion. On another day, the papers might be collected and some of the suggested examples reformatted and returned as a worksheet for the class to determine which are and which are not appropriate examples. Alternatively, and with patience, practice and the right examples, a “conversation” can be held with a group of 300: students can learn how to think while sitting in a lecture auditorium and also learn how to reply to (non-rhetorical) questioning.

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Students who reply in Socratic situations also want to know: Am I being understood? The challenge for a faculty member is to accept and then rapidly understand what point-of-view is needed to produce "wrong" (better: unexpected) answers. This allows an instructor to address the underlying process that generated the unexpected answer in the first place rather than to simply dismiss it (and the individual who suggested it). The same principles of listening to what others say and working to understand the unstated applies to students, too, both in their interactions with faculty and with other students. In collaborative communities, the distinction between who is the "teacher" and who is the "learner" becomes blurred, if not imaginary.

Conceptual Understanding Improves Through Editing, a Critical Analysis Tool

Proofreading, editing, and critique, which are the natural assessment tools used not only in the humanities but are also *de rigueur* in science for professional journal articles, grant applications, and any other writing, can be applied equally well in introductory science instruction. When learning anything new, it seems to us that we rely heavily on sources other than ourselves ("external editors") to assess our understanding as we develop our self-assessment skills (our "internal editors"). Although we intend for students to have developed their internal skills by the time they take our examinations, we traditionally provide little assistance or rationale for them to get to that point. This is in part because we have developed and deploy our own professional skills so tacitly: to a degree, individuals who become faculty members probably follow paths of least resistance, the ones along which they were successful by virtue of their "natural aptitude." Our best advice to students can be wholly inadequate if we only reflect on the surface aspects of what we did as students: "do lots of problems," "write lots of prose," "sit alone and wrestle with the ideas." One of the things we do quite naturally in our professional lives is to rely on external input. Having developed any idea to whatever limit we are able to achieve sitting alone in our workplaces with our internal editors and our reference sources, the next thing we do is to try out the ideas on our colleagues. Expressing our understanding to others is always a teaching activity since we are revealing our interpretation of some aspect of the world to another individual, testing the interpretation against another's point-of-view. In our experience, we find we actually think about our ideas in new ways when we are consciously aware of the fact that we need to describe them to someone else. Learners learn differently, we think more effectively, when they anticipate the need to express their understanding to someone else. The most common example of this is preparation for an examination. Perhaps this falls under anticipatory scenario building which,

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according to at least one theory of evolutionary biology, is a generally advantageous trait [23, 24]. This perspective is not at all limited to expository writing and speaking, the usual modes of expression in the physical sciences; revealing internal perspectives represents "expression" regardless of its modality, and does not favor writers and orators over thespians, pianists, painters, ballerinas, or chanteurs.

The Evolution of Performance

Philosophically, we find Dawkins' notion of "memes" quite compelling from the standpoint of education [10, 25, 26]. As a unit of cultural information, a meme sits at the analogical level of a gene. In our view, the term memetics, which has been recently coined [27, 28], points to underlying processes by which cultural information is transferred, including information such as the "culture" of chemistry or the process of its intellectual pursuit. Formal education, as a constructed tool, is an activity in memetic engineering. Like genetic engineering, memetic engineering is a product of human design and invention that results from an understanding of a natural process: learning, in this case. Although desirable, premeditated outcomes are the objectives from these interventions, unforeseen or undesirable ones can also result. In its fundamental metaphors [29], the rhetoric of genetic transfer (transcription, translation, expression) has already borrowed from memetic transfer![2] We see this view as the closing of a circle, where the cultural world is reintroduced to the physical world [30]. Inasmuch as we recognize the indispensable role that *transcription* plays in education, we readily acknowledge its limited utility in the development of critical skills. Constructivism [31, 32, 33, 34] is a useful contemporary concept for how we come to understand the natural world that is best represented by blending classical Aristotelian empiricism [35] with Heisenberg's uncertainty [36]. At its core, constructivism relies strongly on the notion that learners *translate* their current understanding in the context of their prior experience when they need to integrate new information. Ultimately, as we have stated, it is the *expression* of one's understanding that is perceived by the

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[2] While preparing this manuscript, we stumbled into a surprisingly appropriate case of cultural isolationism. After many inquiries to biochemists and evolutionary biologists failed to uncover information about the origins of these terms, including requests to well-known Stanford "story-tellers" Arthur Kornberg and Paul Berg, we contacted both Francis Crick (Salk Institute) and James Watson (Wood's Hole). Crick wrote that he had "a faint (probably inaccurate) recollection that the terms were invented by Sol Spiegelman. Try asking Ben Hall, if he's still alive." Watson did not know, either. Berg wrote that "It seems to me that the terms...were always there..." As of this writing, our inquiry continues.

