Mea Culpa: Formal Education and the Dis-Integrated World

BRIAN P. COPPOLA AND DOUGLAS S. DANIELS

Department of Chemistry, The University of Michigan, Ann Arbor, Michigan 48109-1055 USA

ABSTRACT. Formal education has removed itself so far from any truly integrated view of the Natural World that fragmentation and certainty are prevailing ethics. Technological progress has resulted in increased specialization within academic disciplines and their concurrent separation from each other. Knowledge is extracted from a fully integrated world, but is examined and defined by the ‘dis-integrated’ world of the compartmentalized university. We have addressed the relationship between re-integrated, value-centered instructional goals and actual classroom practice in introductory science. This essay represents the philosophical framework for further discussions and recommendations about curriculum design and educational objectives.

In 1995, an international conference titled "Einstein meets Magritte" was convened to address whether any basis for a unified world view for intellectual pursuit might be articulated, jumping off from the putative conflict between technological progress (symbolized by physicist Albert Einstein, 1879-1955) and humanistic perspectives (symbolized by surrealist René Magritte, 1898-1967). The meeting provided for a dialogue between scholars from 'Einstein's world' (conscious ordering of the physical and social world; the production of knowledge and technology) and 'Magritte's world' (life outside of and beyond the instruments and objects of technology; the production of sensations and revelations). The conference attracted our attention (Coppola 1995) because we have been recently looking at education from the viewpoint that there are unifying instructional objectives, or 'metacurricular goals', for students that occur within the context of the individual, specialized courses they take. One of our core beliefs is that there are overarching values and skills that can only be achieved through the interaction of multiple perspectives, regardless of whether they originate in Einstein's world or in Magritte's. Our system of higher education sits in an uncomfortable position: it is both the tool and formal construct of disintegrated knowledge. Through the customary process of intellectual inquiry, disciplinary specializations have emerged and separated from one another...as have the specialists. In the name of progress, we educators direct and identify young learners according to our assessment of their aptitudes for pathways we define and (continually) refine. If thinking about unifying educational objectives is to be useful, then it is important to recognize this as a reunification, less in terms of 'integration' and more so of 'reintegration', where we take advantage of our hard-earned depth of understanding to rediscover our common purpose of understanding and expressing notions about the world to each other.

THE DIS-INTEGRATION OF KNOWLEDGE

I. Dis-Integration's Arrow: Specialization to Compartmentalization to Separation to Isolation.

Reproductive incompatibility is the strongest isolation mechanism in biology (Shreeve 1995). Perhaps this is equally true in some academic societies, where joint efforts between individuals from separate cultures, say a faculty member in the science college and one in the education school, are actively discouraged, and where one of the primary metaphors for collaboration is intended to be a disphemism (Allan 1991): '...getting into bed with...'. There are numerous examples of this concept. A common criterion for a positive tenure decision within an academic department is whether a faculty member is in the position to 'propagate themselves' by educating students who share their skills and values. Reproductive incompatibility between two fields becomes complete when no one can be trained in both fields at once and, like a self-fulfilling prophecy, there are evidently no faculty to do the training because there was no way to train them. The strategy is extremely effective: isolation is achieved after only one generation. Perhaps this efficacy reflects the danger perceived to be implicit in a more open intellectual ecology. Integrative unions can produce monsters (new ideas) as 'offspring' that threaten the peace (status quo) in the Village.

The story of science education in the United States is a case study in separation. Through the period ending in the late 1800's, courses of study in 'science' and 'natural science' were commonplace. Although many individuals were trained in the more mature, hence specialized, European institutions, they returned to the United States to join faculty that were too small in number to make individual disciplinary distinctions rational as units within colleges and universities. When the University of Michigan moved to Ann Arbor in 1837, the divisions that made sense were Medicine, Law, Engineering, and the department of Literature, Science and the Arts (LS&A). In 1856, the first free-standing building at a state university devoted to laboratory instruction in chemistry was completed in Ann Arbor, based on the established style of the German model at Geissen (Campbell 1916). During the late 1800's and early 1900's, individual departments and courses of study leading to specialized undergraduate degrees in chemistry, biology and physics emerged within the School (now, College) of LS&A and all around the country.

