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Science Literacy and the Undergraduate Science Curriculum: Is It Time to Try Something Different?

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I had a very disturbing experience a few months ago—one might almost call it a crisis of faith—while leafing through the financial pages of my daily newspaper. Confronted with column after column of virtually indecipherable NASDAQ, NYSE and AMEX stock quotations—and even more nonplussed by articles which made reference to such things as "put" and "call" options, small cap growth funds, and companies taking "poison pills" to avoid a hostile takeover—I realized in a flash of depressing insight that I was one of this nation's economic illiterates.

Probably I have been aware of this for some time—no doubt it explains why I enjoy visits with my financial planner about as much as I do trips to the dentist, and why filling out a Form 1040 every year makes my palms sweat. Like those who cannot read, economic illiterates live in constant fear of the day they might be found out—as when the conversation at a social gathering turns unexpectedly toward the pros and cons of no-load mutual funds, or when someone asks at work whether I'm leaning toward stocks or inflation-adjusted bonds this year.

Particularly unsettling to me this day, however, was not just the sudden awareness of my own ignorance of economics, but the fact that—just a week earlier—I had lectured to a class of graduate students in education about the inexcusable extent of science illiteracy in our country today and what dangers it posed for our post-industrial, technology-oriented society.

It was appalling, I had told them, that almost forty percent of adult Americans believe that rocket launchings cause changes in our weather;

that fifty percent do not believe in evolution; and that sixty percent have absolutely no understanding of what DNA is or what it does. How could our democratic institutions survive in an age of exploding science and technology, I had asked, given such widespread ignorance?

Alas, just a few days later I found myself confronted with—and confounded by—a host of terms and concepts that had little if any meaning for me: price-earnings ratios and liquidation dividends; split-stock options and commodities futures; and, yes, "poison pills." Was I, through my own lack of knowledge about these matters, also contributing to an uncertain and possibly precarious future for our nation? Or at least my own future? And as a scolding science teacher, was I being hypocritical?

THE DILEMMA OF SCIENCE LITERACY

When I left my job as a research scientist sixteen years ago to pursue a new career in undergraduate teaching, including that of future pre-college science teachers, the "science literacy" movement was all the rage. Alarmed by declining science and mathematics test scores among U.S. middle school and high school students as well as the results of a variety of polls which indicated a severe level of science illiteracy among the adult American public, many scientists and science educators were calling for new initiatives on the part of the education community to help address these deficiencies.

The (first) Bush administration responded in 1989 with its "America 2000" agenda which, among other goals, vowed to make U.S. students "first in the world" in science and mathematics by the turn of century and to insure that every American citizen was literate enough in science to make responsible political decisions. This latter goal was seen as a particularly critical point since, as E. O. Wilson (among others) has pointed out:

> *...half the legislation coming before the United States Congress contains important scientific and technological components. Most of the issues that vex humanity daily—ethnic conflict, arms escalation, overpopulation, abortion, environment, endemic poverty, to cite several most persistently before us—cannot be solved without integrating knowledge from the natural sciences with that of the social sciences and the humanities* (Wilson, 1998).

The American Association for the Advancement of Science soon entered the fray with its much-heralded study, *Science for All Americans* (1990), as did the prestigious National Research Council with its own report, *National Science Education Standards* (1996).

As a novice science educator I jumped quickly onto the science literacy bandwagon—writing articles for journals and newspapers supporting the idea; developing and administering my own science literacy questionnaires (Armstrong, et al, 1992; Mullins, 1993); raising the issue again and again in my classes; and giving talks before lay and academic audiences about the dangers we face from widespread ignorance about both the findings and methodologies of modern science. Increased and more widespread science literacy, I argued, would change all this.

And so it would. But from the beginning there remained the nagging questions of what exactly constitutes "science literacy" and whether it can actually be achieved among the non-science public. Does "science literacy" imply that all citizens should have at least a general familiarity with the vocabulary, findings, and theories of the major branches of natural science—physics, chemistry, earth science, and biology—and if so, just how detailed should this knowledge be? And should science literacy also include, as George Mason University scientists Robert Hazen and James Trefil (1991) suggest, some knowledge of the methodology, history and philosophy of science?

Some science educators—most notably Morris Shamos (1995), past president of the National Science Teachers Association, and Keith Devlin (1998), Dean of Science at St. Mary's College of California and a senior researcher at Stanford University—have broken ranks with the proponents of this rigorous interpretation of science literacy, suggesting instead that a far more reasonable objective might be to try to instill some measure of "science appreciation," or "science awareness," in our students, much after the fashion of music and art appreciation courses. As Devlin himself has confessed in the pages of the *Chronicle of Higher Education*:

> *I neither know nor understand most of present-day science. And yet, I am dean of science at a private college, an active researcher, and the author of several mathematics textbooks and science books for the general reader. But scientific knowledge has been advancing at such a pace...that I cannot hope to keep up. No one can* (Devlin, 1998).