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learner. What we expect from a virtuoso pianist is an expression of mood or emotion that this maestro has translated from a transcript of lines, bars, note symbols and clef marks. We would be surprised, disappointed, and uneducated if this pianist were to simply hold the sheet music out to the audience and exclaim, “Isn’t that just beautiful!” The less experienced we are with interpretation, the more appreciative we are when an artist steps outside of a performance and draws our attention to meanings that might escape our more naive perception. The processes that underlie preparing for a successful act of expression (“teaching,” where learners understand and develop their own abilities to express), not only rely on transcription and translation skills, but also the relationship between knowledge of the subject matter and its connection to how its understanding can be expressed; that is, a performance resulting in memetic transfer.

Pedagogical Content Knowledge: Matching Instructional Practice with Philosophical Goals

The last lesson we would like to describe from our experiences is the value that comes from consciously and explicitly linking what we know about chemistry with what we do in the classroom. Although it is possible to simply adopt someone else’s course design or examination practice, the fundamental inconsistencies that arise when philosophy and practice are in conflict result in a kind of cognitive dissonance that characterizes many modern classrooms. To date, the culture of post-secondary reform has appropriately focused on creating the artifacts (as defined earlier, such as books, multimedia tools, and lab manuals) with an implicit assumption that instructors would know how to use them as they were intended. Simultaneously, the growth in the science education research community at the post-secondary level has introduced a lexicon of new terms and ideas that span from methodologies to higher order objectives, many of which have been honestly and sincerely embraced (fostering critical thinking and problem-solving skills, promoting scientific literacy, using cooperative learning, and so on). Introducing the rhetoric of lofty goals and promised outcomes is common fare in many courses as the “first day of class” pep talk. These “Day 1” changes are adopted relatively easily by faculty since they are primarily intellectual changes. Unfortunately, and commonly, little that occurs on Day 2 through Day 40 (the length of a typical semester) comes close to addressing these higher order objectives. Why is this connection so difficult to achieve? Perhaps it is because modifying classroom practices on “Day 2-to-40”, a term we have coined to focus on this notion, falls under the complex psychology of personal behavioral changes; without these changes, reform becomes old wine in a new bottle, and quickly

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degenerates to the point where the promised connections are completely opaque. These connections are critical to instruction that seeks to be inclusive of both higher order skills and their effective expression to the broadest audience. As experts in their discipline, chemists possess mastery of their subject (content knowledge). However, knowing how to blend knowledge of the content of a course with higher order pedagogical objectives goes beyond only the mastery of the subject matter. It also includes insights on how learning the subject matter fosters a given critical skill and which of many examples or strategies are best suited to develop such skills in a given student population. This additional ability of instructors is called pedagogical content knowledge [37, 38].

We have been working to convincingly link the day-to-day activities and lessons in our courses with higher order objectives, in explicit discussions and in demonstrated practice. Dissonance should result in a course where the instructional goals held by faculty and students are in conflict. In a series of interviews, faculty from a traditional introductory chemistry course were asked to identify their instructional goals [39]. In every case, the replies were one version or another of “subject matter mastery”. The articulated goals from faculty included: *“Balance equations, redox chemistry, periodicity, special lectures on environmental and materials chemistry, polymers, problem-solving, doing calculations, atomic structure, do demonstrations to bring ideas together, mixing “spit back” questions with ones that ask students to “synthesize.”* Students in this same course, after it was completed, were also queried about their goals. Interestingly, none of these students tied “getting a good grade” to any other, more general skills: *“I didn’t have any goal, but I wanted an ‘A’.” I got an ‘A’ by memorizing equations and doing exam problems that were exactly like the problems I had seen on previous tests...I don’t know what goals my instructor had...as far as I am concerned I did not need to go to class.”*

We proposed to resolve these conflicts by bringing “cognitive process instruction” to the core, that is, teaching in a way that accounts for how students learn [40]. Learning skills and strategies become common outcomes for faculty and students who are engaged in the collaborative process of learning about learning the subject matter. Faculty in the new program were also interviewed. From the faculty*: “Get to do things for themselves, becoming comfortable with uncomfortable ideas, independent learners, understand how scientists think by using our particular discipline, apply concepts to novel situations and feel comfortable, making connections about what and how very*

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explicit, opening a new intellectual horizon." And from the students: *"To get an 'A' and along with that comes an understanding of what's going on. I equate good grades with understanding, that idea's been drilled into my head."* The structure of our examinations plays a large role in our ability to make these links clear. Almost exclusively, we draw new and different examples of the chemistry under study (content) from recent professional journals. We ask students to encounter this unfamiliar information and to construct understanding from it in much the same way that we do [41]. In Progress in Practice 3, we describe our examinations in more detail, while in Progress in Practice 4, we turn to issues relating to laboratory instruction.

