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Teaching Relevant Science for Scientific Literacy

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ABSTRACT

It is easy, rewarding, and popular to convert a socially irrelevant science course into a relevant one. I discuss how to do this, why we should, and evidence that relevant science is pedagogically effective and popular. Such courses, taught on every college campus to large numbers of nonscientists, can help overcome America's scientific illiteracy.

Readers of this journal are well aware that America is awash in scientific illiteracy, and of the grave import of this fact. For example, David Goodstein, while praising U.S. graduate education as "the best in the world," observes that "the rest of our educational system is bad enough to constitute a threat to the ideal of Jeffersonian democracy. ...Approximately 95% of the American public is illiterate in science by any rational definition of science literacy" (Goodstein, 1992).

What is the purpose of scientific literacy? The American Association for the Advancement of Science presents a powerful answer:

> Science education...should equip [students] to participate thoughtfully with fellow citizens in building and protecting a society that is open, decent, and vital. ...The most serious problems that humans now face are global: unchecked population growth, the pollution of the environment, disease, ...the list is long, and it is alarming. What the future holds in store for individual human beings, the nation, and the world depends largely on the wisdom with which humans use science and technology. ...The life-enhancing potential of science and technology cannot be realized unless the public in general comes to understand science, mathematics, and technology and to acquire scientific habits of mind; *without a scientifically literate population, the outlook for a better world is not promising* (Rutherford and Ahlgren 1990, pp. v-vii, italics added).

In speaking with a variety of groups, I often begin with this question: Have you encountered, in any science course at any level, a significant discussion of any science-related social issue, such as population growth or environmental pollution? Very few raise their hands. Thus, nearly all previous science courses turned out to be largely socially irrelevant. In my own field, physics, perusal of introductory textbooks supports this conclusion. So it appears that, on the one hand, "the outlook for a better world is not promising" unless our science teaching is socially relevant, but that, on the other hand, essentially none of our science teaching reflects this fact!

It is the thesis of this paper that liberal-arts science courses can easily be made socially and culturally relevant, and that doing so improves their pedagogy and their appeal and can help overcome America's scientific illiteracy.

It is surprisingly easy and fun to change an irrelevant science course into a relevant one. This paper describes principles that have worked in my college-level liberal-arts physics course, but these principles apply equally to all the sciences, and to high school as well as college teaching. The following sections discuss five general principles, critical thinking, an exemplary societal topic (global warming), and evidence that relevant science is pedagogically effective and popular.

FIVE PRINCIPLES OF RELEVANT SCIENCE TEACHING

Make It Conceptual, But "Numerate"

Scientific literacy calls for understanding, not for calculational ability. Even aspiring scientists should begin with non-technical courses (Hewitt 1995; Van Heuvelen 1991), and certainly nonscientists have little need for scientific techniques, but an urgent need to integrate science into their lives.

A careful and patient instructor can express sophisticated science accurately, without technicalities. Brian Greene's *The Elegant Universe* (Greene, 1999) is a fine example. Here is a book that presents string theory along with the fundamentals of general relativity and quantum field theory, without oversimplification, in language that is accessible to nonscientists, without algebra or other technicalities. It can be done.

Technical terms should never be introduced for their own sake, or because students "should" know them (Arons 1990). Introduce scientific terms only when they are useful in describing or understanding a significant concept. And introduce the concept first, convince students that it is useful, and only then give it a name. It's the idea, not the name, that is important.

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I hasten to add that nonscientists do need certain quantitative knowledge: the metric system, graphs, probabilities, percentages, efficiencies, estimatation, powers of ten, exponential growth, and proportionalities. In my experience, nonscientists can develop these abilities, once they see the relevance of the course to their own lives. In fact, many students overcome their math anxiety as they develop these skills. Algebraic formulations, on the other hand, generally magnify math anxiety while detracting from the underlying concepts to become a sensitive and distracting focus of the course.

