# BUT HOW DO YOU KNOW?

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by

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Imagine a typical introductory-level class in college physics, after an inspiring lecture, when the following exchange takes place:

I: "Now who can tell me something about the hydrogen atom? [long pause] Jennifer?"

J: "The hydrogen atom consists of a proton with an electron orbiting it [reading her notes] -- sort of like a miniature solar system."

I: "O.K.....But what exactly is an electron?"

J: "An electron is an elementary particle with the smallest unit of electric charge." [again from class notes]

I: "How do you know about electrons? Has anyone ever seen one?"

[long, long, long pause]

J: "Will it be on the test?"

This kind of exchange is all too common. With rare exceptions, science textbooks do not address the "How do you know...." questions, and most science courses operate in the same vacuum.

Or, consider this exchange between a teacher and a group of college seniors who are not science majors:

T: "But exactly what is science?"

S: "Science is scientific knowledge - a collection of scientific facts."

T: "Where does this scientific knowledge come from? How do you know that it is true?"

S: "The textbooks say that it is true."

T: "But how do the books know?"

I want to talk with you tonight about what I do -- teach science - an occupation which is a guaranteed conversation stopper at any cocktail party. What do you do?" "I teach physics." "Oh..I could never do that." or "How dull...All those pulleys and things." Teaching science is

a vital and fascinating challenge, always changing, and always demanding one's full attention. It is also an endeavor which not only is in some trouble, but also finds itself to be of ever-increasing importance to a national economy which is losing its world technological leadership. What follows is more random than orderly, more descriptive than analytical, and more personal than detached. I will focus mostly on science for those who are not planning to be scientists, although it cannot really be separated from science or scientists. Much of what I have to say can readily be generalized to all of education, but I will keep things in the context of science education.

I came to my profession honestly. As long ago as I can remember, I have been fascinated by the special way of knowing the world which we call science. Growing up in rural central Florida, in a family which by today's standards would have been well below the poverty line, I nonetheless was encouraged to study and learn things which were well beyond the ken of my parents. A simple "Golden Guide to the Stars" in early elementary school sent me outside into countless clear Florida nights to locate the constellations and to find the planets. A crude toy microscope began to unlock the secrets of the microscopic world by the time I was ten years old, while an Erector set provided a real introduction to the world of engineering design. I was a junior in high school when Sputnik was launched, and through a church youth leader who was a project manager for the ill-fated Vanguard attempt to launch a satellite, I experienced the agony of defeat for an American technological base which had assumed that such glory was its for the taking. I was inordinately fortunate to have consistently had teachers who at worst simply encouraged my curiosity, and at best, provided genuine guidance and inspiration in shaping the directions my curiosity would take. I took this quite for granted, and

for a long time did not realize how rare such teachers actually are.

These people ranged from elementary school teachers who set me free from certain forms of "busy work" to follow my own interests, to a ninth-grade algebra teacher who encouraged me to work all the way through the book and kept telling me about this mysterious and wonderful thing called "calculus," into which I would be initiated in college, to a tenth-grade biology teacher, who made me her student assistant, to an eleventh-grade chemistry teacher, who was an ABD from Columbia with a hundred published papers to her credit and who had taught my father a generation earlier, to a crusty old physics and math teacher who demanded excellence in both. In various ways, each helped me to answer the call to learn and ultimately to teach science. They were characterized by high expectations, by the fact that they knew what they taught, and by honest enthusiasm for subject matter which many of today's youth find "boring."

Lynchburg College faculty - Rosser, Garretson, Freer, Osborne, Mahan - continued the pattern of exceptional science teachers in my life. Whether in class or in the cafeteria, or in a car on the way to the annual meeting of the Virginia Academy of Science, science was spoken, discussed, argued, and treated as a matter of some import to the world beyond the academy. In high school I had seriously considered and rejected the ministry, but as I pondered goals during my senior year in college, I realized teaching was also a calling, one for which I seemed to have some real aptitude, discovered through teaching at summer camp and through work as a tutor and physics laboratory instructor.