By the 1960's, emergence in 'biology' was accompanied by the significant linguistic shift to the more inclusive 'biological sciences'. At most universities in the United States, now, departments and programs of biology are fragmented in their missions; at some schools, these fragments have formally separated into departments that offer undergraduate and graduate programs in botany, anatomy, zoology, and cell biology, for example. This stress on specialization can be seen in chemistry departments in the 1990's, where 'chemistry' programs are beginning to be called 'chemical sciences', and where major units of interdisciplinary alignments such as materials science and bio-related chemistry are redefining the traditional subdisciplines. Comprehensive undergraduate instruction in the traditional areas of analytical, inorganic, organic and physical chemistry is virtually impossible within the two or three semesters allocated to each of them. In many of the European universities, departments of chemistry have long since given way to more specialized departments of organic chemistry, inorganic chemistry, chemical didactics, and so on.

II. The Sterilization of Science

The consequences of disintegration on science education have been profound. Progress has led to physical and intellectual isolation of many disciplines from one another within universities. Every year, this same progress contributes to the concern to 'cover' the increasing amount of factual subject matter in science. This emphasis has exaggerated the dispassionate, objectivist vision of scientific practice. Separation has slowly stripped away the clearly value-laden dimensions of science from formal science education. The existence of historical, philosophical, sociological, linguistic, and moral considerations, if not ignored completely, are minimized as significant arbiters in decision-making (Matthews 1994). When history does appear, it often does so in neatly isolated and easily neglected textbook side-bars (Figure 1; Bruice 1995).

There has been some noteworthy progress over the last few years in incorporating the ethical decision-making dimension during the professional training of research scientists (Benditt 1995). Somewhat ironically, however, a prime motivation has been a simple injunction from the National Institutes of Health: no training in ethics means no funding. One goal in our teaching in introductory courses at the University of Michigan then, has been to integrate the historical, philosophical and linguistic aspects of science with the factual information. We have also incorporated analysis of ethics case studies as part of a structured study group program, which is described in more detail below. By making these perspectives a part of our teaching, we find that we provide a rich array of entry points through which students can make integrative connections in their learning. By emphasizing the fundamental narrative (story-telling) aspects of science, we have had our best success in demonstrating to new learners that they can, indeed, participate too.

to be broken. This means that the boiling point of a compound depends on the attractive forces between the individual molecules. If the molecules are held together by strong forces, it will take a lot of energy to pull the molecules apart and the compound will have a high boiling point. If, however, the molecules are held together by weak forces, only a little energy will be required to pull the molecules apart and the compound will have a low boiling point.

Only relatively weak forces hold alkane molecules together. An alkane contains only carbon and hydrogen atoms. Since the electronegativities of carbon and hydrogen are similar, the bonds in an alkane are nonpolar. Consequently, there are no partial charges on any of the atoms in an alkane. Alkanes are neutral molecules.

But it is only the average charge distribution over the molecule that is neutral. Because electrons are continuously moving, at any one instant one side of the molecule can have slightly more electron density than the other side. This means that at any instant, one end of the molecule will have a slight negative charge and the other end will have a slight positive charge. This gives the molecule a temporary dipole.

The temporary dipole in one molecule can induce a temporary dipole in a nearby molecule. As a result, the negative side of the first molecule lines up adjacent to the positive side of the second molecule (Figure 2.1). Since the dipoles in the molecules are induced, the interactions between the molecules are called **induced dipole–induced dipole interactions**. The molecules of an alkane are held together by these induced dipole–induced dipole interactions known as **van der Waals forces** or **London forces**. Van der Waals forces are the weakest of all the intermolecular attractions, so the attractive force is felt only by molecules that are close together. In order for an alkane to boil, these van der Waals forces must be disrupted.