Briefly, liberal-arts science should be *conceptual* and *numerate* but not *algebraic.*

Make It Interactive

At least since Socrates, good teachers have known that teaching by dialogue works better than teaching by telling. A convincing body of evidence shows that concept-based interactive engagement methods are far more effective than straight lecturing in teaching physics (Hake 1998), and I suspect that similar conclusions apply to other sciences. Interactive methods have certainly worked for me, stimulating active involvement by students even in classes of over 200. These techniques, by encouraging less-motivated students to think for themselves and less-confident students to express themselves, work especially well with non-scientists.

I use extensively the interactive technique described by (Meltzer and Manivannan 1996). All students receive a permanent packet of six "flashcards" with large letters A through F printed one letter per card. At several points in each class meeting, I project a multiple-choice conceptual question on the overhead, and ask them to hold up the card(s) showing the correct letter(s). Usually, 10-50% miss the question, in which case they discuss it with their neighbors. I walk around, sometimes joining the discussion. Eventually, they "vote" again. If more than a few still have it wrong, we discuss it further. During most class meetings, one flashcard question becomes a 1-point pop quiz, for *extra* credit--so that they look forward to it. In the spirit of group learning, the entire class gets the point provided that 90% show the right answer after discussion among neighbors. They have an incentive to get it right, and to teach their neighbors.

There are many other interactive techniques: brainstorming, provocative discussion questions, and verbal questions to the class, for example. Use them all, to keep the class actively thinking.

Trim the Details, and Unify

In 1990 the American Physical Society and the American Association of Physics Teachers sponsored a session entitled "Slimming the Bloated Elephant," on reducing and managing the encyclopedic profusion of topics usually found in introductory physics courses (APS 1990). The session recognized that courses a mile wide but only an inch deep create more confusion than enlightenment. It is especially important to trim courses for nonscientists, because force-feeding these students will quickly confirm their distrust of science courses. Fortunately such courses, not being burdened by specific professional demands, are easy to trim.

The key in deciding what to omit is to begin from the opposite question: "What to include?" Plan your course with no preconceptions about what "needs" to be "covered," decide on achievable general goals, and include *only* those topics that are really relevant to those goals. Ask why non-scientists need to know each topic, and omit any topic for which a convincing answer is difficult to find. Resist the temptation to include a topic simply because other introductory courses include it, or because it amuses you, or because students "should" learn it. If a topic *really is* all that important, then it should be implied in your general course goals.

One reason nonscientists find science courses baffling is that they can't see the forest for the trees. Even after you reduce the number of "trees" (topics), students might still have trouble distinguishing big ideas from details. They need a roadmap. Thus, tie the course together with a few recurrent unifying themes that reflect your course goals. For example, "how do we know?" (scientific methodology) should be a theme of every introductory course.

Make It Modern

Students deserve to know our best current description of the natural world. Older theories can be enlightening, but the focus in science literacy courses should be on *current* understanding.

Unfortunately, introductory courses often lag far behind modern developments, even when those developments are decades old and not in serious doubt. One observer of science education and textbooks, writing in the journal *Science*, states that "the average high school graduate is unlikely to know, least of all appreciate, the numerous, life-changing discoveries that have taken place in the 20th century. ...The universe looks different. ...The great majority of people do not even realize that a revolution has taken place" (Tachibana, 1998). Tachibana provides telling evidence of this in Japan, but he "suspect(s) that there is little difference in this regard with textbooks of other countries."

My own field, physics, is especially prone to this problem, dwelling on theories that were drastically modified at the beginning of the *previous* century. Although the quantum and relativity theories have long been our basis for understanding the physical universe, most introductory courses still nearly exclude them. Although educators recognize this problem (Holbrow 1995; Howes 2000; Resnick 1997), introductory courses still dwell overlong on

Newtonian physics with perhaps a few lectures, at the end of two semesters, on the earliest "modern" (a misnomer for century-old physics!) developments.

"Pedagogical inertia" is one reason we do not update our courses. Dropping an older topic brings complaints from teachers who can't bear leaving out their long-time favorite, or from an examination committee that always covers it. So, new topics get added to, rather than substituted for, the old ones, the course becomes encyclopedic, and there is no time for the new topics. This problem is a natural consequence of scientific progress. The solution is to ruthlessly trim the older details (see the preceding subsection), retaining only what is needed to understand today's view of the universe.