The goal then would not be to demand a thorough knowledge of the content of science—its facts, figures, and formulas—but rather, as Hazen and Trefil (1991) suggest, "...the knowledge [one needs] to understand public issues...the less precise knowledge used in political discourse": just the kind of knowledge, they imply, required to make sense of science reports in daily newspapers, weekly news magazines, and television news shows, so as to allow personal and political decisions to be based upon what understanding of such matters can be gleaned from these sources.

As a scientist, I sometimes feel this new "fall-back" position to be one of defeat and premature resignation to a lesser, more nebulous goal. A problem with the language of "political discourse," for example, is that a term such as "global warming"—without being able to comprehend and critically evaluate the relevant data—can often be construed to mean "environmental extremism." In my role as a science teacher, however, the idea occasionally smacks of some practicality and perhaps even achievability.

But this scenario, of course, raises again the uncomfortable specter of my own economic illiteracy. After all, it was not my ignorance of terms in the glossary of a college-level economics textbook that befuddled me, but those I found within the pages of my own newspaper! Since any current knowledge I possess of economics—last encountered as an academic subject in high school forty years ago—comes mostly from various electronic and print news media, I can say with some certainty that I have doubts about the efficacy of these media sources as teaching tools were they to be an anticipated component of the solution. More than anything else they seem to lack the "organization" and "pedagogical continuity" of more formal academic curricula. But this then puts the onus for imparting science literacy back on our schools, colleges, and teaching faculty, and so we seem to have come full circle.

COMPROMISE

I wish to propose a compromise, of sorts, between these two positions—on the one hand, the seemingly unrealistic expectations of those who argue for a quite rigorous definition of science literacy acquired through an improved standard curriculum in high school and college science coursework and, on the other, the oft-perceived laxity of approaches (i.e., "watered down") favored by advocates of "science appreciation." To my mind, part of a solution to this dilemma lies first in precisely defining just what science it is we would like our citizens to come to appreciate, and then redesigning the pre-college and undergraduate science curricula to reflect this definition.

In 1991, Hazen and Trefil published *Science Matters: Achieving Science Literacy*, a book that elaborated upon an earlier letter of theirs which appeared in the journal *Science*. In their book, the authors presented an overview of what they believe to be the twenty most important findings, or principles, of contemporary science (**Table I**). Actually, two of these date from the time of classical Greece—the belief that the universe is regular and invariant in its behavior, and hence comprehensible; and the idea that matter is not infinitely continuous in dissection, but eventually yields up fundamental particles which we call atoms (from *atomas*, meaning "not to cut")—and another (Newton's Laws of Motion) was formulated during the seventeenth century. All of the others, however—from the Laws of Thermodynamics to the realization that all life forms on earth are based on the same genetic code—can be attributed to the work of scientists in the nineteenth and twentieth centuries.

It can be argued—convincingly I believe—that anyone claiming to be scientifically literate ought to have not only a vague awareness of these twenty topics, but a fuller appreciation of their scope and real meaning. Much is hidden, of course, in the seeming simplicity of such a cursory list: to understand that scientists believe the universe to be "regular and predictable," for example, requires that one have some knowledge of the methodology employed in exploiting this belief (the so-called "scientific method") and some familiarity with its history and development, not to mention its pitfalls. Alas, it seems clear that few if any non-science graduates from our colleges and universities possess such an awareness or appreciation, a fact that I believe can be attributed to a variety of problems associated with post-secondary science education, not the least of which is the nonsensical nature of most so-called "core curriculum," or "general studies," requirements. It is even more depressing to contemplate the fact that many science majors and even scientists themselves may be ignorant of even the barest outlines of Hazen and Trefil's full list.

At the University of Alabama at Birmingham (UAB), as at most four-year institutions, all undergraduate students are required to satisfy a set of "Core Curriculum" requirements that, according to the university's catalogue of undergraduate programs, are intended "to provide a nucleus around which students can build an educational experience that will improve the quality of their lives" (UAB Catalogue of Undergraduate Studies, 1999-2001). One of these requirements, of course, is in the area of science and technology, which stipulates that graduates of UAB "will understand the scientific process and the influence of science and technology on society." No mention of specific and desired content knowledge is mentioned in the undergraduate catalogue. This curricular goal is to be satisfied by taking eight semester hours in the natural sciences, with the single stipulation that all courses include a laboratory experience, although many programs (e.g., elementary education) also require that students fulfill this goal by taking a mix of courses from the life and physical sciences.