So then there was graduate school! At last, an initiation to the "true mysteries." I vividly recall my first graduate class; the distinguished holder of an endowed chair walked into the room, carefully removed and folded his immaculate Brooks Brothers suitcoat, placed the course text on the lectern, and.....began to read it to us. He read to

us for the entire semester, was given the Thomas Jefferson Award for

outstanding teaching, and eventually became the president of the university. The next class was not much better; that instructor informed us that he knew everything there was to know about the subject and that it bored him to tears. In fact, it was so boring that he was not willing to talk about it, and he did not, not once the entire semester. Although we had weekly quizzes and examinations about the nominal subject of the course, he lectured about things which were, indeed, not related to it. This is the same man who came to the final examination in quantum mechanics, the capstone of the graduate physics curriculum and told the class that he assumed that they knew all there was to know about quantum mechanics; therefore, he would give them an examination in acoustics, just to see what they knew about that subject. He did, graded it, and counted the results as the course grade.

Of more than 130 graduate students in physics, only two of us were interested in college physics teaching. For the most part, the faculty let us know that we were wasting their time; that graduate study was for training research scientists and that only those who could not aspire to do "real physics" should deign to teach. I was again fortunate to have a thesis adviser who thought and still believes that teaching is a high calling; she is as proud of what I do as she is of her best researcher. She not only encouraged me as I sought breadth in my graduate studies, she also gave me a philosophy of teaching which has served me well through the years.

I tell you this as a way of prefacing a brief description of the status of science education in America. My story begins with what happens in elementary school, will touch on high school science, and will, of course, talk about science at the college and university level. The picture is depressing and in many ways is worse each year. I do not in-

tend it as a polemic against my colleagues in the teaching profession,

although it may sound that way. It is as much a criticism of what I do as it is of what they do.

Each year, I spend, at the invitation of teachers, several hours doing science presentations for elementary school children. My most recent performance was for 200 second and third graders at Sandusky Elementary School. I do this for several reasons; I have both a parental and a professional responsibility to be involved; the children are most enthusiastic and eager for what I have to share with them; and I know that in many cases, my appearance is the only science activity they see. The curriculum plan for Lynchburg City Schools calls for little science in the primary grades, and for only slightly more in grades 3-5. This curriculum is delivered by teachers who, although dedicated and excellent in their overall teaching, are not prepared to teach any science. Several years ago, I sought and received support from the National Science Foundation to teach a course in elementary physical science for area elementary school teachers. Twenty-eight teachers, who had been teaching for at least ten years, enrolled and were given a simple pre-test as part of the project evaluation. Their responses, to questions which I would characterize as "Boy Scout" science were more appalling than I had feared. Most had no concept of the way scientists think, of what makes science different from other ways of knowing, nor of what one might consider a basic range of scientific knowledge. Half of them did not know that the sun rises in the east. They do now. But, then, few had had any exposure to science other than biology in college, and many had had only biology in high school.

A recent study by the Research Triangle Institute indicates that nationally only one in three elementary teachers has had a college course in chemistry and one in five a course in college physics or physical

science. My experience is that comparable numbers in Virginia are far

lower. Certification requires one year of a laboratory science, which is usually biology or earth science, and one year of mathematics, which typically is a "math for teachers" course. Courses in the teaching of science and mathematics, usually not taught by a scientist or mathematician, are also required. The recent Report of the Governor's Task Force on Excellence will do little to change this educational pattern. It does require elementary teachers to major in a "traditional liberal arts major," but no one realistically expects that many will choose chemistry, physics, biology, or mathematics.

Clearly, what little science is taught suffers from the lack of well-prepared teachers. Many elementary school teachers are intimidated, and understandably so, by science, particularly, the so-called "hard sciences." No matter how conscientiously they try, their fear or dislike for science shows through to their students. Given some choice, as they often are, between science and social science, you can guess what area suffers. My oldest son, who has been reading science and astronomy books, including whatever texts I had around the house, since he was able to read, had an elaborate theory of science throughout elementary school. He argued that school science does not exist; rather, it is used by teachers to motivate students to do the required work. "When you finish doing all of these workbooks, you will get to do science." Only in the fifth grade did they finish, and their "science" consisted of a field trip to the sewage treatment facility.

The situation in elementary school science has dramatic consequences. Young persons are naturally curious, about themselves and about the world in which they live. In grades K - 3, this curiosity is intense, and students eagerly ask good questions about the simplest demonstration of

scientific phenomena. By the fifth and certainly by the sixth grades, much

of this curiosity has been lost. In addition, sexual stereotypes have been imposed in the sense that a girl who, in the third grade, might have aspired to be a marine biologist, has now decided that science is not for women. At least in part, this is related to the lack of appropriate role models in the form of female teachers who are successful in understanding and appreciating science.