Make It Social

Industrial democracy cannot survive unless citizens are literate about science-related societal issues. If citizens cannot vote intelligently on these matters, then democracy will succumb either to gross misuses of technology, or to a non-elected scientific elite that will make these decisions. Indeed, thousands of leading scientists, including a majority of the world's living Nobel Prize winners, has warned that technology-caused disaster is already overtaking us (UCS 1997).

It is possible to achieve this social goal, within a limited time budget, in general science courses. You can do this by including a sampling of social topics within a standard course structure, using them as illustrations of the basic science. Social topics can do double duty by replacing the standard problems and applications that occupy so much time in more technical courses, while providing vital new information in their own right. A class period devoted to atmospheric ozone depletion, ten minutes on transportation issues, or twenty minutes about the steam-electric power plant's environmental implications, accomplishes wonders in awakening students to the importance of science in their own lives. Although they occupy only a small fraction of the course, such topics impart an unforgettable relevance that affects students long after the final exam. Furthermore, these topics contain plenty of good science in their own right, are perfect for teaching critical thinking, stimulate class discussion, and make fine class projects.

Rather than adding them on at the end, integrate social topics into the fabric of your course. Emphasize general scientific principles when discussing societal applications. Present plenty of evidence, and employ critical thinking, especially if the issue is controversial. Keeping in mind that the exams define your real course goals, be sure to examine over these topics.

As an example, a later Section discusses how global warming might be integrated into a general science course.

PHILOSOPHY, CRITICAL THINKING, AND PSEUDOSCIENCE

Science has always had a strong philosophical influence on our culture, as for example Newtonian physics did in establishing the intellectual background for the American Revolution. Because philosophy has, in the long run, a stronger effect on society than do the more immediate social issues, it should be explicitly included in introductory courses.

Explore the historical context and cultural impact of such ideas as atoms, energy, evolution, the big bang, cosmology, the geological ages, and genetics. Open up, for class discussion, such questions as the nature of scientific knowledge, the idea of scientific progress, materialism, the origin of life, the relation between technology and ethics, the significance of quantum theory, and the origin of the universe. The most significant science-related philosophical topic is scientific methodology itself. Many educators urge this as the centerpiece of science literacy.

Americans must begin to think critically and scientifically, especially about public policy. The basic contradiction of our time is the one between the rationality of scientific knowledge, and the irrationality of the culture within which that knowledge is so powerfully used. The twentieth century has been torn by political, religious, ethnic, national, and economic ideologies, all of them held with complete conviction and yet most of them in utter contradiction with each other. As a result, the potentially helpful power and insight of science has been often overlooked or misused, and scourges such as war, prejudice, fanaticism, needless disease, overpopulation, and pollution, have flourished. The danger in these ideologies lies not so much in the beliefs themselves as in their absolute nature. Even wrong or harmful beliefs can be corrected if one is willing to trust experience and be intellectually honest, while correct and healthy beliefs can become dangerous if accepted uncritically or absolutely.

Thus, in thinking about how we might do better in the twenty-first century than we did in the twentieth, we should perhaps ponder science's most basic value: *All ideas are subject to testing by experience and to challenge by critical rational thought.* This code, often called "critical thinking," might itself be science's most important benefit. This is not a new idea: Educators such as John Dewey and Karl Pearson urged a century ago that science be taught in order to instill critical thinking. Perhaps I am naively optimistic, but it seems to me that a consistent emphasis on scientific methodology in all science classes at all levels could help pull the world through its present crisis of emotionally-held belief systems. (Hobson 1996) has more details.

As one aspect of critical thinking, science education should elucidate pseudoscience. A 1996 *Science* editorial observes that "This is a tough time for many scientists. The ... nation as a whole shows alarming antiintellectualism, most notable recently in the revival of efforts to ban the teaching of evolution or to insist that 'creation science' be given equal time in grades K-12. Our institutions of higher learning do not insist that undergraduates master the fundamental elements of scientific understanding..." (Greenwood 1996). The 1999 decision of the Kansas State Board of Education to strip from the Kansas state science education standards all mention of the Big Bang, radioactive dating, continental drift, the age of Earth, and any reference to biological evolution, illustrates the implications for every field of science (Scott 2000).