To this day—nearly a decade after the implementation of the Core Curriculum—I find myself dumbfounded by the claims of those who believe these requirements actually result in graduates who "understand the scientific process and the influence of science and technology on society," much less have even a minimal grasp of the facts, findings and theories of contemporary science. As a means of allowing students the opportunity to broaden their intellectual experiences and perhaps discover areas of academic interest they might otherwise not, the Core Curriculum no doubt serves a useful and important function. But I have argued since its inception that the Core Curriculum in the natural sciences does not at all satisfy the above philosophical premises of the core; does not acquaint students with even a fraction of the content knowledge available in all the natural sciences; and may in fact help perpetuate the antipathy and aversion toward science which many students develop and refine during their pre-college educational experience.

In most instances, non-science majors will opt first for a course in introductory biology, plus an associated lab, and then perhaps a physical geology or introductory, non-calculus based physics course, again with an associated laboratory experience. In both cases, the determining factor seems to be the extent to which the courses are perceived to be free of a rigorous quantitative component. In any event, at least two of the four broad categories of natural science will be ignored, with the result that students are left unable to make important connections between these, as is essential for understanding innately interdisciplinary (and politically relevant) fields such as environmental science.

One possible solution to this dilemma might be to scrap the current

Core Curriculum requirement of two (or more) distinct introductory disciplinary science courses and substitute these with a completely redesigned, two-semester interdisciplinary course in the natural sciences which would introduce students to all four basic disciplines—physics, chemistry, earth science, and biology—vis a vis the list of major scientific understandings about the world as presented by Hazen and Trefil. As a prerequisite, students might be required to fulfill whatever mathematics requirements are currently in place for non-science majors. Except in some rare cases, this would almost certainly necessitate that the physics and chemistry components of such a course be non-calculus based, though I do not see this as a major impediment to the goal of familiarizing students with a broad overview of our modern scientific understanding of "how the world works."

In a two-part article in the fall and winter of 1994-95, in the pages of the *National Honors Report* (Mullins, 1994; 1995), I described the conceptualization, development and implementation of just such a core course for students in the Honors Program at UAB. Titled *The Mythology of Western Scientific Materialism: The Evolutionary Epic*, the course was designed around E. O. Wilson's concept of the "Evolutionary Epic"–our science-based culture's contemporary understanding of the origin, evolution, and possible fate of the universe, as well as that of our solar system, the earth itself, and life on our planet, including the human species. In these articles I outlined the basic format of the course, here reproduced as **Table II**. It should be noted that I have not included–mainly for the purpose of brevity–several additional lectures and class discussion sessions which dealt with relevant literary and philosophical matters. They would likely not be included in an interdisciplinary *science* course in any event.

I offer this outline only as a suggestion for the kind of course I have in mind for all undergraduate non-science majors. Other Honors programs have experimented with similar kinds of interdisciplinary offerings in natural science, though perhaps not as Core Curriculum requirements. I suspect that such curricular innovations are rare beyond the confines of such unique academic units (although Auburn University in Alabama has long taught "The Human Odyssey," a non-Honors science and humanities-based interdisciplinary course which can be used to satisfy some general studies requirements).

Yet another approach might be to require all undergraduate students—in lieu of disciplinary course selections—to complete a specially designed, two-semester course in environmental science, a topic explored in the UAB Honors Program's nine-semester- hour fall 2000 interdisciplinary offering. In my opinion, there are three principal advantages to constructing an undergraduate core curriculum science requirement around such a theme:

- With the possible exceptions of impending revolutions in molecular genetics and artificial intelligence, no other topic is more likely to dominate the interface between science, society, and politics during the twenty-first century than the issue of the environment;

- The topic of the environment lends itself handily to an interdisciplinary format, allowing for the incorporation of both theoretical and practical knowledge culled from the fields of physics, chemistry, earth and space science, and biology;

- Such a theme would allow for the ready incorporation of both laboratory and field research experiences, pedagogic items which many science educators believe vital to achieving an understanding of the "ways and means" of contemporary science among students.

In addition, there are already several excellent "Environmental Science" textbooks on the market (some with an extensive "on-line" component), and my own contacts with various academic publishing firms suggest that several more are in the offing (Arms, 1990; McKinney and Schoch, 1998; Chiras, 2001). Although most of these texts are written by scientists with specialized training in the earth and life sciences, all can easily be supplemented by material in general and organic chemistry, physics, and the space sciences.

