

K-12 Education

A Primer for Materials Researchers

Rustum Roy

Interest by materials scientists and engineers in matters of K-12 education has increased dramatically during the last two or three years. This article presents a basic framework for those wishing to get involved in working with the K-12 education. It covers:

- A description of the magnitude and complexity of the K-12 system.
- An analysis by professionals of the alleged failings of the system—with very surprising results.
- Alternative goals that societies or individuals may have, including (a) improving technological literacy of all Americans or (b) increasing numbers or quality of future scientists/engineers.
- The need to choose among alternative epistemologies in science education: principles practice, or practice principles.
- Opportunities for service by materials scientists and engineers on (a) personal activities; (b) system improvement by working on new instructional materials, new courses, new curricula.

If it is to be effective, it is essential that involvement in K-12 education be preceded by a clarification among the above goals and choices. It will be shown that materials scientists and engineers have a very special opportunity to restore U.S. science education to its traditional style, very different from the present.

The National Setting

Any efforts to improve “science education” in the United States must start with a look at the total system and the “system constraints;” otherwise, one can get involved in hopelessly naive wheel-spinning.

The United States as a culture finds itself, today, in the middle of a social paradigm shift:

1. From a self-image as a monoculture of European extraction emphasizing absorption of new elements into the American melting pot, it is rapidly changing to a self-image of a multi-cultural mix of groups emphasizing different cultural roots on three continents;

2. From the towering economic power of the world, the United States has become a

tottering giant unable, for political reasons, to cope with its grave economic problems.

3. From the world’s undisputed leader in technology, the United States has become one in the pack of nations with respect to civilian technologies.

4. From a more egalitarian society, the United States is increasingly shifting to a third-world layering of rich and poor. The migration to the cities has intensified and been intensified by some of the above, and that reality has placed at least half of the U.S. children into poor school systems.

5. Six to seven hours a day of TV watching by school age pupils.¹

6. From the world’s leading creditor nation, the United States has, by far, gone to being the leading debtor nation, simultaneously coping with a national debt service load that is growing from a quarter to a third of the national annual budget.²

The Education System

Education is, in the United States, a state responsibility for funding and oversight. Most states, moreover, delegate an enormous amount of responsibility to the local school districts. Further, each state has a virtually unique infrastructure for education. There are some 16,500 school districts in the United States. They spend some \$200 billion each year. In many states the local school boards are totally autonomous with respect to curriculum, courses, etc. In others (e.g., New York) they are somewhat constrained by the existence of state-wide exams, a powerful Board of Regents, etc.

Teachers are prepared for teaching “science” by nearly 2,000 universities and colleges. In probably 98% of these institutions, “science” is limited to physics, chemistry, and biology, the now familiar “PCB”—a radical departure from pre-1950 America. A few train a few teachers

in earth science. But the general equation of contemporary science education is: science = P + C + B—an absurdity that passes unchallenged.

The state departments of education typically have some general power to specify the curriculum in broad terms. For example, after all the publicity on how badly the United States is doing, many states now require an “extra year of science.”

The professional organizations which run the “system” include:

- The National Science Teachers Association (50,000 members),
- National Association of Biology Teachers (60,000 members),
- Association for Supervision and Curriculum Development (120,000 members),
- National Council of Teachers of Mathematics (70,000 members), and
- Two major teachers unions, the National Education Association (NEA) and American Federation of Teachers (AFT).

Materials scientists and engineers who wish to change the system should realize the magnitude of the problem and the system, and also the fact that huge numbers (NEA has 2,000,000 members) of our professional colleagues know a great deal more about how to engage the system constructively for change than we do.

We must work with the teacher cadre from the beginning and with the teachers of teachers (professors of education in universities), and the designers of curricula, and the school boards and state agencies that set broad guidelines, if we are to have a long-term, broad-based effect.

