Mea Culpa: Formal Education and the Dis-Integrated World

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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. In practice, a science education is still defined by most curricula as the mastery of some corpus of facts. In the conflict over content, value-based and integrative (critical) reasoning issues were among the first casualties. Education is not a neutral activity, and 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.

The students of Magritte can teach
the students of Einstein
that "H_2O" is not, in fact, water,
but only its representation.

WHEN EINSTEIN MET MAGRITTE

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 [1] 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. "Integration of knowledge bases" is a common rhetoric, serving everything from a tacit architecture in *The Sciences*, a periodical where Einstein meets Magritte on a bimonthly schedule, to an explicit recommendation from researchers in pedagogy and curriculum design. However popular "integration" is, we propose that "re-integration" is a better choice. We are inclined to think of the world as an integrated and unified whole that has continued to be dis-integrated (and appropriately so) through the normal process (progress) of intellectual inquiry. Whatever form re-integration or unification takes, it needs to reconcile (a) the nature of progress that dis-integrates the world and (b) the manifestation of both more and less complex representations for the dis-integrated aspects of the world that, when free of disciplinary constraints, point to an underlying commonality. Our system of higher education sits in an uncomfortable position: it is both the tool and formal construct of dis-integrated knowledge, its disciplines are the pathways along which we direct young learners away from more integrated worldviews, and yet it is the place where a deep understanding of underlying commonalities should be accessible through the highly contextualized disciplines that make up the modern academy. Hence, mea culpa: an ironic apology. If Einstein does not speak the same language as Magritte, or if they seem to describe different worlds, then it is because either they or we learned it to be so.

The consequences of any conclusions and recommendations about reintegrating the world need to be addressed in the context in which the majority of individuals develop their intellectual identities: in their formal educaton. A mother's practical reaction to the consequences of technological progress upon education can be found in a letter of comment to *Science'84* magazine [2].

> “When my six-year-old learns that we heat the house with forced air, she immediately wants to know who is forcing the air, where natural gas comes from, and how it got stuck underground. Then she asks, ‘If we didn't have natural gas, would we die in winter?’ There you have geology, engineering, physics, and biology, all together in a logical hierarchy of concepts and facts.
>
> But a few years from now, my daughter will be studying the structure of earth's crust, combustion, hydraulics, and the classification of living beings - all in different years and quarters, neatly separated, tested, and graded.”

Wellinghoff's concern centers on the consequences of technological progress on education, and its echos can be heard from many different directions: as often from Einstein's world, where scientists bemoan the ability of the general citizenry to make informed decisions about technological issues, as from Magritte's world, where humanists worry that our new technologies have been created in a moral vacuum, at a rate that has surpassed the development of skills with which to deal with them. As tempting and typical it is to view the "dis-integration of knowledge" in terms of only discouraging outcomes, it is also unfair. After we take account of how the negative outcomes have affected education, we will present a prospectus that not only resolves the conflicts created by rapidly emergent systems, but also reveals a way to make use of the disintegrative process.

THE DIS-INTEGRATION OF KNOWLEDGE

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

Definition and distinction are natural features of emergent systems.[1] Along the path of inquiry, specialization occurs when physical or intellectual constraints limit an individual or group to make progress in an area of investigation. Once specialization occurs, however, we contend that the compartmentalization that ultimately leads to isolation is only one of many possible consequences. Separation persists because it is a natural process that accompanies intellectual progress. In the institutional academic culture, separation can also be driven by external pressures such as resource allocation or anything else that can bring an advantage to one group over another. Clearly defined separations, once made, invite ranking, competition, and a drive toward self-preservation by educating the next generation to the discriminating realities of "them" and "us". Isolation is the last stage of dis-integration. Biologically speaking, reproductive incompatability is the strongest isolation mechanism [3]. 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 [4]: “...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 their own students. Reproductive incompatibility between two fields becomes complete when no one can be trained in both fields 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 perceived danger 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 in separation that follows the history in Europe. Through the period ending in the late 1800's, training in "science" or "natural science" was most common. There were simply not enough faculty of any given *specialization* to make individual disciplinary distinctions rational. 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 [5]. 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. Today, at some institutions, there are still Natural Science divisions without specific departments, generally those with lower numbers of faculty where the threshold level for separation's benefit has not been reached.

By the 1960's, emergence in "Biology" caused the significant linguistic shift to the more inclusive "Biological Sciences". At most Universities, 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 specialization stress 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 traditonal 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, chemistry didactics, and so on.