IN CONCLUSION

There are no doubt many reasons for a general lack of curricular experimentation in basic science Core courses, though I suspect that most have to do with the reluctance of many science teaching faculty to cooperate across disciplinary boundaries for a variety of reasons: credit-hour production concerns or a fear of losing potential majors; a general lack of non-research based inter-departmental communication; and the problems of instructional compensation associated with interdisciplinary efforts in general. Whatever the reasons, it seems clear that, from the standpoint of achieving even a modicum of science literacy—or even science appreciation—across the full breadth of the natural sciences among a majority of our collective graduates, what we are doing now is not working, and it may be time to try a new tactic.

Most working research scientists are well aware of the fact that the old disciplinary boundaries between the natural sciences—physics, chemistry, biology, earth sciences—are fast becoming obsolete. In the laboratory setting today, such specialists as molecular biologists, quantum physicists, organic chemists, computer scientists, and ecologists can frequently be found cooperating on a variety of complex projects including environmental science, sub-tropical health issues, and the photo-reconnaissance and surface sampling of other worlds. It is perhaps time that we recognize this "blurring" of disciplines within our science classrooms as well.

No other academic units on our various campuses seem as poised to pioneer such changes as do Honors Programs. While most do not have the capacity to effect major changes, if any, in Core Curriculum requirements, many have the freedom to experiment with and perhaps "test" new curricula, and to try to model what educators refer to as "best practices." As Sam Schuman points out in his essay later in this issue (*Cultivating: Some Thoughts on NCHC's Future*):

> *...real excellence in undergraduate teaching and learning requires a certain daring, a willingness to experiment. Liberal education demands the liberation of open minds. While respecting and cherishing classical texts and classroom techniques which time has proven valuable and effective, we need to be the advocates as well of the risky, the new, the untried.*

In our undergraduate introductory science curricula, it seems to me time to try the risky, the new, and the untried.

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Table I

Hazen and Trefil (1991) contend that most scientists will basically agree on which are the most important and fundamental ideas underlying all of contemporary science:

1. The universe is regular and predictable
2. One set of laws describes all motion (Newton's Three Laws of Motion)
3. Energy is conserved (First Law of Thermodynamics)
4. Energy always goes from more useful to less useful forms (Second Law of Thermodynamics)
5. Electricity and magnetism are two aspects of the same force (electromagnetism)
6. Everything is made of atoms
7. Everything—particles, energy, the rate of electron spin—comes in discrete units, and you can't measure anything without changing it
8. Atoms are bound together by a kind of electron "glue"
9. The way a material behaves depends on how its atoms are arranged
10. Nuclear energy comes from the conversion of mass
11. Everything is really made of quarks and leptons
12. Stars live and die like everything else
13. The universe was born at a specific time in the past, and it has been expanding ever since
14. Every observer sees the same laws of nature (Einstein's Special and General Theories of Relativity)
15. The surface of the earth is constantly changing, and no feature on earth is permanent
16. Everything on earth operates in cycles
17. All living things are made from cells, the chemical factories of life
18. All life is based on the same genetic code
19. All life forms evolved by natural selection
20. All life is connected

Table II

The Mythology of Western Scientific Materialism: The Evolutionary Epic

Introduction
- An Overview of Mythological Narratives, Religion and the Evolutionary Epic
- Science Illiteracy and the Science Education Crisis
- The Origin and Evolution of Science
- The Scientific Method

In the Beginning…
- Creation Mythologies
- The Large Scale Structure of the Universe
- The Origin, Evolution and Fate of the Universe
- The Motion of Waves
- Light and the Electromagnetic Spectrum
- Stars and Galaxies
- Atomic Theory and the Periodic Table
- The Subatomic Structure of Matter
- The Conservation of Momentum
- The Calculus
- The Conservation of Matter and Energy
- 1895-1925: Thirty Years that Shook Physics
- Albert Einstein and the Theory of Relativity
- Fundamentals of Quantum Theory
- The Copernican Revolution

Terra Firma
- The Origin of the Earth and Solar System
- The Grand Tour
- The Earth Inside and Out: Igneous, Sedimentary and Metamorphic Rocks
- The Age of the Earth
- Continental Drift and Plate Tectonics
- Earthquakes and Volcanoes
- Meteorology
- Climatology

A Small Warm Pond...

- Chemical Bonding
- Stoichiometry and the Concept of the Mole
- Chemical Reactions
- Acids, Bases and Salts: All About pH
- The Origin of Life on Earth
- The Living Cell
- Charles Darwin: The Man, His Time and His Theory
- The Evolution of Life on Earth
- Biological Taxonomy
- Energy and Food Chains
- Mendelian Genetics
- 1900-1953: Fifty Years that Shook Biology
- DNA, RNA and the Central Dogma of Molecular Biology
- The KT Event: The Return of Catastrophism
- The Origin and Evolution of the Human Species

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