Progress in Practice 3: Case Study Examinations

Classroom rhetoric and instructional strategies aside, examinations, probably more than anything else, transmit the actual learning agenda to students. Tobias refers to this attribute of examinations as the "latent curriculum" [41]. If examinations do not consistently and exclusively reflect the intended goals, then any reform efforts are ultimately ignored by the learners for whom they are intended. If we survey standard first-year chemistry texts used in the introductory course called General Chemistry, we find little to no variation, and reports from the General Chemistry Task Force itself describe a course that has replaced a great deal of authentic "chemistry" content in favor of recognizing and applying the appropriate algebraic algorithm to some subset of general chemistry word problems. In our courses we have tried to ensure that explicit instructional goals and examinations were inextricably linked.

In order to achieve our goals in the *Structure and Reactivity* course, we recognized that organic chemistry was structured in such a way that state-of-the-art information, derived from the primary literature, could be presented to novice students on their examinations. This strategy assures us that we are being honest to the actual facts of science and that we are not simply inventing trivial derivatives of our classroom examples. We include the citation along with some contextualizing statements, which sends two messages to our students: (1) just memorizing all of the previous examples is not enough, and (2) understanding the subject matter of the introductory course allows you to understand some of what chemists actually say about the things they study. The context of these problems carry a great deal of intrinsic interest, or relevancy, because many of the examples come from the areas of medicinal and pharmaceutical chemistry or materials science. In a sense, the examination questions we use are like short case studies that can be explored by 1200 introductory chemistry students. Figure 9 is an example of a typical examination question from the middle of the first term course.

We also reinforce the idea of multiple representations for the same phenomenon. A student might be asked to provide words, pictures and numerical versions of the same idea. There are many times when there are four, five, or more correct solutions within the context of the course and the information provided in question. On nearly every exam, students suggest completely reasonable alternative solutions that we did not anticipate. These are also important lessons to make note of in class.

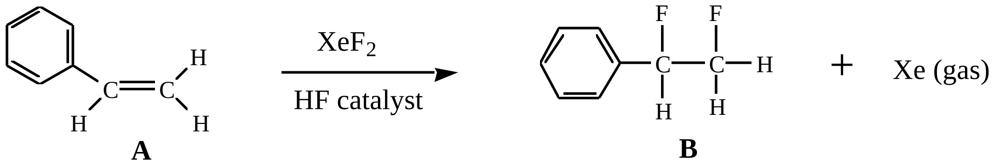
Two principles that seem to be overlooked in beginning courses have influenced our approach to undergraduate education, and these appear in the context of the examinations: to be as utterly honest as possible about the origins, operations, and limitations of science as one of many human endeavors, and to consistently and explicitly provide the underlying assumptions, connections, and implications contained in the representations used to describe the aspect of the natural world known as chemistry. Nelson [42] describes these two lessons as a willingness to give students the rules of the game so that they can play too. These are not the usual lessons of introductory chemistry instruction, however, where “content obsession” [43] is nowhere more strongly perceived than in traditional sophomore organic chemistry courses.

Finally, because students develop their new skills at different rates, and because the course is truly cumulative each step along the way, we have devised ways to make improvement count. One simple but effective technique is increasing the point value of exams throughout the term without increasing the length of the exam. It is “worth” more to do better later, so you do not have to be perfect at the outset and practice has tangible value. We also make judgments about improvement by considering the set of exams and the final as two independent measures of cumulative performance.

Progress in Practice 4: Collaborative Laboratory Tasks that Promote Cooperation

By the beginning of the twentieth century, laboratory instruction had become an integral part of undergraduate science training. For many years, laboratory courses fulfilled a crucial role in the vocational training of future scientists. Today, large

The details of the mechanism for the following reaction were recently reported (*J. Org. Chem.* **1994**, *59*, 589).



a) What is the IUPAC name for the product, **B**?