As Roald Hoffmann[1] reminded us, the natural origins of separation favor its occurrence. How the resulting isolated entities will interact is uncertain. In the educational system that worries Wellinghoff, students <u>learn</u> that intellectual and rhetorical separations characterize the disintegrated academy. As they adopt their intellectual identities, students also learn that a great deal of time is spent on the idea that "our" viewpoint is somehow a better or more enlightened one than "theirs". Idiosyncratic representational systems, such as drawings for molecular structures or any other jargon, can serve to exclude the uninitiated like any secret code used by a covert group. Language does not need to be invented in order to support exclusion, either, since redefining exisiting words is even easier to do.[2] Put a musician, a surgeon, an analytical chemist and a cognitive psychologist in a room and ask them to define the word "instrument"; they are as likely to debate how much better the word is suited to their personal application as they are to agree to the multiplicity of language. Many times, in fact, the same word is used in different contexts to carry the same underlying idea, which makes any debate even less rational. It is worth reflecting on the how the the words "culture" and "colony" are used to describe both sociological and biological constructions. Indeed, without the proper points of reference and a timescale, the growth of various cultures within the Univeristy of Michigan (Figure 1) exhibit patterns of development and specialization that reminds an observer of the view of cultures within a Petrie dish. Academic units compete for entitlements, physical space, and financial resources in a way that encourages differential distinctions to be clarified and championed: " 'We' deserve our budget increase or raise because of the greater value we provide over 'them'."

Particularly when budgets are tight! However naturally separation occurs in response to the stress of specialization, competitive compartmentalization that leads to isolation is still a learned perspective. Eldredge [6] has addressed the decoupling of our physical and cultural evolutions, and the impact on our physical evolution resulting from our increasing reliance on cultural imperatives, which he explicitly defines as learned behaviors.

II. The Sterilization of Science

The consequences of "separation" on science education have been profound. Over time, technological progress has only 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, linguisitic, and moral considerations, if not ignored completely, are minimized as significant arbiters in decision-making. In those cases when history does appear, it often does so in neatly isolated and easily neglected textbook side-bars (Figure 2) [7]. The philosophy and sociology of science are defined by the action of scientists, but only described, in large part, by philosophers and sociologists from a place so rhetorically distant that translators are necessary for scientists to participate in the conversation. These distances also make integrative instruction difficult precisely when it would be the most beneifical: during the formative professional training periods. We do not mean to imply that science is therefore practiced without any historical, philosophical or moral imperatives. Just the opposite: like it or not, the world is an integrated whole, and it is a decision born from ignorance or neglect to deny the explicit inclusion of these linked perspectives. There has been some noteworthy progress over the last few years to incorporate the ethical decision-making dimension during the professional training of research scientists [8]. 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, then, has been to integrate historical, philosophical and linguistic aspects of scientific activity along with the factual information. We have also incorporated analysis of ethics case studies[3] as part of a structured study group program, which is described in more detail elsewhere [9]. 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.

> Section 2.9 Physical Properties of Alkanes, Ethers, Alcohols, Amines, and Alkyl Halides 73
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> 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 2. 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 indentify the major topic for students, relieving them from developing their own identification skills. The current mood in publishing is to promote the literal use of computer and text modules, with an explicitly stated goal of customizable, teacher-proof instruction.

Ultimately, education is an important topic in discussions about integrative perspectives because they are things that need to be actively learned, the same way, we contend, that the disintegrative perspectives are developed. In Wellinghoff's 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. Although instruction alone cannot produce a re-integrated world, it is impossible to imagine how it can occur with participants who learn that intellectual compartmentalization, isolation, and competition are inevitable. As Pogo said, "We have met the enemy...".

PROSPECTUS FOR EDUCATION IN AN INCREASINGLY RAPID EMERGENT SYSTEM OF KNOWLEDGE

1. Choosing between (re)unification and maintaining fragmentation

If the "Dis-integration of Knowledge" has these outcomes, and if they are as discouraging as we think they are, then what are the choices for education in the fallout from the information explosion?