Alleged Failures of the U.S. Educational System

The media and lay-press have publicized the so-called failures of U.S. schools and focused on one or two areas. However, these presentations grossly distort reality in the view of the professionals in the field. Hence materials scientists, who are laypersons in the field of pre-college education, should take extreme care in accepting the problem definition offered in the press. The publicizing of the dire straits of science education started perhaps with the serious analyses in *A Nation at Risk* (1983).³ This was followed by 100 (yes, 100) or so similar reports by commissions and committees (see references below for some examples). No one should embark on working in the K-12 system without some familiarity with these professional reports. Moreover, it should be kept in mind that poor performance in “science” by U.S. students is at least matched by their poor performance in many other subjects from geography to English to politics.

Material Matters is a forum for expressing personal points of view on issues of interest to the materials community.

What, then, do these million dollar plus reports on science education suggest that the nation do to fix the problem? I list below a selection of recommendations from the most influential of such reports, grouped in various ways to orient the beginner in science education.

"Science curriculum grades 9-12 [should] be 'structured around the interactions of science and technology with the whole society,' with instruction centered around problems that 'integrate knowledge' from engineering, physics, biology, earth science and applied mathematics."

"Integration of science, technology, and applied mathematics throughout basic education."

*National Science Board
Conference on Goals for
Science and Technol-
ogy Education Grades
K-12 (April 1983).*

"The greater the degree to which all the sciences and technology can be integrated in new curricular approaches, the broader the understanding in these fields will be."

"A curriculum 'organized around problem-solving skills, real life issues, and personal and community decision making.'"

*Educating Americans
for the Twenty-First Cen-
tury, Commission on
Pre-college Education
(October 1983).*

These are substantive examples of guidelines for improvements in content of our K-12 science education. Of course, there are personnel issues also. It is certain that the percentages of minorities and women in science are lower than in other areas. The total number of U.S. citizens earning PhDs in science and engineering has declined substantially, but in a "free market" economy it is ludicrous to regard this operation of market forces as a catastrophe. Another problem often perceived as a major one by the scientific community, not well read in these matters, is totally at variance with consensual expert opinion. The naive belief that the nation faces a "shortage of scientists and engineers" now or in the plausible future is challenged by the following four authoritative studies that conclude the opposite:

■ Lawrence P. Grayson, Chair, American Association of Engineering Societies (1991). Order Bulletin #105, *Engineering*

Manpower Bulletin, \$14.00. Tel.: (202) 296-2237.

■ Robert M. White, Presidential Address to the National Academy of Engineering, Oct. 2, 1990, "Science, Engineering and the Sorcerer's Apprentice."

■ Alan Fechter, Executive Director of the National Research Council's Office of Scientific and Engineering Personnel. "The Bridge," National Academy of Engineering, Vol. 20, Fall 1990.

■ Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School* (1988).

The shortage is not supported by a single published study. No materials society should embark on a goal of increasing the number of scientists without studying these works.

The area in which there is little disagreement that we have a problem is in the technological illiteracy of Americans. Prof. J. Miller's data, collected over decades,⁴ present a picture of a society in which 90% of the population—those who have no professional connection to science and technology—cannot deal with the realities of the technological society in which they live. This is a radically different, albeit complementary problem to the quality of science of the 5% who use science and technology in their professions. But it is the only area in which everyone agrees the nation has a problem—technological literacy.

Who or What Is to Blame?

One of the most egregious errors on the part of professional scientists in academia and industry is to blame the schools and the teachers. This is grossly unjust. As Paul Hurd, former dean of Stanford's School of Education, and the nation's dean of science educators has pointed out,⁵ it is society that has radically changed (failed?). The advent of television, the radical change of family structure caused by divorce and both parents working, drugs, teenage pregnancy, new immigration patterns, and the general decline of discipline all originated in society. Their effects are naturally found in the schools. Moreover, another of the certain causes of the failure was to keep the content of what is being taught appropriate to the needs of society. Increasingly since 1950, the scientific community has dominated, and changed, what was taught in K-12. At the same time they showed little responsibility for funding change. And this can directly be placed at the door of the scientific research community. The National Science Foundation (and the National Science Board speaking for the research community) decreased the percentage of the total NSF budget for science education twentyfold even while its

own total was growing tenfold. Since 1983, after NSF's science education funding was zeroed out by President Reagan, with not one published word of protest from any scientific body in the United States, the steep growth of science education funding has been mandated by Congress over the objections of the science-research community. Indeed, it is all the more ironic that much of the newly found interest in science education is a reflection of the very substantial increases in funding made available by Congressional, not scientists', insistence.