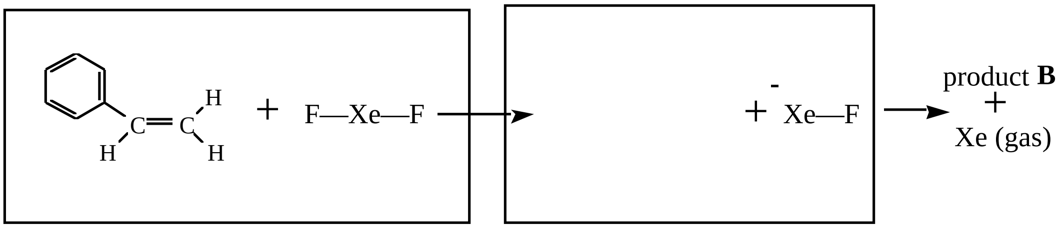
The electrophilic addition mechanism is proposed to operate here. The direct fluorination of the double bond to give a carbocation is the first step of the 2-step mechanism.

b) In the box below, use the curved arrow notation to represent the first step of the mechanism.

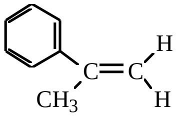
(Don't overlook the hint provided by the structure in the second box!)

c) In the second box, draw <u>two</u> things: (1) draw the expected intermediate and (2) draw the mechanism of the intermediate's subsequent reaction with fluoride ion to give **B**.

(NOTE: $\overset{-}{Xe}$*—F → Xe+*F^- *so assume* F^- *is present)*



d) Consider the molecule **C**:



The rate of fluorination of **C** is 4 times faster than **A**. Provide a brief explanation for this that is related to the structural difference between **C** and **A**.

e) Assume that the relative energies of **C** and **A** are equal. Complete the energy diagram to show the difference in rate described in part (d). You should only show the parts of the graphs necessary to illustrate the formation and relative energies of the reactive intermediate produced from each of the two starting materials.

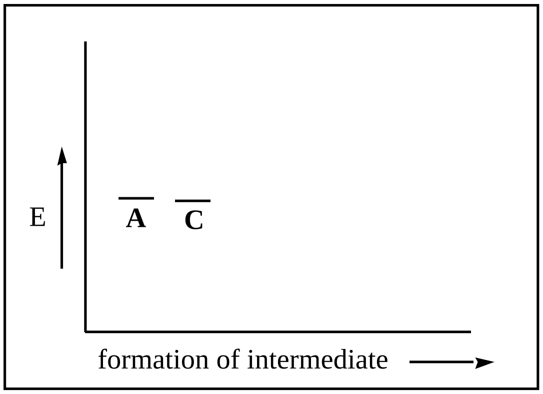


FIGURE 9. A SAMPLE EXAMINATION QUESTION FROM THE FIRST-TERM *STRUCTURE AND REACTIVITY* COURSE. THE FINAL AS TWO INDEPENDENT MEASURES OF CUMULATIVE PERFORMANCE.

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numbers of students take these courses, many of whom will never actually do laboratory work in their careers. Yet, in our interviews about the goals for their laboratory courses, faculty in traditional programs most frequently cited the development of manipulative skills for laboratory procedures as a primary course objective. These goals are reflected strongly in course designs that emphasize professional standards as a basis for assessment (amount and purity of a substance in a chemistry lab) without the opportunity for repetitive practice from which expertise develops. For the last 30 years, the discourse on (manipulative and procedural skills) versus discovery (process skills) has been dominated by yet another false dichotomy: cookbook (manipulative and procedural skills) versus discovery (process skills). "Cookbook" and "Discovery" can be better understood as related attributes of expertise on the axes of Figure 1: in order to make discoveries, but not to reinvent the wheel, we all rely on how existing information and procedures can be used either directly or from which to create analogies. Once again, we sought to reintegrate these attributes in our instructional design by addressing higher order objectives in the context of the coursework.

Whether by consulting a reference text or using our recall of physical, chemical, and spectroscopic properties, we compare the data we collect in lab with some set of standards in order to answer the question "What is this?" As chemists, we consider *What is this?*, along with *How much is there?*, *Where might it come from and where might it go?*, and *How fast and by what pathway?* to be the defining questions that chemistry answers (and asks!) about the material world. Rather than provide inexperienced students with an explicit algorithm for making an absolute identification of a substance, we have taken the core of this activity and created a problem in relative identification that is at once a simple, honest inquiry and a vehicle for developing technical and communication skills. The question we pose is authentic, and we have structured the task to make the answer accessible: *Who has the same thing as I do?* On the second week of college, students in each section of a 22-student *Structure and Reactivity* laboratory course are presented with a box of 30 vials, numbered in sequence, that all contain a few grams of a finely powdered white solid. In addition to referencing parts of a techniques manual where melting points, solubility tests, thin layer chromatography, and infrared spectroscopy are discussed, students are provided with very little except a discussion about the idea of identification [44].