Choice A: Throw up your hands and quit. Perhaps we should accept the disintegrative consequences of compartmentalization as inevitable. Perhaps we can only appreciate the intellectual value of an increasing array of highly specialized inquiry through highly trained professional participation. Although we do not intend to indict any particular group, the following statement from a "first day of class" talk in an undergraduate physical chemistry course sums up the essence of just giving up: "If you are not going to be a theoretical chemist, then it does not matter very much if you get the point of this course..." Another defining aspect of curriculum debates in the late 20th Century is "content obsession" [10], and the belief that there are sets of indispensable facts that must be shared in order to be considered educated (the "cultural literacy" movement). This is directly related, in our view, to the intellectual arrogance that accompanies an education that has occurred deep within a tightly focused compartment. We do not seek to deny the intrinsic value embedded in the deep understanding of a subject, nor do we take exception to the idea that a discipline's "cultural identity" depends on shared understandings and at least some set of interesting facts and concepts. To us, the flaw in this choice is it's implicit ignorance of the integrated, pluralistic ("multicultural") nature of inquiry [11].

Of course, we prefer a second choice.

Choice B: Reintegrate the dis-integrated to recover overarching values. There are two significant aspects of reintegration that we wish to highlight.

(1) Reintegration is neither reduction nor de-evolution. The "reintegration" concept provides a valuable alternative to reductionism ([12], [13]) which seeks to unify complexity by describing disparate systems with a single representational system (such as mathematics), and also to de-evolution, which would ignore the value of progress that creates complexity in favor of "simpler times." In a recent PBS production, "The Nobel Legacy", one critic of technological progress

was "skeptical about how chemistry is contributing to my humanity," and "now that we have filled the world with Styrofoam cups...maybe it's time we stopped forward movement [progress]" [14]. Dudley Herschbach, in the same production, reminded viewers not only that technology's Genies can never be returned to the bottle, but also that the Genie is not the problem in the first place, rather what we ask the Genie to do.

Years ago, Polanyi suggested reintegration as an alternative. He postulated that there might actually be advantages from a set of more thoroughly defined compartments, provided that one thinks explicitly about the relationships between them [15].

> "The destructive analysis of a comprehensive entity can be counteracted in many cases by explicitly stating the relation between its particulars."

(2) Reintegration resolves the problems of dis-integration at many levels, including placing "intellectual pursuit", the construction of knowledge, at the core of a formal education. We see the differences between the disciplines as both valid and real, yet also as differences that are more like using different words to describe the same object. This does not devalue words, but appropriately moves the focus from the surface information (the words, or signifiers) to the relationship between information and meaning (the signified). In other words, although dis-integrative progress creates more elaborate, albeit compartmentalized, descriptions of the world, taking these descriptions together should consequently be better at representing the core process, which we call intellectual pursuit. The disciplines are the "signifiers", intellectual pursuit is the "signified". According to an old Chinese aphorism, "When a finger points to the moon, only an idiot looks at the finger." Content obsession, metaphorically, is like "staring at the finger."

2. Education is not a neutral activity

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 [9]. 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 [16], as have we for moral development [17]. 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 from a course than a list of topics does.

One implication of this expressed student awareness 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 [17] have put it to faculty: "Like it or not, we are all moral philosophers."

3. Counteracting the destructive analysis of the Natural World

The following provocative view of emergent complexity in the Natural World (Figure 3) has constantly evoked a positive response from classrooms of students who are the products of dis-integrated education. To students for whom factual content is perceived to be an end in itself, this Figure provides a jarring "big picture", an unfamiliar context in which Wellinghoff's daughter might find great comfort. We note with interest the examples of shared language that occur at comparable levels of complexity: "forces" of physics and "forces" of history, the "chemistry" we attribute to personal attraction, and the use of "culture" and "colony" mentioned earlier for both biological and sociological constructions.

	PHYSICAL WORLD		**SOCIAL WORLD**
(Modes of Representation/Expression: mathematics, language, art, music, dance)			
individual/system	***laws***	***individual/system***	***laws***
fields, subatomic	**Physics**	events	**History, Law**
atoms, molecules	**Chemistry**	sentient beings	**Psychology**
living	**Biology**	being/being society	**Sociology, etc.**
& non-living	**& Geology**	& being/environment	**& Geography**
planetary	**Gaia**	*???*	***???***
planetary systems	**Astronomy**	*???*	***???***
galaxies, universe(s)	**Cosmology**	*???*	***???***

Figure 3. Understanding the Natural World (a goal of the liberal arts education).

