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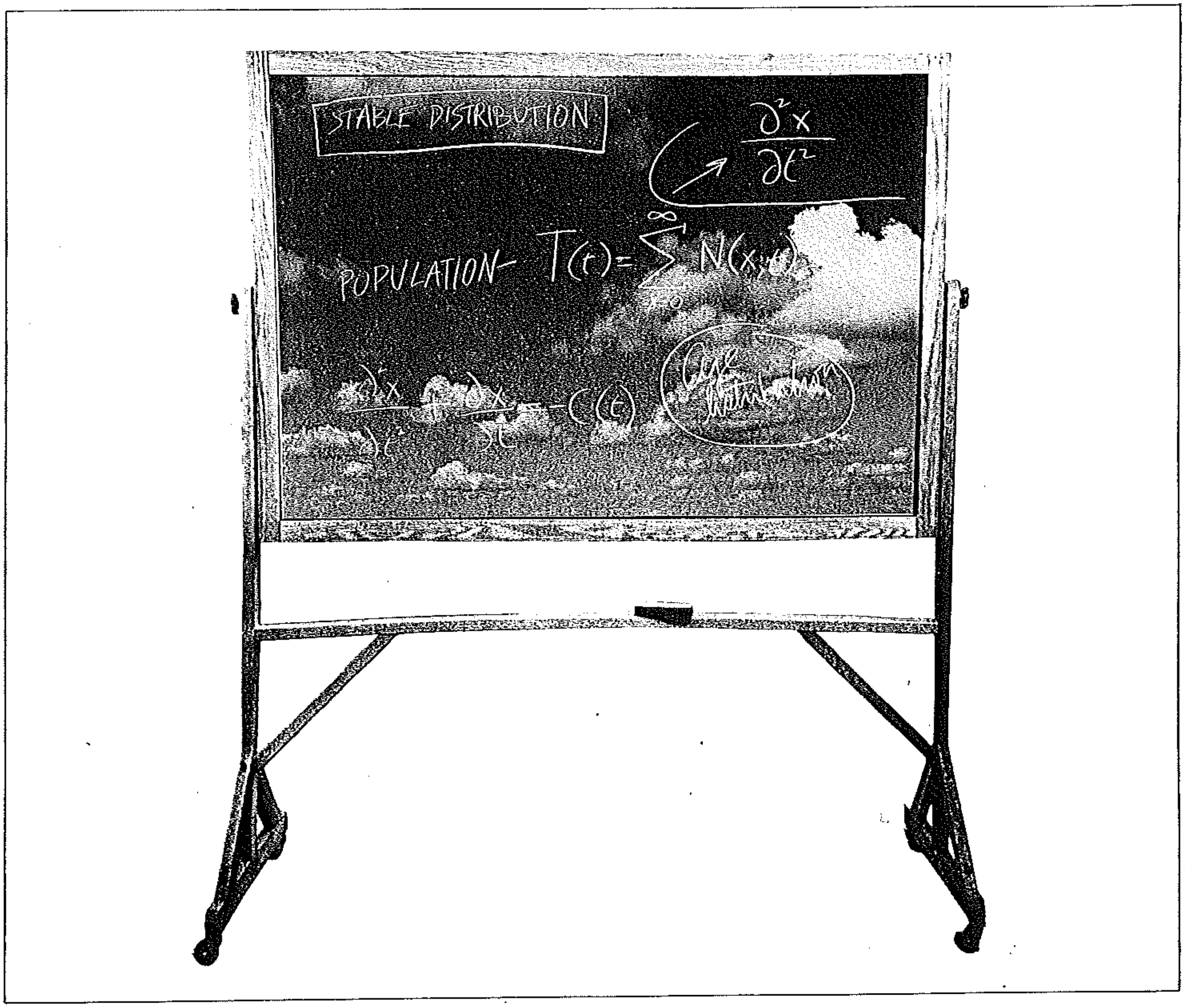
Teaching and the



environmental challenge

Educators can find direct connections through the subject matter of physics, the physicist's approach to problem solving and his special understanding of nature.

Robert H. Socolow

Underlying the increased concern for environmental quality is the realization that the earth is vulnerable. This is a quantitative concept: the disturbances that Man is capable of generating on the earth are capable of substantially altering its character. Until recently Man's activity could not affect the viability of the earth in a substantial way in a period as short as a generation. Man's understanding of the earth's processes was also insufficient to detect and interpret the slower effects that he *was* responsible for. As Man's capacity to harm the earth increases, his capacity to monitor and control also increases—fortunately. The task ahead is to refine our understanding of the interaction of Man with his environment, to disseminate a consciousness of this interaction, and to make adjustments in values and behavior where necessary.