The pseudoscience danger goes deeper than naive ignorance. Anti-intellectual "true believers" necessarily regard knowledge of the real world to be a threat, because such knowledge might disturb their carefully-maintained belief system. True believers are not merely "ignor-ant" of knowledge, they actively oppose it. But in this scientific age, true believers feel required to ape the methods of science. Hence, pseudoscience. Pseudoscientific beliefs are surprisingly widespread in our culture even among public school science teachers and newspaper editors, and are closely related to scientific illiteracy (Holden 1990; Norman 1990; Miller 1985).

Topics such as evolution and the big bang will disturb some students' religious beliefs. Although instructors should not shy away from this religious connection, it is imperative to respect all students' religious views. Thus I prefer to keep my own religious views to myself, while encouraging and respecting student presentations of their own views. I present sensitive ideas as "the scientific consensus" rather than as established truth (such non-dogmatism is, after all, the central message of the scientific method), emphasizing that I do not require students to believe this consensus, but only to know what it is and why scientists accept it.

AN EXEMPLARY SOCIETAL TOPIC: GLOBAL WARMING

Although it is easy to get into lengthy class discussions about global warming, I restrict this topic to one 50-minute period. I will present here some teaching ideas from the perspective of introductory physics, but this topic is also rich in chemistry, geology and biology, and could be taught within any of these fields. For further details see (Hobson 1999).

As prerequisites, the course should have already presented conservation of energy, the second law of thermodynamics, the electromagnetic spectrum, and a rudimentary view of atoms and molecules. Survey the chemical composition of the atmosphere, listing (perhaps by class "brainstorming") some of the many trace gases that collectively form much less than 1% of the atmosphere. One example is ozone, which protects life from deadly ultraviolet radiation, and is present at less than one part per million--imagine a single person in a city of over one million. The atmosphere is indeed a delicate and diverse web containing myriad threads vital to life. It is not surprising that Earth's first truly global environmental problems, such as ozone depletion and global warming, have arisen in this complex and tenuous medium, for the chemical that you release today will mix through the entire atmosphere within just a few years.

Review the electromagnetic spectrum, emphasizing the infrared, visible, and ultraviolet radiations that dominate the solar spectrum. Discuss the flow of solar energy as it is received and re-emitted (as infrared) by Earth. Describe this energy flow through a hypothetical Earth whose atmosphere lacks only the trace "greenhouse gases," primarily carbon dioxide and water (Figure 1). The temperature of this hypothetical Earth would be -19^{o}C, the temperature of the top of the real Earth's atmosphere. Now describe the vastly different energy flow through the real Earth that contains the "greenhouse gases" (Figure 2). These trace gases absorb and re-emit in the infrared, creating an “infrared recycling” that is enormous in energy terms. This "greenhouse effect" makes Earth 33^{o}C warmer than it would be without these gases. The effect is analogous to a blanket trapping your body's radiation, or the glass on a greenhouse warming the interior by trapping infrared.

It is remarkable that these tenuous gases can so strongly leverage the energy relationship between the Earth and the sun. It's as though a small tail were wagging a huge dog.

During the industrial age, humans have increased the atmospheric CO_2 concentration by 30%, from 280 ppm to over 360 ppm. Without drastic action, atmospheric CO_2 could double by 2050. These excess emissions are causing global climate changes, known as "global warming."

Although it has been a controversial topic, scientists have recently come to a consensus that global warming is occurring now. Thousands of international scientists are about to issue their third 5-year report (for the previous report, see (IPCC 1996)) representing the current state of scientific understanding of the issue. As of this writing, the draft of the new report concludes "that there has been a discernible human influence on global climate," i.e. that global warming is occurring. The draft states further that "three of the last 5 years have been the warmest in the instrumental record, which goes back 140 years. And three different records of temperature preserved in tree rings and elsewhere have now revealed the large, abrupt 20th-century warming to be unique in the past 1000 years" (Kerr 2000).