Johannes Diderik van der Waals (1837–1923) was born in the Netherlands, the son of a carpenter. He taught himself enough to be able to enter Leiden University in 1862. He received a Ph.D. in 1872 with a dissertation on the gaseous and liquid phases. Later a professor at the University of Amsterdam, he received the Nobel Prize in physics in 1910 for his work on gas equations.

Figure 1. Instructional Isolationism in History and Chemistry

III. Formal Education: Fragmented and Certain

Within departments, thorough training in traditional subdisciplines is increasingly difficult; and in the introductory 'survey' courses, dis-integration continues: many contemporary innovations seek to formally 'modularize' or compartmentalize topics from one another. Textbook and examination questions routinely identify the major topic for students, relieving them from developing their own identification skills.

Ultimately, education is an important topic in discussions about (re)integrative perspectives because they are things that need to be actively learned, the same way, we contend, that the disintegrative perspectives are developed. In a world where neatly defined separations are reinforced and where disciplinary units actually compete over resources within the university, it is productive to maintain isolation and to achieve a favorable reputation. Within this world, formal education is a fragmented and certain enterprise, and keenly so in science instruction. There is an antithetical relationship between this state and the themes of both unity and uncertainty that sit at the core of an integrated world view.

PROSPECTUS FOR EDUCATION IN AN INCREASINGLY RAPID EMERGENT SYSTEM OF KNOWLEDGE

Over a number of years, we have restructured our introductory chemistry instruction in ways that are consistent with the principles of a reintegrative perspective stated above (Coppola & Daniels 1996). Appropriately, many of the important results appear through incremental development and iterative reflection along with instruction in the subject matter. Although it is a difficult task to simply state a few strategies and then dissect methodologies out from a course where reintegration is a prevailing ethic, we can point to what we consider to be positive outcomes. During an exit interview conducted in 1994, for example, one of our students summarized his experience in our course in a way that reflects our metacurricular goals:

> We would start studying with a specific problem, but that would lead to underlying issues...friends don't just talk about the answers because we already have those in the book...*we didn't learn examples, we learned by example*.

This statement reflects an important reminder for instructors about instruction: it is not a neutral activity. Goleman uses the word ‘character’ to describe the basic psychological effects of intellectual development (Goleman 1995), as have we for moral development (Coppola & Smith 1996). A sustained program of education inevitably affects the way a student looks at the world, and as a result it must have some effect on the student's character. Even if we educate poorly or the effect is small, the aggregate outcome on students is still significant, as are our responsibilities. We provide instruction in the attributes of our intellectual and moral lives, by example, with every decision we make and every action we take in the collaborative enterprise of education. In order to help attend to the more complex issues that arise in courses, we support the idea that instructors should think beyond a list of topics as a syllabus. In addition, or perhaps alternatively, a course can be described in terms of intellectual and professional goals and objectives that are intended to be delivered through a study of the factual material, the instructional strategies used to accomplish those goals, and annotated examples of the assessments that are used. At a minimum, even a set of examinations does a much better job of describing the expectations of a course than a list of topics does.

One implication of this express awareness of students for instructors is that there are no value-free environments. The minute you take responsibility for shaping an instructional environment, you also provide lessons in leadership, in how you relate to intellectual inquiry, and in the relationship between you, your discipline, and your discipline's place in the academy. Or, as we (Coppola & Smith 1996) have put it to faculty: "Like it or not, we are all moral philosophers".

In our teaching, we emphasize the concept, in practice, that understanding the meaning represented by the scrawlings of any representational system requires instruction and example in the inferences and implications that are not present in the literal symbols. Phrases such as "When I see this, I also see ..." or "From the other information present, I infer the following..." are a constant feature in our lectures. The students of Magritte can teach the students of Einstein that 'H_2O' is not, in fact, water, but only its representation. The attachment of meaning to representational information is a feature of all intellectual activities. Therefore, it is critical for instructors to relate how experts assign meaning (signified), which they do not see, by attaching it to or extracting it from information (signifiers), which they do. In our chemistry course, there is as much a place for Magritte's *La Trahison des Images* (“The Treachery of Images”), with its disarming message *Ceci n'est pas une pipe*, as there is for images of gamboling, space-filling yet two-dimensional molecular representations that are no more ‘molecules’ than Magritte's pipe is a pipe (Gablik 1991) (Figures 2 and 3). In fact, since introducing the Magritte image and language into the course, our students are much more inclined to understand the larger lesson, with chemistry's example serving as one among many.