Several specific problem areas are likely to lead to modifications of social and economic behavior; they are:

▶ Resource depletion, which will change the relative costs of certain raw materials, give greater gravity to recycling efforts in some areas, and require unfamiliar types of rationing.

▶ Land use, where irreversible changes are most serious, including the loss of wilderness.

▶ The disappearance of species that had shared the planet; the task of resurrecting vanished species is likely to remain beyond the capabilities of the biologists, and thus the fact that Man, through greed and carelessness, has endangered numerous species of birds, whales, and other forms of wildlife, implies an impending irreversible loss of variety in nature.

▶ Pollution, threatening the integrity of our climate and water supply.

Robert Socolow is associate professor of environmental science at Princeton University.

Physicists, and more particularly physics teachers, have a natural tendency to feel that these issues lie outside their domain of competence. It is my purpose here to try to probe this argument and ultimately to refute it. I am concerned in particular to establish some connections between the *physics classroom* and the environmental challenge.

The study of physics is helpful preparation for environmental problem-solving in several ways. The most direct connection is through the subject matter: The gas laws and the earth's atmosphere, nuclear physics and radiation standards, Carnot cycles and thermal pollution. But I will deal first with deeper and even more important connections.

Attitudes to be stressed

Physics is noteworthy for its skepticism and irreverence, qualities of mind of great value in dealing with the environmental agenda. We are faced, in the next few decades, with constraints on human activity that are unprecedented and for which our psyches and methods of social organization have left us unprepared. Over the centuries, men have been engrossed in the task of protecting themselves from nature's excesses—of cold and fire, wind and water; now, relatively suddenly, men must discover ways of protecting nature from their own excesses. Perhaps the most significant message that the physics teacher can impart, even to a casual student, is that such a rapid extension of consciousness has many precedents in the history of physics: the central scientific dogmas of one generation have often been overhauled by a later one. Where jurisprudence, by contrast, is founded on the idea of *gradual* change, physics is a story of continual upheaval and reorientation.

The physics teacher might also consider the utility of communicating the internationalism of physics to his students. The fact that physicists are comfortable with a global perspective is in a large part the result of working with subject matter that retains its validity from one country to another. Moreover, experiments designed to study the earth from space, worldwide programs to coordinate ground-based measurements in geophysics, measurements in astronomy using two telescopes on opposite sides of the earth, all reinforce the global point of view. A very serious deficiency of most current discussions of environmental issues in the US is the absence of a global perspective, and thus whatever the physics teacher can do to communicate the internationalism that is deeply imbedded in his field ought to have a salutory effect on his students' capacity to grasp an essential feature of many of the most serious environmental problems.

The teacher might also give greater attention to the *quantitative styles* of physics. Especially I would single out the "zero-order approximation," with all the knack for making rough estimates that this involves. These skills need to be more sharply identified and to be directly highlighted in physics curricula. Although most physicists know that the ability to estimate is a central part of their craft, they tend to belittle this ability and do not try to teach it in elementary physics courses. (The emphasis on estimation in the first chapter of Robert Adair's *Concepts in Physics*[1] is a pleasing exception.) All too often, physics teachers and textbooks stop an analysis when an answer has been reduced to an *algebraic* formula, without working out numerical examples. Yet the student expecting to confront the technical issues of our day will be greatly handicapped without a feel for numerical argument; he will be several steps ahead if he has learned to handle big numbers and put small corrections in their place.

The teacher might also provoke a fruitful discussion of "time-frames." Physics challenges the student to become adept at conceptualizing over a wide range of time-frames, from the picosecond time-frame of electronics to the billion-year time-frame of astrophysics. The student may be led to discriminate among the variety of time-frames that are superimposed in environmental issues: a range of time-frames intrinsic to nature (shorter and longer atmospheric residence times, for example) and another, overlapping range of time-frames intrinsic to the perspectives of the people involved.