In the secondary schools, the situation is little better. The simple fact is that relatively few highly qualified persons choose to teach, when faced with far greater financial awards for jobs which are, for the most part, less demanding and more upwardly mobile. A generation ago, before the rise of the women's movement, a woman who wanted to work at a professional level could choose between education and nursing. Many married women who chose to teach did so for their own personal rewards and not for the money. The current economy almost demands that women work, and income is very important. Additionally, the opening of opportunity across the spectrum of business and industry makes teaching less and less attractive. Public perceptions of teaching as a profession have decreased so that the prestige which once offset low salaries is now largely missing. A recent study of secondary teachers in Virginia indicated that 23% of earth science teachers met the 1982 certification standards, while 38% of the physics teachers met those standards. Six of ten physics teachers in the state did not meet the new standards, which are much less stringent than are most college major programs. For example, 24 semester hours of biology is required to teach biology, with similar requirements in chemistry, or physics. One is regarded as prepared to teach science with 24 undergraduate hours, when the same regulations stipulate that English teachers need 36 hours in the field in spite of the fact that they take 12 years of English and enter college with substantial

prior knowledge of English. Foreign language, music, and physical

education also require 36 hours, the equivalent of a typical college major.

In addition, many high school teachers of chemistry and physics, as well as upper-level mathematics suffer from what I call a "macho syndrome." "Physics is the toughest course at Hiwassee High School." Of course this is a self-fulfilling prophecy of the worst kind, and one which perpetuates negative attitudes toward the subject on the part of many of those who take it. Actually, physics ought to be the easiest of the science subjects encountered.

In early March, two articles appeared in the Washington Post. One of these celebrated the winners of the annual Westinghouse Science Talent Search, the best and brightest of our young science students. Most of these will succeed regardless of the quality of their public school science preparation. The second described a National Science Foundation report on international educational achievement. American high-school seniors were 12th out of 13 nations in knowledge of chemistry and 13th in knowledge of biology. Another study of science achievement in 17 countries found that American 8th and 9th graders ranked 14th, roughly equal with Thailand and Singapore. Curiously, the same study indicates that American 5th graders rank 8th among the 17 nations. They get worse as they get older. The study also shows that of the 70% of American high school students who graduate (the rate is 97% in the USSR), only 21% have taken physics (about 14% of the total population), while all students in the USSR take physics. Furthermore, a typical Soviet student will have 492 hours of classroom instruction in physics, while the typical American would have only 180 hours of instruction. I do not wish to imply that Soviet education is superior, but rather to give an impression of the seriousness with which

they and much of the rest of the world view science education.

The high school science curriculum exacerbates the problem. In Virginia, students begin with earth science, move to biology, then to chemistry, and finally to physics. Students who are not college bound leave science after completing earth science; others drop out after biology, and still more after chemistry. While this sequence is familiar, it is not clear that it makes pedagogical sense. First of all, earth science is a mixture of geology, oceanography, astronomy, and meteorology, often taught by persons with no real expertise in any of the above areas. It draws upon concepts from physics and other sciences which must be introduced on an ad hoc basis. Modern biology is far removed from the simple botany and zoology we all remember, and much of it also depends on concepts taken from physics and chemistry. One who is unfamiliar with the history of American education might observe that the sequence is more or less upside down. Since physics is prior to all of the other sciences, and since it is the simplest, it ought to be the first one encountered. Biology, which deals with living systems and thus is by far the most complex, ought to be last. Two problems prevent this suggestion from being taken seriously. The first is the inertia which all bureaucracies exhibit where change is proposed. The second, and perhaps equally formidable, is that physics seems to require mathematical skills which students do not have until later in high school. It is true that, as now taught, physics is quite mathematical, but it is not true that one needs great mathematical sophistication to understand the important and basic physics concepts. Why not challenge students with Newton's laws and the laws of thermodynamics at an earlier age so that they may apply them to the other sciences as they study them? Why should one wait until the age of seventeen or more to learn that perpetual motion machines cannot be built?