A second major error which developed slowly after World War II was the importing of the European education systems designed for the elite, and supposedly making them available to the masses in the United States. Thus began the abandonment of the balanced education of technician, technologist, and scientist cohorts, and the creation of the impossible ideal of using the abstract scientist as the superior model of doing technology and science. Paul Hurd recently described the radical change in the goals of American science education starting from 1900-1990.⁵

So much for motivational errors; let us consider the goals. A great deal of attention was focused after Sputnik on making more and better scientists. As a result of millions of dollars of development, the schools started New Math, PSSC physics, and Chemstudy, and all kinds of advanced placement courses in PCB. These "super courses" failed in two ways. First they alienated even more students from science. But second, and this should be an important lesson for our present situation, the best students didn't get better. It is self-evident that these new approaches and all the new computers and related technologies have not produced any better home-grown scientists than the Linus Pauling or Richard Feynman genre. We simply cannot improve the number of quality at the top. In fact, empirical evidence would suggest the opposite has occurred. We find fewer and fewer scientists at the top of their professions today with the social, political, and philosophical capacities and concerns of Einstein, Szilard, Pauling, Weinberg. This is, we believe, a result of attempting to increase specialization, to professional narrowing of the educational focus to science alone, and to neglecting the connection not only to applied science but to the humanities and social sciences.

Alternative Goals Available to Concerned Scientists/Engineers

Thus every professional society will observe that there are two complementary goals in improving science education that

are very different and obviously of different importance at any given time.

■ One is to ensure an adequate supply of technically trained personnel for all levels of the workforce. The United States has a substantial undersupply at the bottom (technician) while the shortfall of native-born Americans at the top of the spectrum (PhD) has been compensated for by immigration. At the bachelor's level, supply and demand seem to be in reasonable balance NOW. In 1992, with worldwide upheaval and migration of scientists, there is a very substantial oversupply of materials researchers.

■ The second challenge is much more global. It is the challenge of technological literacy of the voter, the 100% of the population entitled to and, in fact, making enormously significant decisions that affect all of American society. How do we achieve such literacy in a population where perhaps only 20% of the total school population will ever take a physics or chemistry course? Clearly it cannot be done by improving the physics and chemistry courses alone. First, the vast majority never take them; and, second, they are irrelevant to all the jobs people live on and the societal issues they vote on, anyway.

That these goals are parallel ones and are potentially synergistic is revealed in the opening language of the science education bill introduced by Senators Kennedy and Hatfield in January 1990. The bill's purpose is as follows:

"This title declares national objectives to be:

(A) Improved public scientific and technical literacy;

(B) Increased supply of scientists, engineers, and technologists; and

(C) Increased participation of women and minorities in math, science, and engineering."

In response to the second national goal of "technological literacy," some states (e.g. Arizona and New York) and Canadian provinces (British Columbia) have moved to mandate science, technology, and society (STS) courses to be taught in the extra year of science required in many states.

The STS approach is clearly the most developed way to reach this second goal. STS, as will be seen below, attempts to teach both new attitudes to science and technology, as well some basic understanding of technology and the kind of rudimentary science that a citizen will actually need and use in daily life. By the year 2000 it is virtually certain that many, many more students will be taking STS than, say chemistry and physics courses. Scientists and engineers can and must

play a major role in shaping what is presented in STS courses. It is quite futile to "prefer" that the students be exposed to rigorous physics and chemistry. We've tried that; that approach got us into the mess in which we now find ourselves.