The students will probably agree that the time-frame of a legislator worried about re-election is too short to grapple with the environmental agenda. They may also sense that there is a time-frame that is too *long:* We scientists can be as encumbered as politicians because the longest time-frame often most appeals to us. I would suggest that a time-frame of 10 to 40 years, beginning now, is the time-frame of the most significant environmental discourse: the time-frame during which population, productivity and pollution are likely to deviate substantially from current trends, whether for planned or unplanned reasons. This is a time-frame relatively unfamiliar to all of us (perhaps least unfamiliar to new parents). By contrast, the physicist's *forte* may be a more far-ranging speculation: Freeman Dyson[2] contemplates taking a planet apart and building a spherical lattice that will harness all 4π steradians of solar energy. In *that* time-frame, all constraints on the energy budget of the earth get set aside. (Dyson is not advocating this project; he is interested in guessing what technological societies elsewhere in space may have done. Others, linking the exploration of space with the finding of a new, unpolluted home for Man, have their time-frames seriously confused.)

The student has had a worthwhile course if he emerges more skeptical of conventional wisdom, more internationalist, calmer in the presence of big numbers, and with a time-frame stretched just the right amount. But there is another level of communication between teacher and student in physics courses that is at least as critical to the student's capacity to deal with the problems of our planet. In physics courses the teacher has an opportunity to communicate a respect for and a love of *nature.* Respect and love are not the same thing, and both are crucial. The physicist's respect is intrinsic to his knowledge that nature has not been designed for Man's convenience; this is built not only into the fundamental laws of physics but also into Murphy's Law: in the laboratory, if something can go wrong, it will. That law is not a bad place to start from in contemplating a pipeline across the arctic tundra or a scheme to divert the flow of Siberian rivers. The love of nature is even more essential; above all, environmental problems need the attention of those who *care* about the outcome.

Laws versus data

The physicist's love for nature operates at several levels (as love usually does), and he faces difficult choices in determining which levels to try to communicate in the classroom. Along with an instinctive preference for distant future and past, we physicists have a preference for the very large and the very small. Work on these frontiers is not going to help deal with most of the pressing environmental problems, unless some unexpected discovery in one of these domains makes contact with the ordinary macroscopic realm, a possibility that can never be excluded. Teaching about these frontiers is still essential, not only to enlarge the student's appreciation of the manifestations of order in the universe, but also to make him aware that these endlessly open areas of knowledge will be a source for dynamic growth even when other avenues of growth (population, resource throughput) are someday closed.

The physics tradition, however, contains ample physics bearing directly on the environmental agenda. In this connection, the imminent return of fluid dynamics to the physics curriculum is welcome. Those of us who were schooled while macroscopic physics was on the back burner have some dietary deficiencies that we will have to struggle to overcome.

The tension within physics and within physicists between the great generalizations (the laws) and the special cases (the phenomenology) is another central fact of the field. As teachers of physics we must accept that tension and must communicate it. We must do justice both to the unifying ideas and to the details of important systems.

It is probable that in recent years we have not done justice to the details, in our attempt to communicate the unifying ideas. We took a whole raft of poorly explained technology out of the basic courses, and we didn't put very much technology back. Most unfortunately, we forgot to tap geophysics for examples.

Yet nearly every topic of a physics course permits enrichment with the detail of our surroundings: teaching about electromotive force, include something about thunderclouds;[3] teaching about black-body radiation,

Work local technology into your course

You can stimulate an interest in technology, and its influence on the environment, among your students by a critical examination of familiar services and problems that might otherwise go unregarded. Here are some questions you might ask:

How much power do the **overhead power lines** carry? How and where was the power generated, where is it going, and how efficiently will it do its work before becoming heat? What does it cost?

Ask a similar set of questions for the **gasoline** in the filling station at the corner and for the **coal** or **oil** on its way to the home heating unit.

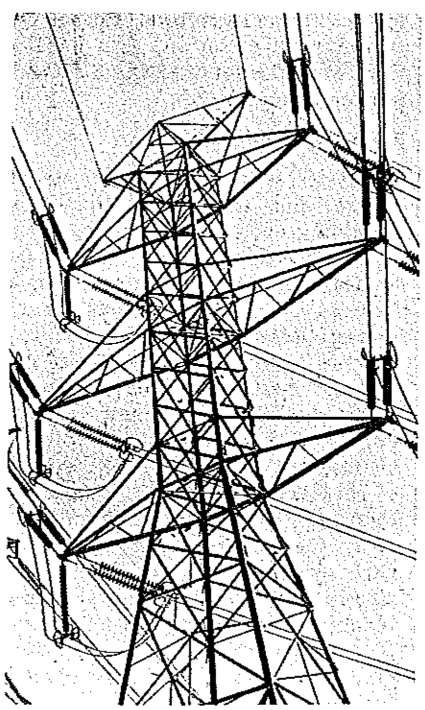
Ask where the **tapwater** comes from and where it is going.