Before leaving secondary science education, two additional concerns

must be addressed. The first of these is the language of academic sciences: mathematics. One cannot pursue college-level courses in the basic sciences or engineering without a solid background in mathematics. I was a reasonable math student at a very good high school, and I took all the math that was available to me: two years of algebra, a year of plane geometry, and a full semester of trigonometry followed by a semester of solid geometry. Today's college-bound students do most of the above by the end of the tenth grade. The eleventh grade is spent in a course called "pre-calculus," which used to be an introductory college course and the senior year is spent in taking calculus, which I did not see until I was a sophomore in college. Analytic geometry has been compressed into the junior and senior years of high school. I do not believe that today's high school students are so much more capable than those graduating in the fifties. Certainly, the results of standardized tests such as the College Boards do not indicate that to be so. International studies comparing the mathematics achievement of U.S. students confirm the trend. In 1982, U.S. 8th graders answered 45.3% of items on a standardized math test correctly, falling below the average of those tested in the areas of algebra, geometry, and measurement. They ranked 13th out of 18 nations, ahead of Israel, Luxembourg, Nigeria, Sweden, and Swaziland. A similar test of 12th-grade students yielded an average score of 52.2% compared to an international average of 57.1%, to rank 10th of 11 participating countries.

Many students enter college having taken calculus in high school, but they are not able to apply it to real problems. Much of the math which students encounter in high school and college is taught in a vacuum. Applications are rarely explained, with the result that learning math is often a real drudgery for anyone who is not turned on by the intrinsic

beauty of the subject. A coherent integration of mathematics into the science curriculum would result in enhanced learning in both areas. Not only are many incapable in formal mathematics, almost all are incapable of certain useful computational skills, including using mental arithmetic to estimate answers to problems, elementary statistical skills, and real understanding of calculators and computers. One of the goals of the high school mathematics curriculum in Lynchburg is competence in mental arithmetic. Last spring I read about 75 high-school algebra textbooks as a member of the mathematics textbook selection committee. Not one of them, including those adopted, mentioned mental arithmetic.

A second concern is that high school schedules usually preclude any real experimentation or hands-on work in science courses. Science should not be vicarious, and it is difficult to understand the nature of magnetic attraction if one has never played with magnets. Hands-on work with the basic phenomenae is not done in neat one-hour blocks, nor is it readily done with obsolete equipment. Appropriate laboratory work can both enhance learning and generate enthusiasm for the process. Most practicing scientists would argue that experimentation is part of the fabric of science, which cannot really be separated from other forms of scientific enterprise. One only need attend a local science fair to see the results of the lack of ongoing attention to experimentation. The rare project which displays some insight into the process of science stands in stark contrast to experiments done on a single subject, experiments which lack all notion of controls, and projects which are not experiments, but rather library work or art work. The Lynchburg schools require that upper-level science students participate in science fairs, even though they, and often their teachers, have no idea of what projects might approximate real

science. I recall several years ago observing a student teacher, in a

seventh grade science course. He spent an entire hour showing and explaining all of the variety of glassware, test tubes, graduated cylinders, Erlenmeyer flasks, beakers, etc. and telling the students that they would have a test on what transpired. After class I asked him and his cooperating teacher what kinds of chemical experiments the students would do and was told that students were not allowed to do any experiments because they might break the glassware.

College science teachers enjoy a different set of challenges. Many share the perceptions and frustration of their high school colleagues, 80% of whom believe that students enter high school with deficiencies in basic skills. While I have suggested that this may also be true at the college level, it is not a personal concern. I regard it as an obligation to address students at whatever level I encounter them and to take them as far as I can in the time they share with me, and I find great personal satisfaction in doing that.

I find it useful to describe college students in terms of two or three distinct groups, not based on intelligence; one (small) group who have not yet been turned off by science and who thus may be pursuing careers related to science, and a much larger group -- a more or less hostile audience -- who find themselves forced to take science courses only to satisfy some externally imposed requirement. In terms of native intelligence, the two groups likely contain the same distributions. The first group generally possesses innate mathematical and/or mechanical abilities and interests, which become very obvious when one talks to them. Curiously, an increasing portion of the first group is not adequately prepared for the mathematics of college science, even though they may have taken five years of mathematics in high school. Teachers in a typical

college science course dare not assume that students will be conversant

with such esoteric topics as right triangle trigonometry, the binomial theorem, solutions of systems of three or more equations in three or more unknowns, etc., nor can they safely assume that everyone in the class understands the periodic table, or Avogadro's number, or how to balance a simple chemical equation. But they learn to do so quickly.