As a leading example of social decision-making and the importance of scientific evidence in issues of potential technological risk, global warming can furnish a springboard for education in critical thinking. A handful of scientists such as Richard Lindzen and S. Fred Singer, together with some businesspeople, publicists, and politicians, insist that there is insufficient evidence to warrant serious concern about global warming. Students can compare these views with the evidence, and with the IPCC conclusions (Ehrlich and Ehrlich 1996).

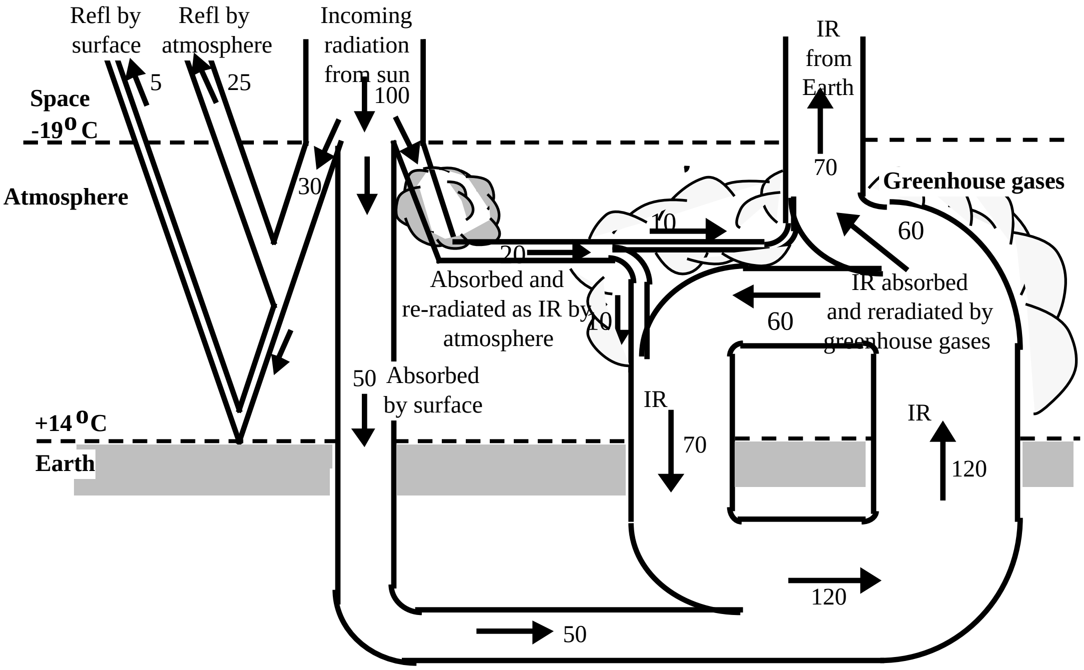

Figure 2. Energy flow near Earth's surface. The large difference between this and Figure 1 is due to trace amounts of greenhouse gases, gases that have large leverage over Earth's energy flows.