We argue that a non-reductionist view of the traditional mathematics to biology hierarchy makes for distinctions based on degree of complexity that are reminiscent of the structure of emergent systems, and that reading from the top to the bottom of each column of this Figure is a chronology. [i.e., at time=0 there was only that thing we describe in terms of representational modes, such as math (nothing there) or music (no sound) or art (blank canvas)] Then, in a universe with time's arrow, distinctive differentiation defines an event (the most simple representation-construction of the purely 'social' world), and subatomics (the most simple representation-construction of the 'physical' world). It did not take long for the physical world to emerge (complexify) as subatomics coalesced into atoms ('creating' chemistry), while it took a bit longer for emergence to occur in the social world. The two-column presentation is a purposeful reminder of the linguisitic, visual (and mathematical?) parallels that exist for the horizontal relationships that suggest favorable comparisons as emergent levels of complexity.

4. Semiotic representation and the treachery of images

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 and derivation of meaning from information is a feature in 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 [18] (Figures 4 and 5). 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 4.

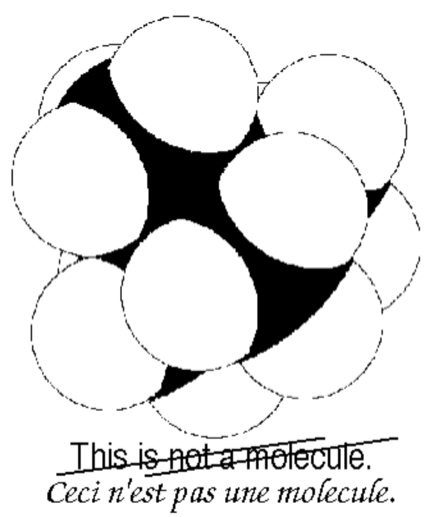

Figure 5.

5. You can't see the forest without the trees, either!

The early history of modern chemistry contains a powerful example of recognizing how compartmentalization (as categorization) provides access to a more comprehensive understanding. Lavoisier created the semiotic system of chemical nomenclature that contributed to the evolution of the sophisticated structure-reactivity relationships that are used today. In order to introduce this notion along with his system of nomenclature, Lavoisier [19] wrote extensively about the role that precise language plays in the effective communication of scientific ideas, and used an imaginative analogy to chemical nomenclature that involved how understanding "tree" as an (integrative) classification relied on (disintegrative) identification of enough clearly distinguished examples of trees ("oak", "maple", "pine", and so forth).

> L'impossibilité d'isoler la Nomenclature de la science et la science de la Nomenclature, tient à ce que toute science physique est nécessairement formée de trois choses: le série des faits qui constituent la science; les idées qui les rappellent; les mots qui les expriment. Le mot doit faire naître l'idée; l'idée doit pendre le fait; ce sont trois emprientes d'un même cachet.

It is impossible, wrote Lavoisier, to separate scientific actions, the ideas they represent, and the words used to represent them.[4] Over 150 years later, Heisenberg [20] would develop uncertainly as the anthem of relativism: “method and object can no longer be separated.” The systematic nomenclature described in Lavoisier’s *Traité de chimie* helped to define the beginnings of modern chemistry by virtue of making an explicit connection between the linguisitic (thereby conceptual) and phenomenological descriptions. Bickerton’s thesis on the origins of language itself are consistent with this view [21]. Language, argues Bickerton, arose as a representational system and an adaptation that allowed humans to gather fragmented information that could be acted on later without needing to wait for new experiences. As a technology, systematic nomenclature created implications and suggested future directions for investigation to a degree that would be later mirrored by the development of the periodic table.

Lavoisier's contribution is re-integrative at its core. Naming substances derives its traditions from naturalistic roots, where substances were identified by their appearance (gilt, gild: gold), location (Cyprus: copper), source (temple of Amen, sal ammoniac: ammonium hydroxide), or physiological effect [brome (Fr., stench): bromine] and is a practice that has continued to the present (asparagus: asparagine, 1868; Münich: münchnone, 1964; Buckminsterfullerene, 1985). But by also systematically collecting the individual "oxides" under the name oxide (oxide of phosphorus, oxide of sulfur, and so on), a more generically useful category of chemical identity was created, which allowed predictions about properties of unknown substances and predictions about experiments that had not yet been performed. In effect, chemistry was created as an intellectual construct based on the (usual) assumptions about an underlying order ([22] [23]). A re-integrative analysis of the particulars, as Polanyi would write much later, reveals the more comprehensive entity. Lavoisier understood this as a general phenomenon that applied to his view of chemistry, and he used an analogy to help express this view to readers of the *Traité*. The word "tree" illustrates the role of categorization relative to understanding the representatives of the category. Only after encountering a number of different trees, Lavoisier argued, can a young learner leap past their association of the word "tree" as representing the first or second of these objects that are encountered. Differential distinction provides richness and depth of appreciation of the broad category, allowing individual identity to be retained within the group, in the same way that different trees can bear different fruit and still be called trees.