> Most scientists collaborate and cooperate with each other in making scientific discoveries. Modern science involves a lot of team work. Many times, also, the

> same discovery is made at the same time by different scientists in different parts of the world. They then have to exchange data and samples of chemicals or biological specimens to prove that they are indeed dealing with the same substances.
>
> In this experiment you will be attempting to solve a puzzle together with your classmates while you learn basic techniques used for the analysis and identification of organic compounds, as well as getting to know your classmates. We hope that this will be the beginning of a habit of working together in learning your lecture material as well as in the laboratory.
>
> The puzzle is simple. Chemists define substances on the basis of an accumulation of observable properties. For example, when we say “water,” we mean “that clear, colorless, odorless liquid with a boiling point of 100 °C, freezing point of 0 °C, a density of 1 g/mL that dissolves substances like salt, that upon electrolysis gives a mixture of hydrogen and oxygen gases in a definite ratio...and so forth. Using our molecular model of matter, itself a result of the collective imagination of chemists, we say that “water” is “H_2O,” and we mean to indicate that whole accumulation of information behind that simple symbol. Thus, a fundamentally important skill is to accurately determine and compare the physical properties of substances.
>
> You will obtain a sample of an organic solid. You will determine properties such as its melting point, its infrared spectrum, and how it moves on a thin-layer chromatography plate in one or more solvent systems using one or more visualization techniques. *Your goal is to find the other students in class who have the same compound as you do.* Comparisons of different samples may be made in a number of ways: (1) by spotting the samples side by side and co-spotting on a TLC plate; (2) by comparing solubility and appearance of the samples; and (3) by taking melting points and “mixed melting points,” a melting point of an intimate mixture of the two compounds. If the two compounds are identical, the mixture will not melt any lower than the individual samples do. If the compounds are different, one will serve as an impurity in the other. Impure substances melt at lower temperatures than pure samples do.
>
> Your laboratory section should work out a method for sharing and reporting your sets of individual data. Once you have identified yourselves with a particular compound, the group should affirm the predictions about who has the same substance, and also confirm that there are no others in your lab room who belong with the group.

One of the questions that spontaneously arises every term is what constitutes a valid comparison. The melting point data only group together rather than occur with exact duplication, so we always hear a version of the following: “Is 156–7 ºC on my thermometer the same as 152–5 ºC on yours?” A very productive iterative cycle occurs

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as the need for reproducibility causes students to revise their original reports in the context of new information. The experimental techniques are clearly seen as tools by which data are collected and from which a simple question can be answered.

Another unique aspect of organizing an activity around the “Who has the same thing as I do?” question is that collaboration requires communication. As a group, students in a lab section must establish procedural norms for collecting data, such as what proportions to use for solubility tests, and for reporting and exchanging data, which is required in order to solve the problem. On any afternoon, we can have eight sections of the *Structure and Reactivity* laboratory course operating with eight different sets of procedural standards and communication strategies. Lastly, this is a *collaborative learning task* [11, 45]. After the entire group has established its common experimental procedures, individual students are responsible for collecting data from their own substance. As the information flows from individuals to the whole classroom community, smaller collaborations occur spontaneously as subgroups begin to gather around a common substance, along with the need for building consensus about the properties of the substance they suspect they share. Finally, “Who has the same thing as I do?” is actually a blueprint for designing activities in any discipline that make differential discriminations (compartmentalizes); in other words, in all of them.

Conclusions and Outlook

To summarize, we have made progress in our view of instruction by taking a more re-integrative perspective about our goals. In restructuring our classroom practice, we have identified five principles that have guided our instructional design, and which, in our experience, have helped students develop their higher order skills:

1. Give out the implicit rules.
2. Use Socratic instruction.
3. Create alternative metaphors for learning.
4. Use authentic problems to elicit authentic skills.
5. Make examinations reflect your goals.

The content and the methods of instruction of any course convey messages about philosophy and values whether or not the course instructor consciously subscribes to such a philosophy and value system [1]. It has been as important to be aware of the changes that were needed (or that had already occurred) in ourselves as it was to think about changing our instruction. The five design principles listed above are outcomes of and inextricably linked to our underlying philosophical context, below. Like it or not, we are all intellectual and moral philosophers.

1. Formal education is both the tool and product of the dis-integrated world.

2. The intellectual value of a liberal (arts) education overarches all subject matter.

3. Explicit identification, articulation and mapping of instructional goals for faculty and students creates a less dissonant learning environment.

4. Knowledge is constructed, not recorded, by learners.

5. Faculty and students are both learners; faculty happen to be more expert at it.

6. Cognitive process instruction reveals transcription, translation and expression of understanding, and promotes the development of more desirable skills.

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