Figure 2.

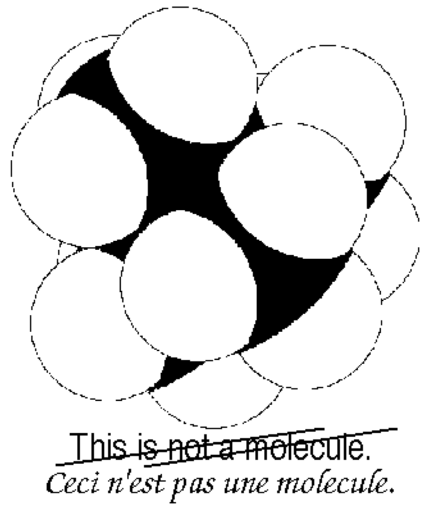


Figure 3.

THE EVOLUTION OF PERFORMANCE AND EXPRESSION

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, perhaps even more effectively, when they anticipate the need to express their understanding to someone else. The most common example of this type of anticipation is preparation for an examination. 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.

Philosophically, we find Dawkins' notion of 'memes' quite compelling (Dawkins 1982, 1985; Dennett 1995). 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 (Moritz 1990; Speel 1995), 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 technology, a product of human design and invention that results from an understanding of a natural process: learning, in this case. In its fundamental metaphors (Ege 1988), the rhetoric of genetic transfer (transcription, translation, expression) has already borrowed from memetic transfer! We see this view as the closing of a circle, where the cultural world is reintroduced to physical world (Eldredge 1995; Maasen 1995). Inasmuch as we recognize the indispensable role that *transcription* plays in education, we readily acknowledge its limited utility in the development of critical skills. Understanding relies strongly on the constructivist (Garafolo 1993; Roth 1993; Lochhead 1990; Bodner 1986) notion that learners *translate* their current understanding in the context of their prior experience when they need to integrate new information. Ultimately, it is the *expression* of one's understanding that is perceived by the 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!" As learners, for example, we appreciate Peter Schickele’s ('P.D.Q. Bach's') musical ability as well as his lessons precisely because he can be within the performance and then in an instant be standing alongside of it, guiding his listeners to the composer’s art. 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. Teaching is analogous to such a performance where naive learners develop their own abilities to express their knowledge. The processes that underlie preparing for a successful act of expression 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.

THE MAKING OF--- THE LIBERAL (ARTS) EDUCATION

In 1995, a senior student from the University of Nijmegen in The Netherlands did a chemistry didactics internship at the University of Michigan. He was a participant and expert observer in our introductory organic chemistry course for first-year students, *Structure and Reactivity*. The Dutch chemical education system, like that in the States, is undergoing a period of introspection and assessment. As part of a report on his experiences and observations, van Nisselroij (1995, 1996) described the advantage of the instructional design in our course by an extended analogy: relating the difference between using only the evidence gathered from watching a well-crafted motion picture in order to create your own production (a description of traditional science instruction) with having the opportunity to see a director's 'The Making Of ---' along with the film, where what goes on behind what you see is made clearer and invites greater and more intelligent participation. The analogy is particularly keen in its tacit reminder that in traditional instruction (showing the movie), the objective is to keep evidence of the ‘director's’ participation as low as possible, providing the audience with the most professional presentation possible. In the type of instruction advocated by 'The Making Of ---', on the other hand, the objective is to explicitly relate the final version of the movie to the work that goes into creating it.