> Ces distinctions ne sont pas faites comme on pourroit le penser, seulement par la métaphysique, elles le sont par la nature. Un enfant, dit l'abbé de Condillac, appelle du nom d'*arbre* le premier arbre que nous lui montrons. Un second arbre qu'il voit ensuite lui rapelle la même idée; il lui donne le même nom; de même à un troisième, à un quatrième,

> et violà le mot d'*arbre* donne d'abord à un individu, qui devient pour lui un mot de classe ou de genre, une idée abstraite qui comprend tous les arbres en général. Mais lorsque nous lui aurons fait remarquer que nous les arbres ne servent pas aux mêmes usages, que tous ne portent pas les mêmes fruits, il appendra bientôt à les distinguer par des noms spécifiques et particulieurs. Cette logique est celle de toutes les sciences; elle s'applique naturellement à la Chemie.

6. The Making Of --- the Liberal (Arts) Education

In 1995, a senior student from 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 [24] has 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 with the work that goes into creating it. As learners, for example, we appreciate Peter Schickele's ("P.D.Q. Bach") 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.

> "Instructors too often take (unconsciously?) a positivistic point of view: they assume that by showing all of the frames of the picture itself that it is also clear how you make a movie. Especially in chemistry, perhaps, the movie makers (the chemists) who want to portray and transfer the art of making movies (chemistry) simply forget to demonstrate "The Making Of ---" story, which is the most important thing they have to offer! It is how directors (chemists) think; it is chemistry in its purest form.
>
> "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 precesses 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 analgous 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 each level in the educational process, reintegration is a chance to represent intellectual pursuit in its distinctive venues: across the University, within Departments, and within individual courses. 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 been part of a liberal arts education, Smith hits a resonant chord with all faculty, regardless of their specialization [25].

Attributes of the Liberal (Arts) Education

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 over any other can accomplish these goals better. 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.

7. Conclusions and recommendations within the theoretical framework

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.

Reintegrative instruction draws from the pre-existing relationships between Einstein and Magritte's world(s). The comprehensive mastery of a subject that results from an education occurring deep within its separated compartment is vital, but necessarily insufficient, for a faculty member to provide reintegrative instruction. Understanding the structure of the metaphorical forest is at issue. Is intellectual pursuit the entire forest, comprised of disciplines that are the trees, streams, and rocks? This represents the viewpoint of inevitable isolation: while there may be variety within the generic category called “tree” (subdisciplines within the discipline), understanding the complexity of trees does little for understanding streams. Alternatively, perhaps intellectual pursuit is simply one of many trees, whatever the others may be, and the disciplines comprise the specializations represented by branches, bark, roots and leaves. Interdependency is regained from this viewpoint, but the fundamental structure is now hierarchical and tends towards reductionism: back to its roots. We prefer our interpretation because it has ultimately been the most sucessful in resolving the problems in instruction that we were working on: intellectual pursuit, like the notion of a tree, is understood by reintegrative examination of its representatives (like oaks and maples), which are the individual disciplines (chemistry, biochemistry...) in the case of inquiry. The representatives emerge through specialization, and their identities are constrained by the kind of distinctions that allow an oak to be differentiated from a maple...or chemistry from biochemistry. *The same and not the same* [26]. Intellectual progress will continue to dis-integrate the description of the natural world, so the responsibility for retaining, understanding and expressing the relationship between the parts rests within formal education.

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 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.