The second and much larger group is really two subgroups; one whose members are very good in verbal skills, and a second which is very strong in interpersonal communications. Students from the mathematical/mechanical group may choose not to pursue a science-based career after exposure to college-level science, but it is rare, although not impossible, for a member of the second group to choose a career in science or in science teaching. Thus, the maximum size of the pool of potential science and engineering students is largely determined before students reach college. It is in fact largely determined by the fifth grade.

This second group is composed of persons who have very limited experience in manipulating the real world. Students in this category have likely not participated in Boy Scouts or Girl Scouts, they have not built models, have not built radios, have not worked on cars, have not wired circuits or even lamps; some have never built a fire. Those with high verbal aptitude can and do overcome their fears and succeed in college science courses, but they, for the most part, are not those who elect to teach in the public schools. I wish that more could be convinced to do so, for these are often very articulate persons, with highly effective communication skills. The second subgroup, which has a strong interest in social skills, contains the bulk of those who aspire to be teachers. Their strengths are in the arena of personal concern for others, of altruism, of wanting to "work with people." The challenge for college

science teachers is how to compensate for the lack of interest in and

exposure to the physical world and effectively communicate science to the second group. Twenty years of teaching has not yet shown "the way" to do this consistently. Small successes provide some signs, but the road is very difficult. At this point I am convinced that strong attention to the "how we know" part of science is a major factor in reaching these students. This implies greater emphasis on the intellectual history of science, something which is not a part of the typical Ph.D. program. Teachers are on their own as they work to build courses which help students to understand and appreciate the web of scientific reasoning which compels science to postulate and to believe in such things as electrons and quarks.

Of course, colleges also bear a substantial share of responsibility for the condition of the public schools. Teachers are trained in our classrooms; we help to shape their values, and we tell them what is important to transmit to students, by both explicit and implicit means. More than one might imagine, much of the current high school curriculum is material which you might first have seen in college. High schools and high school teachers tend to emulate colleges, and one way to do this is to teach at the high school level courses which were traditionally offered at the college level. The ever-increasing amount of knowledge, especially in the sciences, is also an important factor in this "trickle-down." The problem is that little is ever officially discarded. As I described above the bulk of what used to be the first two year's college program in mathematics is now taught in high school, with solid geometry being the only topic officially omitted.

Few colleges require more than a single year-long course in science as part of their general education programs. Scientists are expected to, and should, know something about Shakespeare, Plato, and Picasso, but

few outside of science are equally conversant with Newton, Einstein, or

the second law of thermodynamics. Despite catalog statements which talk about educating students in the arts and sciences, outside of engineering schools, little emphasis is placed on real understanding of science. I find it interesting that colleges and universities require more science and mathematics to get in than they require to get out. In addition, typical college courses often "cover the content" with regard to student learning and student understanding of what makes science different from other ways of knowing. College teachers are torn between the need to pace a course so that most students learn most of what is presented, and the expectations of the discipline itself for the content of that course. Consequently, it is potentially dangerous to one's career to work on the type of course I described above, since one would have to eliminate many topics from the course content in order to how the remaining topics are understood to be true.

Such conflicts are especially acute for those who teach in engineering schools. I can't avoid commenting on engineering education. It is such an inviting target. First of all, what sense does it make, when facing a shortage, to admit, say, 900 prospective engineers, all of whom are well-qualified and highly-motivated, knowing full well that only 300 of them will make it to the sophomore year. The other 600 will transfer to the commercecschool, or go to other colleges to pursue careers outside of science. In graduate school, I was a teaching assistant for the engineering physics course, which was designated as the official "weed-out" course (in some schools chemistry serves this noble purpose). It's always something other than engineering, to avoid the blame. It was understood that the failure rate had to be very high; in some years, the pace was so artificially devastating that a final composite score of 40% was passing, and 75% was the highest score in the class. One year, my research