> What is so important about 'The Making Of --- Chemistry' ? The pictures that our students will make of chemistry tomorrow will be different from the one we see today. The way of thinking, however, is the more persistent and essential part; like the persistent ways in which a movie is built, we have the use of scripts, camera positions, points of view, and the whole notion that the thing is constructed. This knowledge, in chemistry and in movies, constitutes every new frame of the picture and is therefore crucial when new movies have to be made.

> In the University of Michigan course that I was a part of, the most important thing I observed and experienced was instruction where not only is the motion picture of chemistry shown, but also that the students are explicitly demonstrated and involved in thinking about 'The Making Of ---'. Students are not only exposed to an enormous amount of information, but their instructors also offer them a powerful grip on how to develop the expert skills pertaining to the thinking processes that the instructors themselves developed unconsciously. Students are actively guided in the process of

developing strategies and skills to deal with new information and problems, and to assess what is going on behind the represented view. By making students aware of these unconscious and often latent skills, and by accessing them in different but analogous situations, they really learn to think more like the expert chemists (directors) do. When it comes to making new movies, that is, constructing new knowledge, they can rely on these incorporated skills: the skills of intellectual pursuit.

If intellectual pursuit is at the core of the Liberal (Arts) Education, then what are its attributes? At a time when we were trying to articulate these attributes, we were kissed by an unlikely muse: Roger Smith, former Chair of General Motors Corporation. In a speech describing a set of attributes for business managers who had had a liberal arts education, Smith hits a resonant chord with all faculty, regardless of their specialization (Smith 1985). The following attributes are extracted from the text of Smith's speech (Perlman 1994).

<u>Attributes of the Liberal (Arts) Education</u>

1. Individuals are trained to recognize recurring elements and common themes.
2. They are trained to see relationships between things that may seem different.
3. They are trained to combine familiar elements into new forms.
4. They learn to arrange their thoughts in logical order, to write and speak clearly and economically.
5. They learn to tolerate ambiguity and bring order out of apparent confusion.
6. They are accustomed to a relatively unstructured and unsupervised research and discovery process, and feel comfortable with nonconformity.
7. They learn about the kind of creativity that leads to visionary solutions.

In these attributes, we see no advice to do triple integrals, to translate Goethe, or to learn the mechanism of how ozone depletion is attributed to environmental chloroflurocarbons; nor is there any indication that one discipline can accomplish these goals better than any other.

Instead, we recognize a tacit reminder that the responsibility for translating knowledge from the highly contextualized understanding within the disciplines to this set of attributes falls squarely on the disciplinary experts who know and create that knowledge in the first place. This is the essence of reintegration.

PROGRESS IN PRACTICE: THE PERFORMANCE STUDIO FOR SCIENCE STUDENTS

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 rightness and wrongness. By pointing out to students that during examinations they are assuming the teacher's role, we allow them to confront the need to learn how to express their understanding before the examination. We have actively promoted ways for students to practice their teaching skills before the examination. Another aspect of 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. 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. We use the multiplication problem exercise in Figure 4 with our students and in discussions on pedagogy with graduate student and faculty colleagues.

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 4. An exercise for demonstrating the importance of adopting the learner's perspective

This example demonstrates the advantage of trusting that students tend to be internally consistent in their use of strategies, and that even incorrect strategies can produce the same answers as correct ones some of the time. The multiplication example points to why just checking for right and wrong answers may not be much help for revealing a student's understanding. 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. 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 that have been created by the student 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.

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.