A New Paradigm: Applied Science and Technology as the Key and Its Base in Education Theory

The state of U.S. technology has been blamed in part (in a book by Shapley and Roy)⁶ on our irrational science policies. No "science education" plan that ignores this problem is either rational or defensible. Any analysis of the magnitude of the problem and the way the U.S. system works and the resources available will immediately conclude that it is physically impossible to fix the problem by any conceivable amount of optimization of the system within the present paradigm. Shapley and Roy argue that our present paradigm is built on the fundamental error in misunderstanding the relation of science to technology. Instead of the historically established, common-sense verified, technology leading to science, the present paradigm includes the claim that science leads to technology. This will be rectified in the new paradigm.

In his seminal twin works, *School and Society* and *The Child and the Curriculum*, John Dewey,⁷ the greatest figure in the history of American education, argued convincingly at the turn of the century for a central role for teaching practical and applied (technological) skills in the nation's compulsory schooling. He argued for using the vocation as the organizing principle and departure point for all education—not for vocational training, but education. That is, start with the real world and bring academic knowledge to bear on it. Yet, the content of "science and technology" education slowly evolved into two separate approaches—a practical, vocational, skills-oriented part, eventually to become industrial arts vocational education, etc. ("vo-tech"), and the "college preparatory" approach equating science with the then-emerging abstract sciences: physics, chemistry, and biology (PCB). In a recent article, Paul Hurd⁸ masterfully summarized this evolution.

This change was reflected in the early decades of the century by the slowly solidifying structure of university teaching of "science," and its slow and subtle equating of science with PCB. Although in the lengthy entry under "science" in the *Oxford English Dictionary*, the words "physics", "chemistry," and "biology" do not even appear, the U.S. university world, es-

pecially since World War II, has structured itself so that it attempts to monopolize the word "science," and moreover to claim (contrary to all historical analysis) that "...science leads to technology..." while D. de Solla Price of Yale, dean of American science historians, has summarized "...the arrow of causality is exactly the opposite."

Moving to the present, J. Myron Atkin, former dean of Stanford University's Education School also recently presented the case for the applied science route to learning.⁹

Human needs motivate most human learning. These encompass food, shelter, clothing, and health. Going down the hierarchy, they encounter the needed technologies, then the applied sciences such as agriculture, materials, earth, health, and engineering. The idea that learning science (PCB) is the necessary precursor to learning technology is absurd. All human history is proof. Even the U.S. Department of Defense has shown that specific, even "high-tech" tasks can be taught well, and rapidly, without any science at all.

Paul Hurd⁸ has traced the long history in America of teaching science that is valuable to, and related to, life. Its champions were Benjamin Franklin, Thomas Jefferson, and his friend Dupont de Nemours. At the dawn of the 19th century, Hurd relates how physics principles were taught by being derived from spring-driven toys. In all of these subjects, practical and technological applications of science were featured. In 1932 the National Society for the Study of Education Committee's very first position was "science teaching should contribute to life-enrichment through participation in a democratic social order." As late as 1945 the Harvard Committee on general education argued that science education should relate to the problems of human society. "Only such broader perspectives can give point and lasting value to scientific information and experience for the general student." So the PCB error in K-12 (narrow, discipline-driven, divorced from technology) is only about 40 years old.

In the present era, there is, of course, a movement for greater rigor, more mathematics, more of a sequence of courses as one approach to reforming the present system. U.S. history has proved that this approach can, at best, affect a very small minority, and there is no evidence that they will achieve any better science. The AAAS under Dr. James Rutherford, perhaps the most knowledgeable senior designer of education reform, has projected a 75-year-long reform under Project 2061 in their outline, *Science for All Americans*. Project 2061 is totally compatible with the re-

form movement that has established the most widespread foothold in the United States, the STS movement. And both of these strongly argue for the applied-science approach.

Hope for U.S. Education via Applied Science/Technology

Background

It is the principal thesis here that the recognized crisis in K-12 science education offers new communities of engineers and scientists a golden opportunity both to help the national posture in science and technology literacy, and to vastly increase the percentage of students who can become interested in these applied science and engineering fields enormously more important to the nation's technological health.