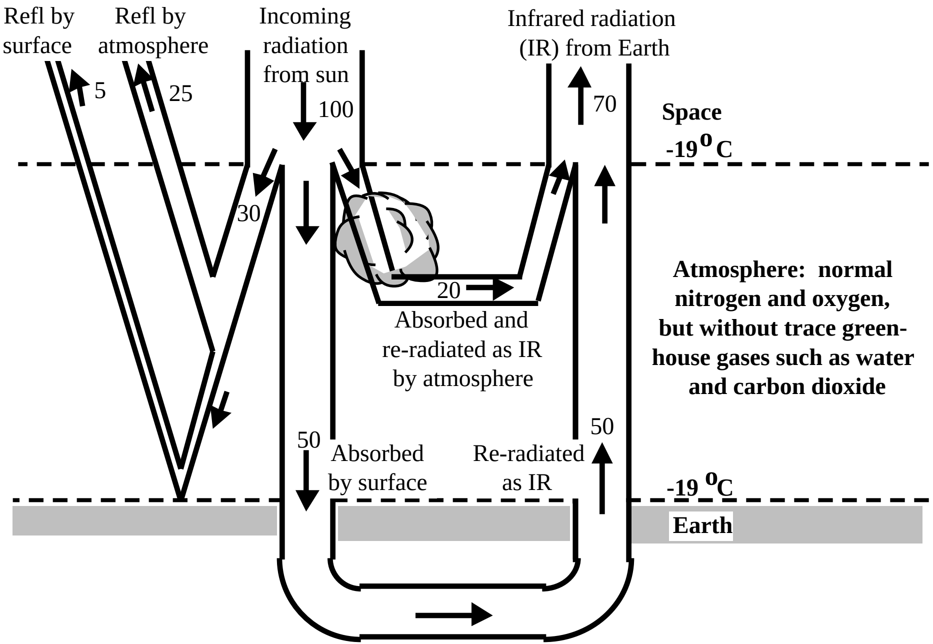

Figure 1. Energy flow near the surface of an imaginary Earth that has no greenhouse gases but that has an otherwise normal atmosphere. The numbers represent percentages, relative to the radiant energy received from the sun.

According to the IPCC, a CO_2 doubling would increase Earth's average temperature by 1-3.5°C. Discuss the computer models of the atmosphere upon which such predictions are based, and the validation of those models (Schneider 1989). Present some of the data, such as the striking 1000-year temperature graph appearing in (Kerr 2000). The polar ice core CO_2 and temperature records are revealing (Figure 3). This record shows (1) a close correlation between CO_2 levels and temperature during 160,000 years, (2) that the difference between an ice age and an interglacial warm period is only about 5°C, and (3) CO_2 levels remained in the range 200-290 ppm for 160,000 years, until jumping to 360 ppm during the past 200 years.

Predicted and observed effects of global warming include heat waves, sea level rise, coral reef bleaching, downpours, heavy snowfalls, flooding, drought, fires, shifting climate zones, plant and animal range shifts, melting glaciers, enhanced warming of the Arctic and Antarctic, melting polar ice, increased or decreased plant growth and agricultural yields, and the spread of disease vectors. See (UCS 1999) for details and references on these global warming "footprints."

Fossil fuels are the largest source of global warming, although chlorofluorocarbons and methane contribute together about 30% of the problem, and deforestation contributes about 20%. Emissions can be reduced by energy efficiency (i.e wasting less), lifestyle changes that reduce fossil fuel use, switching to non-fossil energy sources, and preserving and expanding forests. As a group "brainstorming" exercise, ask your class to compile a list of suggested reduction measures. The innovative discussion in (Hawken 2000) points to massive current inefficiencies, and to money-*saving* efficiency measures that might by themselves solve the problem.

The needed reductions are massive. To merely hold long-term temperature increases to an estimated 1-2°C, the long-term CO_2 concentration should be held to 350-400 ppm. Achieving this requires a 50% reduction in annual global *emissions* (Azar 1997).

Figure not available in Web Version

Fig. 3. Global average temperature and carbon dioxide concentration, 160,000 B.C.-present.

This seems daunting, given rapid global industrialization. But the situation is far from hopeless. In 1997 in Kyoto, Japan, the industrial nations agreed to an average 5% emissions reduction by 2012. Many analysts suggest that incorporating environmental costs and benefits into the economic system could rapidly produce vast changes (Daly 1996; Roodman 1998; Hawken 2000). Recent evidence indicates that the link between fossil fuels and economic growth is weakening: global emissions fell 0.2% during 1998 while the global economy grew 2.5%, China's emissions fell 4% despite strong economic growth, and U.S. emissions held steady despite a booming economy (Brown 1999). The success of the 1987 treaty to protect atmospheric ozone provides a hopeful example of quick massive action on a huge environmental problem (Hobson 1999). Global warming can be solved, if we have but the wit and the will.

AN EXPERIMENT IN RELEVANT SCIENCE

During 1975-1999, I developed and taught a course of the type described here. This section describes this experiment in science education (Hobson 1995).