We have created an option for introductory science students that draws from the principles outlined above. In our structured study group program, a cohort of 120 first-year undergraduate Honors students, while taking standard coursework and examinations in a 1200-student course, earn their Honors credit by participating in extra weekly 2-hour sessions that are shaped, metaphorically, along the lines of a 'performance studio' in 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 (Hurley 1993), 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 5 rational examples of molecules with the same formula. They then propose rankings for their created molecules based on 3 of 6 properties, including, for example, magnitude of dipole moment, boiling point, and solubility. Later, a typical assignment might be to find an example of an S_N2 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 curriculum for the groups. 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 (FMO) theory. During the last month of the first term, the students examine 2 or 3 short publications written by a departmental colleague in order to develop a set of questions that one might ask of the author. Like the common practice used in language composition courses, our students then meet with the author after having studied his or her writing, and then ask questions from a set refined during the group work. In the second term, spectroscopy, bioorganic chemistry, and more FMO-related work (electrocyclic, sigmatropic and cycloaddition chemistry) are introduced over the course of the meetings. Case studies in research ethics are also included in the second term's curriculum. Casebooks appropriate for undergraduate and graduate instruction are beginning to become available. In chemistry, Kovac (1993) has produced *The Ethical Chemist*. The Association of American Medical Colleges has prepared a complete handbook for instruction (Korenman 1994). Casebooks for other disciplines are being developed at the Poynter Center for the Study of Ethics and American Institutions (Indiana University). A final responsibility for the group leader is to outline the next week's assignment along with any supporting discussion, examples, or instruction in the use of chemistry software (from molecular graphics to research-grade molecular modeling and dynamics). 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 5 is an example of a student's first assignment, and Figure 6 is an example from the second term of the year-long organic chemistry course for first-year students called *Structure and Reactivity*.

The educational experience for the 7 or 8 undergraduate group leaders has been profound. They, 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 <u>really</u> hard!" About half-way through the term, the group leaders also develop the ethic of what they call 'active non-participation'. Their comments revealed that the teaching abilities of these student leaders evolved rapidly: moving the center of classroom activity from the role of "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 encourage 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 (Walters 1991).

Students in the groups participate in an 'ice-breaker' activity during their first 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 halves. 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. The 'student' can ask for an instruction to be repeated. 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.