The special contribution from formal education, schools and Universities is centered, we believe, in being the place where connections between general and professional objectives are maintained. As a significant counterpoint, however, we do not mean to suggest that technical training is valueless in the absence of these connections. Quite to the contrary, practice and experience suggest that this is the way of the world: we usually learn to use technology's products quite separately from the underlying context, and we can make successful and productive contributions without even being aware of any appendant knowledge. The level of sophistication to which one understands a process is predicated by the local (relative) needs and objectives ([27], [28]). Driving a carload of medical supplies to an accident site does not require a cognitive awareness of the thermodynamics of combustion, the thermodynamics operates just fine without us. We use calculators to help us do arithmetic, and we choose to need to understand how learning arithmetic allows us to make the necessary judgements about the outcomes of button-pushing, while at the same time we choose not to understand things about batteries, liquid crystal displays, the manufacture of silicon chips and the marketing of calculators. Performing a specific task on an assembly line can be done well when the laborer is completely unaware of the other tasks on the line or even the object being assembled. Sometimes that is the learner's choice, also. On the other hand, 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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NOTES

1 After reviewing an early version of this manuscript, Roald Hoffmann, Chemistry Nobelist and poet, reflected on our view of reintegrative value through specialization: "Please reread the first chapter of Genesis. God is busy dividing this from that...[And] a look at the cell, with all its intricate machinery - nucleus, ribosome, membranes, cytochrome - makes you think that specialization is nature's way. Of course I don't agree...There is interest in difference, but only if you see the potential similarities." Hoffmann has eloquently explored this last theme in *The Same and Not the Same* [26]. Gould [29] also uses Genesis I as a fundamental metaphor for differentiation.

2 (a) When Alice meets Humpty Dumpty in *Through the Looking Glass*, she objects to the way he has used the word 'glory" [30]:

"But 'glory' doesn't mean 'a nice knock-down argument,' " Alice objected.

"When *I* use a word," Humpty Dumpty said, in rather scornful tone, "it means just what I choose it to mean - neither more nor less."

"The question is," said Alice, "whether you *can* make words mean so many different things."

"The question is," said Humpty Dumpty, "which is to be the master - that's all."

Alice was much too puzzled to say anything; so after a minute Humpty Dumpty began again. "They've a temper, some of them - particularly verbs: they're the proudest - adjectives you can do anything with, but not verbs - however, *I* can manage the whole lot of them! Impenetrability! That's what *I* say!"

"Would you tell me, please," said Alice, "what that means?"

"Now you talk like a reasonable child," said Humpty Dumpty, looking very much pleased. "I meant by 'impenetrability' that we've had enough of that subject, and it would be just as well if you'd mention what you mean to do next, as I suppose you don't mean to stop here all the rest of your life."

"That's a great deal to make one word mean," Alice said in a thoughtful tone.

"When I make a word do a lot of work like that," said Humpty Dumpty, "I always pay it extra."

(b) One of our colleagues, Reed Konsler, pointed to the telling example of language and culture in chemistry in the recent debate about the naming of Elements 106-109. Historical, social, and moral considerations have been clear arbiters in this debate. Historically, the group of researchers that discovers an element has taken the right of naming. But, the short lifetimes of Elements 106-109 present an intrinsic difficulty to affirming their existence. The claims to discovery occurring between the Soviets, Americans, and West Germans were subject to the obligations of scientific confirmation and reproducibility. The suspected Element 106 came to be known as unnilhexium between the time of its first evidence and its confirmation. In 1994, the American Chemical Society proposed names for the elements that were consistent with tradition (106: Seaborgium, after Glenn Seaborg; 107: Nielsborium, after Niels Bohr; 108: Hassium, after the German State of Hesse; and 109: Meitnerium, after Lise Meitner). The International Union of Pure and Applied Chemistry proposed an alternative set of names that sought to include the contribution from the Soviet scientists. Whose right is it to name an element? How will this debate be understood, in the future, when it has been isolated from its Cold War context?

[3] Casebooks appropriate for undergraduate and graduate instruction are beginning to become available. In chemistry, Kovac [31] has produced *The Ethical Chemist*. The Association of American Medical Colleges has prepared a complete handbook for instruction [32]. Casebooks for other disciplines are being developed at the Poynter Center for the Study of Ethics and American Institutions (Indiana University). The Poynter Center also offers training workshops for instructors through the Teaching Research Ethics TRE) project, which publishes *TREnds*, a newsletter for TRE participants (http:// gopher.indiana.edu/poynter/gopher).

[4] Earlier versions of this manuscript included a longer series of passages from Lavoisier's *Traité* in the original French. All of the non-French reading reviewers, except for one, failed to see this inclusion as an object lesson as to what it feels like if you do not "know the language". Many of the individual words almost look like English equivalents and although the text seems to make sense, it cannot be simply decoded for its meaning.

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