adviser was assigned to teach this course. She was appalled by the failure

rate (the mean SAT for the freshmen class was about 1300) and decided that the course should be taught at a pace which would allow students to gain some real understanding of physics. After all, suppose an engineer actually had to apply it? She was unceremoniously removed from the course when the E-school got wind of her plans. Students who survive the "weed-out" course go on to get excellent preparation in engineering, often at the cost of understanding anything else, especially limitations imposed by basic fundamentals of science. Two examples to make my point: First, a classmate who now is dean of a large textile engineering program relates that a design engineer employed by a manufacturer of feminine hygiene products found in a table of material properties a material with an extraordinarily high capacity to absorb fluids. He then proceeded to design and field test a tampon made of this material, without ever wondering how much the material would expand as it absorbed fluid. Several test subjects required surgery to remove the product. From my own experience, several years ago I was consulting with the Atari Corporation, helping to design analog filters. I am not an electrical engineer; I was dragged into this by a local man who was desperate for help. Apparently, none of the more than 1000 electrical engineers employed by Atari knew anything about such filters. Neither did I, but a trip to the library yielded some books which appeared readable, and I dove in. Several months after I began, Atari sent an electrical engineer with a masters degree from Stanford to Lynchburg for two weeks so that I could teach him what I had learned from reading library books. This man was brilliant and superbly trained for his basic work, but had absolutely no idea of how to expand his personal horizons.

These, then, are the basic parameters of the situation. Inadequately trained teachers affect student attitudes towards science and mathematics,

often in irreversible ways, at a very early stage in the educational

process. Many of those who are so affected go on to become elementary teachers who unintentionally perpetuate the cycle. Persons who do have aptitude for, and interest in, science are not encouraged to enter the teaching profession. The latest employment survey done by the American Institute of Physics indicates, for example, that the median starting salary for physics majors who elected to teach in high school was $1320 per month ($15,840 annually), compared with a median starting salary of $2160 ($25,920) in manufacturing, and $1620 ($19,440) in the military. Nationwide, only 52 physics bachelors chose to enter teaching in 1986. The secondary schools are most seriously affected, with the result that many of those who retain interest after elementary school are athen turned away from science by their high school experiences. You may be surprised to know that low salaries are not necessarily the greatest deterrent to teaching. Equally important in the minds of many are the effects of the overwhelming administrative bureaucracy in the public schools, the lack of real freedom in determining what is to be taught (the syllabus specifies how every minute is to be spent), and the severe time demands of the profession.

All of this is happening against a background of declining college enrollments, of declining numbers of persons entering the teaching profession, and of projected severe shortages of teachers by the end of the century. Such projections also imply a shortage of doctorally prepared persons for college faculty as well as for government and industry. A large percentage of college and university teachers will reach retirement age around the year 2000, and fewer people are in the pipeline to replace them. At the same time, many economists attribute a steadily increasing balance of trade deficit to a shortage of scientists and engineers and the concurrent loss of technological leadership.

Two successive Nobel-prize winning economists have argued that the key to

American economic growth is technological progress. Although American science is still healthy, I believe that it is imperiled by the situations which I have described.

What should we do about it? I offer little in the way of hope, but only some ideas about science curricula, science teachers, and science teaching. Thirty years have passed since Sputnik sent shock waves through America's scientific and educational establishments. What clues might we find from the subsequent national response? The National Science Foundation has been the prime mover and shaker in establishing directions and priorities for science education. It has supported science education in three basic ways; by awarding graduate fellowships, by purchasing or helping to purchase equipment, and by offering support for the development of new programs and curricula in science, including textbooks. Directions and priorities, especially for college science, are subtly arranged by the nature of the grants programs. The most visible results of NSF efforts are probably the large-scale curriculum projects completed with NSF support. PSSC physics, now 30 years old, and Harvard Project Physics, 20 years old, are used by a substantial majority of high school physics classes. Created by scientists who were far removed from the high school classroom, they are suitable for the mathematically/mechanically inclined students, although many of those find them to be unnecessarily abstruse. Typical high school teachers find them difficult. NSF funds also were instrumental in such programs as BSCS, for high school biology, and ESS and SCIS for elementary school science. Much of this development is based on sound educational and cognitive psychology, and the published results look very slick, but the same major problem accompanies them. For a variety of reasons, the Foundation has consistently elected not to provide funding for subsequent implementation of the curricular materials which they have developed. So

the materials either are not adopted and wither away or they are adopted

and then taught by teachers who may have great difficulty in understanding and implementing them and who often do not have the full range of lab apparatus called for. At best the results are mixed and at worst they are disastrous.

Furthermore, materials developed with federal support for various age groups are not vertically integrated. School systems cannot look to the NSF for a K-12 science curriculum. They can look to the for-profit publishers of textual materials, but most of those are too glossy, with too little attention paid to sound pedagogy. They are in fact written to be adopted, and only secondarily for students.