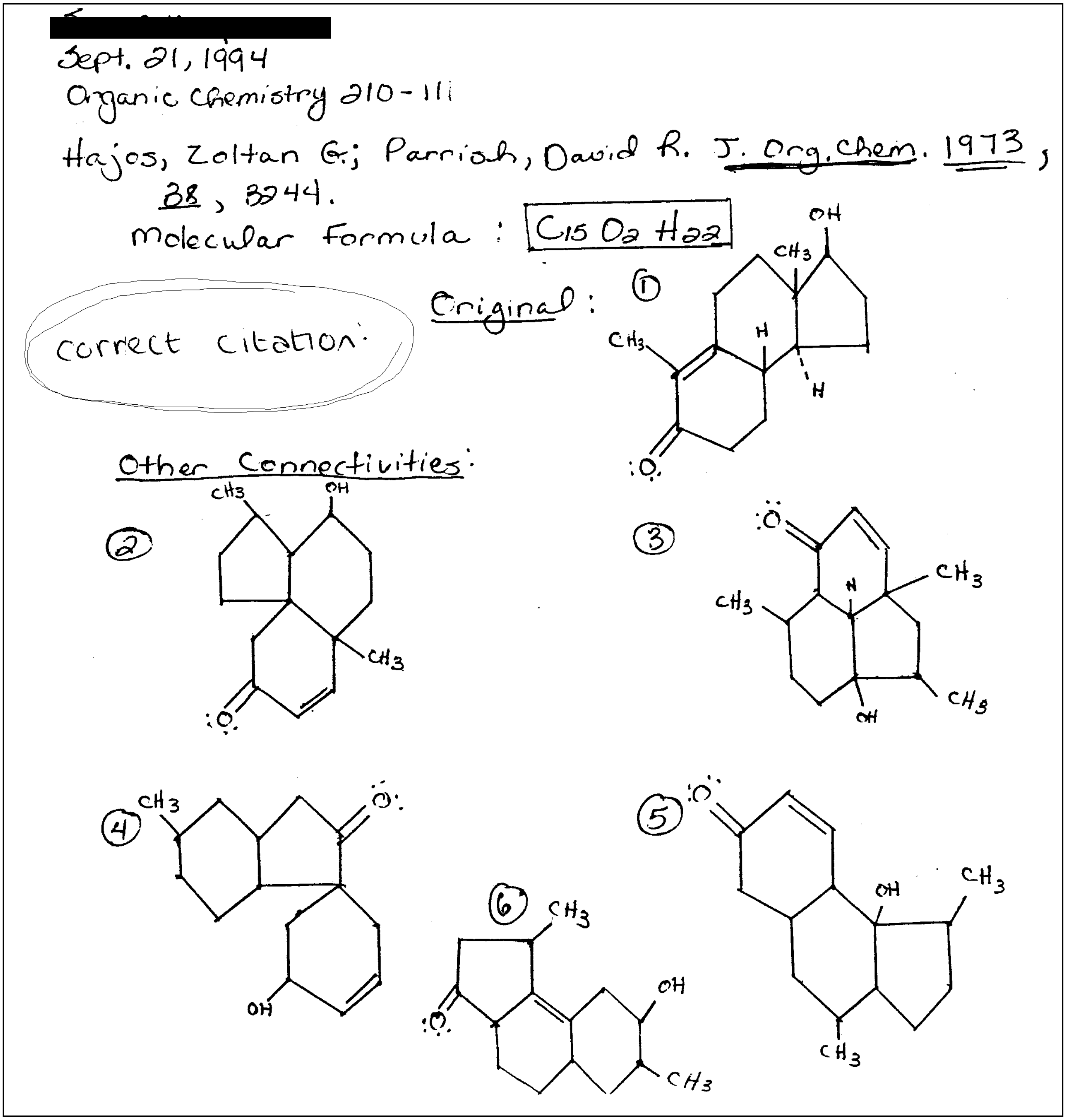


Figure 5. A representative study group assignment from the first term course

[redacted]

Section 213
Chem 215H
Winter Term 1993

Topic <u>Enol/Enolate Substitution</u>

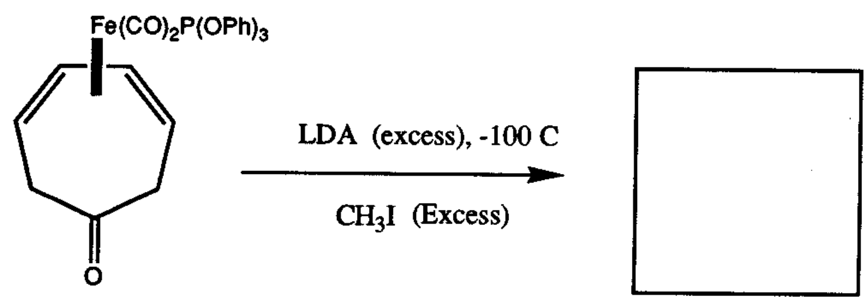
I. Reference

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:

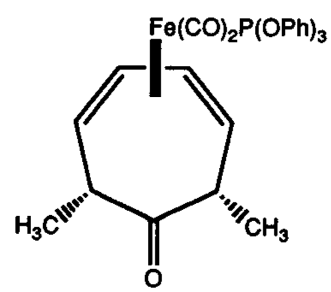


Figure 6. A representative study group assignment from the second term course

CONCLUSIONS AND RECOMMENDATIONS

The diversity of instructional needs and objectives creates a familiar tension in formal education between training students in the technical content of the disciplines and more overarching liberal arts values. The Roger Smith attributes describe some *general intellectual* objectives for education. *Professional intellectual* objectives are the overarching values for a more specific literacy at the disciplinary level. The fundamental questions that chemistry asks of the world, for example, are comprehensively representative of the discipline: What is it? How much of it is there? Where might it have come from and where might it go? How did it get there and how fast? These are the strands, we argue, that could explicitly link formal courses and a student's experience within them during an authentic chemistry curriculum. Instruction would also need to attend to the connection between the *professional* and *general intellectual* objectives. Lastly, individual courses are embedded within the richness of *professional technical* objectives: the factual subject matter that typically comprises a written syllabus or table of contents. Technological progress in the disciplines and the detailed articulation of the *professional technical* subject matter should be exploited in order to make clear connections about how learning triple integrals or translating Goethe is not only representative of *professional intellectual* objectives, but also addresses *general intellectual* ones.