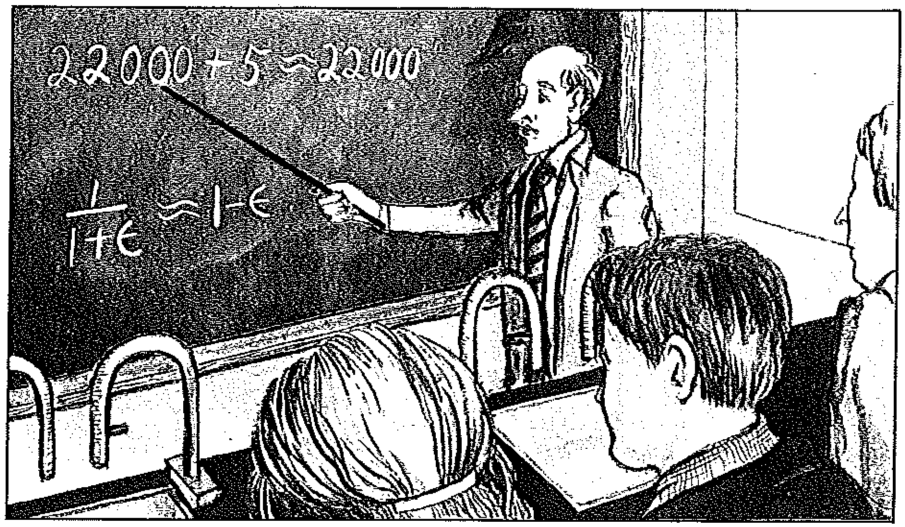
Ask which nearby facilities monitor **air quality,** what they measure and what they find.

Ask what **radiation doses** are delivered by the x-ray machines in the nearest hospital and how they are measured.

Look for examples of **local technology gone wrong:** John Harte at Yale had his students verify that a faulty tide gate was affecting the salinity of New Haven's Mill River.

Look for ways to tie into **environmental research programs:** Charles Creager of Kansas Weslyan had his students collaborate in a governmental study of the mercury level in pheasants.





The zero-order approximation. Physicists should call more attention to the way they add and divide; the ability to estimate is a central part of their craft.

mention albedo and calculate the earth's temperature;[4] teaching about entropy, calculate the minimum energy to desalinate sea water;[5] teaching about radioactive decay, work out the radiation dose a person gets from the potassium-40 in his body;[6] teaching that the atomic constituents of matter are separately conserved unless nuclear energies are available, ask for a discussion of the implication for moon travel of the fact that there are probably no protons on the moon. (To an excellent approximation, the moon has no protons, other than those blown by the solar wind, if it has neither free water nor hydrated crystals such as clays, mica and gypsum. When moon rocks were studied in the laboratory no such crystals were found. Their absence, it is usually argued, rules out the possibility of free water in a permafrost layer beneath the surface, because such water, it is believed, would have had to be accompanied by hydrated rocks. I do not have the background to evaluate a recent contention by a group at Rice University that they have detected water vapor on the moon. The conservation law for hydrogen makes the issue critical.)

In the liberal-arts colleges and in the high schools, the physics teacher is the interpreter of technology as well as science. It is his job to sensitize the students to the technology in their surroundings, just as it is the job of the art teacher to sensitize them to the interplay of shapes in their surroundings. Otherwise, colleges will graduate men and women who are partially blind. There is no one else to do this job.

Getting the students to explore the technology in their *immediate* field of view may be a way to reach many of them. See the box on page 34 for some examples. Exercises like these may develop, in a few students, a serious interest in design and systems engineering; there appear to me to be numerous opportunities for technical and social innovation, throughout the economy, that counters the environmental challenge with strategies for using energy and materials more efficiently.

We are in for a period of adjustment to the constraints imposed by a finite and vulnerable planet. An understanding of how these constraints arise will require a consciousness of the earth as a physical system and of Man's technology that in some instances threatens to overwhelm that system. The physics teacher, as soon as he recognizes that he is responsible for imparting that consciousness, ought to have yet another reason to feel confident that his task is a pertinent one.

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This article is based on a talk presented at the summer meeting of the American Association of Physics Teachers, in Beloit, Wisconsin, in June 1971. In revising it I have benefitted from the helpful criticism from Heinrich Holland and George Reynolds of Princeton.

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