If the NSF chooses to support the future development of curriculum materials, then it should plan to integrate them into a consistent vertical curriculum, and it should commit to fully implementing them. I believe, however, that federal money would be better spent in helping to establish a firm national consensus about the goals of science education. What precisely do we expect students who study science to know and to be able to do? The goals for those on the fast track might be more comprehensive, but they should include the broader goals set for all students. I suggest that any student who completes a course in science ought to have as much understanding of "how we know" as knowledge of what we know. Such a consensus does not now exist, not even within a single discipline of science, let alone across disciplines and up and down the curriculum. The lack of such a consensus accounts for much of the current weakness in the teaching of science.

Federal money should continue to be available to support the acquisition of increasingly sophisticated instrumentation, especially for colleges which do not have research functions. The emergence of computers and the

existence of a vertically integrated curriculum will eventually allow

the public schools to acquire instrumentation, which can be used at multiple levels with sophistication appropriate to each, and which is far less expensive than currently existing apparatus.

A third area of crucial federal support used to be more or less readily available and ought to be reinstated, because it is the most valuable and useful form of support. Summer institutes, at which groups of teachers, within a single discipline, across disciplines, across school levels, etc., spend some time, with support, in studying and learning about curriculum developments, in staying current in their disciplines, in upgrading teaching skills, and in learning what their colleagues do are quite valuable. Shared experiences build morale and a sense of community, which is especially important for public school teachers and for teachers of college science who, in small departments, can easily become isolated from their professional counterparts. Such institutes also build knowledge of content, which is crucial for effective teaching, and which appears to be far more useful for science teachers than existing options for recertification.

On the local level, several things are important. The creation and continued support of the Central Virginia Magnet School is a most important aspect of quality education in science for students who have an aptitude for science and mathematics. However, even without considering the ongoing problems of securing funding, the school faces two major challenges.
The first is the same problem which everyone else faces; how to identify and attract the very best teachers possible. The second challenge is how to identify and encourage potentially excellent students in science, whose abilities and interests may not be obvious. At present students are screened by performance indicators, which identify students who achieve,

but not necessarily those with the best talent. This is typical of most

existing programs for the so-called "gifted" student. Some of the students who enter the magnet school find that they really do not like science after all. This fact simply confirms the argument that most have not really experienced science prior to enrolling in the Magnet School. I would argue that much would be gained by extending the notion of a Science-based magnet school to the middle-school level, so that the few who do emerge from elementary school with their fervor for science intact, would be encouraged to become their best.

But as I said earlier, my major concern is not with science for the scientists; rather, it is science for the general public. I will simply outline several priorities, in no real order, although I suppose that the first priority ought to be to carefully design goals for science education which lead to understanding as opposed to analysis. This ought to be as true for high school biology as for college physics.

A second goal ought to be familiarity with the basic phenomenae of science. Since I do not foresee any dramatic shift in the nature of those who are attracted to teaching, I do not foresee that elementary teachers who really understand science will suddenly appear to teach our children. The standard prescriptions for teacher reform will simply not work. The notion of recruiting better quality students to enter teaching, to require much greater exposure to content, to require much greater professionalism, and require them to rigorously evaluate their students in order to earn their greatly improved salaries sounds good, but simply will not pass muster. Most of the best and the brightest will still go in other directions. The pool of students who enter teaching will still be the same as we now have. Real reform has to take place largely within the existing structure of teacher education and the school environment.

For this reason I propose that an elementary curriculum in science be designed which asks only that teachers encourage student hands-on experience with magnets and batteries, with seeds and soil, with microscopes and pond water, etc., so that teachers who are prepared in science can, at the middle school level, begin to build on experiences which students own, as opposed to looking up the answers in the text. Paying careful attention to the courses teachers take in their programs of general education is part of the necessary reform of higher education. I have already mentioned the way in which science courses at the college level should be restructured. The restructuring should be accompanied by high expectations for student performance and achievement in these courses.

A third goal should be to increase cooperation between colleges and schools. As I said, I enjoy being in public school classrooms and readily agree to do so. I would encourage more formal kinds of arrangements, which might involve using a college mathematician to teach the AP calculus course or bringing students to campus for special laboratory experiences. The students are not the only ones who benefit from this. I believe that both college and school faculties would benefit from an increased sense of collegiality. Industries who employ scientists should also play an important role here, by providing internship experiences for interested students and summer employment opportunities for teachers whose expertise is relevant to the purpose of the company.