The underlying strengths of the higher educational system in the United States can be used to support reintegrative instruction. At least for now, all the dis-integrated parts are still together in the same place, especially where graduate and undergraduate research coexist with classroom instruction. Open access to institutional resources is typically available to everyone, and occur with few restrictions in a culture that promotes independence and innovation. The mechanisms that support joint efforts between interested individuals or groups generally exist and the intellectual climate is invariably enhanced by these efforts. And yet, dis-integration's arrow still points towards isolation, and a faculty who are the products of dis-integrative instruction will tend to enhance its development. We are the products and thus the agents of intellectual incompatibility. Mea culpa. Progress in reintegrative instruction will not come from core curricula but rather core ideals akin to the ones on Roger Smith's list. If faculty drawn from a wide variety of disciplines believe that these attributes are contained in a study of their subject matter, then there are two additional challenges to address. First, the faculty need to be able to express, to themselves and to others, the nature of the connection and the methods used to promote its understanding. Second, the faculty must respect and support how these same attributes are represented by many different academic cultures. If these goals can be achieved, then the outlook for students is bright: after all, it is they who actually travel from classroom to classroom, and who will weave a rich conception of inquiry that intertwines rather than unravels during their formal education.

Schools and Universities need to be inclusive of the broadest menu of choices. They need to be places where the answers to reintegration's questions can be found. Indeed, even progress in the design of assembly lines has been reintegrative: in many manufacturing plants workers learn to perform many tasks and, in some cases, groups take collective ownership for the whole product. Can we do less? As our substantive progress in intellectual inquiry continues, disciplinary separation that leads to cultural isolation threatens to remove reintegrative choice from the menu of formal education. We can choose to do this, mea culpa; but let us first make sure that we realize there is a decision to be made.

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About the Authors

Brian P. Coppola is a Lecturer in Chemistry and Coordinator for Undergraduate Curriculum at The University of Michigan, and Faculty Associate at The University of Michigan Center for Research on Learning and Teaching. His 1984 Ph.D. is in organic chemistry from The University of Wisconsin-Madison. He has organized a multidisciplinary collaboration with colleagues in education and psychology that involves assessment and evaluation projects related to a new undergraduate chemistry program that he helped to develop at The University of Michigan. His publications cover content from organic chemistry research to educational philosophy and practice. Publications of interest are *Progress in Practice: Using Concepts from Motivational and Self-Regulated Learning Research to Improve Chemistry Instruction*, in Issue No. 63 of the Jossey-Bass New Directions for Teaching and Learning series, and *A Case of Ethics* in *The Journal of Chemical Education*. Articles that contextualize the concepts discussed in the present *Mea Culpa* paper are:*Structuring the Liberal (Arts) Education in Chemistry*, in *The Chemical Educator*, and the forthcoming*The University of Michigan Undergraduate Chemistry Curriculum. 1. Philosophy, Curriculum, and the Nature of Change, and 2. Instructional Strategies and Assessment*, both to be published in *The Journal of Chemical Education*.

Douglas S. Daniels received a BS in Chemistry with Highest Honors and a BS in Cellular and Molecular Biology from the University of Michigan in 1995. He currently holds a National Science Foundation Graduate Fellowship in the Combined Program in Macromolecular and Cellular Structure and Chemistry at The Scripps Research Institute. He will be undertaking a PhD program in an area at the interface of bioorganic chemistry and molecular biology.

Contact information for Brian P. Coppola:
Department of Chemistry, The University of Michigan, Ann Arbor, Michigan, 48109-1055, USA
office phone: 313-764-7329; fax: 313-747-4865; home phone: 313-459-1368
email: bcoppola@umich.edu