The course began in 1976 with 30 students. Previously the physics department had offered a traditional physical science course, one with no "impure" (interdisciplinary) topics such as scientific methodology or global warming, a course that students avoided in droves. By contrast with the fading traditional course, the new course doubled its enrollment every two years until, in 1982, it reached 220 per semester where it was forced to remain until 1995 because of insufficient teaching resources and the low priority given to courses for non-scientists. Some 23% of our university's 9400 non-science undergraduates were then taking this physics course at some point during their college career. In 1995, the course was finally allowed to expand, to 330 per semester taught in two sections. Not only did all 330 seats fill immediately, they filled faster than competing introductory courses such as geology, biology and astronomy.

Statistics on class attendance and exam scores provide some evidence that the "lectures" (which were significantly interactive) were pedagogically effective. For example, during one typical semester, those students with an attendance record of 85-100% had an average final exam score that was 16 percentage points (1.6 letter grades) higher than those students with an attendance record of 0-50%. Because the final exam is comprehensive and focused on the significant ideas, it is a good measure of course knowledge. This correlation is not conclusive evidence of course effectiveness, since better-attending students may also have naturally higher ability. But one suspects that at least some of this "gain" was due to attendance.

This experiment underscores the science community's own culpability for science illiteracy. A survey of 1800 campuses indicates that only about 50% offer any physics for non-scientists, and that most of the offered courses are quite small (Henderson 1995). Yet the experiment indicates an enormous potential for high enrollments and learning gains in such courses.

Consider the elementary education students who will teach the next generation, the journalism students who will report the science news, the political science and law students who will go into government service, or the business students who will develop new technologies and hire scientists: All of these are non-scientists. We ignore them at our peril. Our attention, or inattention, to these students has a large future multiplier effect.

I suggest the following practical science education goal: Biologists, geologists, chemists, astronomers, and physicists on every campus should see to it that a large fraction, say 50%, of all non-science students complete a socially relevant general science course in their own field.

In other words: Every non-science student should graduate with several *socially and culturally relevant* general science courses under their belt.

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View Scientific Literacy Research Papers on Academia.edu for free.Â During teaching, studying and learning processes, teachers and students therefore discuss what the meaning of knowledge and skills is for the students' life now and in the future. Preservation of life requires concern about the environment, and a way of living that takes care of the environment. The basis for this is created at schools.Â Turtles are animals vulnerable to extinction. Scientific literacy is the main goal of the science curriculum. Augmented Reality technology is very helpful in the education process of animal conservation. Turtle mobile learning is one of the scientific literacy sources developed on Android smartphones. Teaching literacy is not always explicitly done in science. However, if students are to understand and take part in science, they need to make sense of a variety of words, both scientific and non-scientific. In this way, good literacy is as important to a studentâ€™s science education as an understanding of evolution or atomic structure. If students canâ€™t write or talk about science, they probably donâ€™t understand it. Donâ€™t be fooled. Complex literacy is the ability to use and speak within the literate terms of that discipline. It is the ability to create something that someone else with that literacy can read and understand. Itâ€™s easy to see how wide and varied that definition is, how much room for complexity that leaves us. But how can we use such a wide definition in teaching?Â This idea of different literacy skills and the importance of teaching towards literacy or intelligences has been increasingly important in the last few decades. Ideas like Howard Gardnerâ€™s multiple intelligences, discussed in his text Frames of Mind, have driven and shaped teaching philosohpy. Scott Seider chronicles this change, and his own person experience in the article, â€œAn Educatorâ€™s Journey Toward Multiple Intelligences.â€ Scientific literacy â€“ what it is, how to recognize it, and how to help people achieve it through educational efforts, remains a difficult topic. The latest attempt to inform the conversation is a recent National Academy report "Science Literacy: concepts, contexts, and consequences." While there is lots of substance to take away from the report, three quotes seem particularly telling to me.Â Constructing a literate answer implies two distinct abilities: the respondent needs to be able to accurately interpret what the question asks and they need to recognize what an adequate answer contains. These are not innate skills; students need feedback and practice in both, particularly when the question is a scientific one.