A fourth goal, which may be related to the third in a way not yet clear to me is to study the model offered by the Fern Bank Science Center for the DeKalb County public schools in Georgia. A full-time staff including Ph.D.'s in all science areas is available to aid the teachers in the county. If Ms. Jones wants a 30 minute presentation on simple machines

at the second-grade level, all she need do is call the center and schedule it. The center also houses such things as a planetarium and an extensive arboretum; thus it serves as a site for student field-trips and experiences.

While I support ongoing assessment of what schools and colleges do, I would also urge that we take a careful look at the kinds of testing we do. I know that so much attention has been paid on the elementary level to preparing students for the SRA tests, that it appears to students that nothing else is done; no new topics are covered after the tests are given. As I said earlier, many students successfully complete AP tests, which establish college credit for certain courses, but do not really understand what they have learned. Tests can be deceiving; in graduate school, I was required to demonstrate competence in two languages. Since I had taken French in college, that one was easy. German I had to learn on my own. To motivate myself, I signed up to take a newly devised standardised test which the university required. The test date was months away, but my good intentions soon dissolved when my adviser "suggested" that I undertake a special research topic for a paper she had agreed to present at about the time of the test. I spent enormous amounts of time doing her project and virtually none on German. When the test date arrived, I decided to take it, since I had paid a sizable sum for it, for the experience. I passed it, with no substantive knowledge of German. Two years later the university returned to its traditional requirement, which consisted of entering the office of an instructor of the language, who would hand you a book written in the language and tell you to translate. He or she certified that you had met the requirement. Too many tests, of the wrong kind, get in the way of real student understanding.

Constructive parental involvement, which does not interfere with the day-to-day teaching activities, but rather which keeps the pressure on school administrators to reward good teaching and to deal with those teachers who cannot teach, or who choose not to do so, is crucial. This is difficult to do. Six years ago, when my son was in the ninth grade, he brought home an earth science astronomy quiz with a grade of 60%. Now that was not unusual, but he knew and still knows astronomy that I do not know. I was shocked. I was even more shocked when I read the quiz and discovered that all his answers were correct. My first impulse was to confront the teacher, but Jonathan argued that everyone knows that he doesn't know anything, but he's a "good guy." Subsequent conversations with the principal revealed that the school was quite aware of his shortcomings, but he was nearing retirement. He is still there, despite consistent complaints from many, many parents. Until people such as this are removed from the classroom, all of us will perceive public education as less that it deserves to be. Incidentally, a corollary of this cry for parental involvement is to cooperate, or to encourage talented employees to cooperate, with school requests for classroom visits and presentations, etc.

A final priority involves something I have not yet mentioned. We must find a way to introduce students to the effects of technology on society. A sound understanding of the opportunities and limitations imposed by basic science is a necessary precursor to understanding technology, but it is not sufficient. The ignorance which underlies public discussions about such disparate subjects as Amtrak and nuclear energy, superconductivity and SDI, space-based research and recombinant DNA is appalling. If this nation is to have an informed citizenry, then the schools must find ways to address this new body of knowledge about technology and its effects on all of us. If we do not learn to control technology, then it will certainly control

us.

Twenty-two years ago, I heard I.I. Rabi speak about science education at a meeting of the AAAS. He said......

> ".....I believe, basically, we have not been cautious enough of the meaning of science in our generation, to teach it in a way which would be understood and appreciated and felt by students. We have very little of the positive values of science outside of the applications.. .....We have been teaching science, at every level,..as a certain bag of tricks which the bright boy or girl could learn and show off with. ......Now science is a very different thing.....it is an adventure."

Nothing has really changed in science teaching since 1966. We still mostly fail to share the joy, the challenge, the beauty, and the sense of high adventure which characterizes the doing of science with most of our students. But when we succeed, when students can respond to the "how do you know?" question, then.....there is understanding, understanding of self, and the beginning of a sense of human capacity far beyond one's previous horizon, of an infinite extension of human possibilities. When at the college level we can offer courses which effectively communicate this excitement to all of our students, then we will begin to break the cycle which leads to the general lack of interest in science, for these are the people who will share that excitement with their children and their students.

Edna St. Vincent Millay once wrote that "Euclid alone has looked at Beauty bare." Euclid is not the only one. Once in a while, one of my students sees that rare beauty and catches the excitement. That's why I do what I do.