This article is a primer on how the professional materials science and engineering community can contribute significantly to the national effort in K-12 education. The K-12 system is a \$200 billion-per-year enterprise with 16,000 centers of power. Personal local action can become significant only if connected into an alternative systems approach. Some options for the latter are presented.

The accelerating economic decline in the United States will provide this opportunity. The end of the American half-century is now clearly in sight. The opportunity to return to a measure of reality will never be greater. The awareness that the present U.S. "science-emphasis" approach has been a devastating failure for U.S. technology and the economy must be accepted and reinforced at every opportunity by anyone concerned about better science and technology education for improving the national economy and technological literacy.

Opportunity and Responsibility

Those concerned with such changes face an enormous challenge. First, they must clarify the relationships between science and technology, and especially clarify the place of both in the context of the economy and the political life of the country. Second they must rethink, *de novo*, how and what one would teach the average citizen about technology, and secondarily what should be taught about science. (See Hurd⁸ and Dewey.⁹)

For historical background and a discussion of what kinds of science and technology we need, I refer you to two recent papers.¹⁰ We turn now to the new strategy that introduces the applied sciences (including materials science as the primary contact with science) for at least the 90% of

the student body who will not use science or engineering in their professions.

Strategy: Pedagogy from the Obvious, Instead of the Obscure

From time immemorial, communicating "tekhne" was the passing on from generation to generation of the most important stored up knowledge and wisdom about the most obvious, most common, most often encountered human contacts with those parts of reality that affect humans the most.

Each generation learned as much as possible about food, shelter, security, and so forth and passed it on to the next. For the last century, and rapidly increasing over the last 50 years, school systems have attempted to teach all students about reality viewed from the particular formalism and stance of abstract science. This science is characterized by two key parameters: abstraction and mathematicization. These features are responsible for the power and rapid growth of the more esoteric sciences. They are at the same time responsible for its unintelligibility to, and lack of interest for, the vast majority of the population. Moreover, common sense and widespread human experience show that the vast majority of citizens do not need much abstract science, and only modest quantification, to function very effectively, even in a highly technological society. The President of the United States, the chairpersons of most of our largest corporations, and the leading playwrights, poets, and university presidents have very little knowledge of the level of science some would demand of all students. It is not at all clear that a course in AP (advanced placement) physics or chemistry would have made an iota of difference to them.

A technology-focused curriculum for all would eschew abstraction for obviousness. Every citizen would be expected to know about those parts of contemporary human experience that are obvious to all, that affect all in daily living.

A simple algorithm to guide the choice of what to know, which can expand and deepen with advancing grade simply by going into greater detail, is to follow the activities of an average pupil through an average day. From the alarm clock to the light switch to the clothes worn, the rubber in the sneakers to the stove heating water for coffee to the car being driven to work, to the snow, salting of highways, and the recycling bin, there is an infinite opportunity to use these objects and experiences for teaching technology and applied science, and derivatively basic science. This "applied science" must become the necessary

core for all students, prior to their being exposed to any abstract science. The beauty of using the same common human experience—eating, getting dressed, driving—is that they can be updated at each successive age level; and with increasing depth and sophistication, they can form the connection to life and introduction to any part of physics, chemistry, and biology. This is the technological literacy necessary for all citizens; it is also much better groundwork to make science more likely to be attractive to larger numbers. Most significantly, it would make better citizens out of physicists, chemists, and biologists.

Educating Americans in Applied Science

If the foregoing is an accurate, albeit necessarily qualitative and anecdotal, description of the present situation of educating Americans about and in technology, it would call for several radical reforms in the entire structure and content of K-12 education in technology and science.

The major and substantive change should be in rectifying the gross and unnatural imbalance in all formal education towards abstraction and away from relevance and concreteness in all technical subject matter. This kind of change is essential. This degree of abstraction from felt and experienced reality is what has isolated the entire culture of science and technology from the masses of U.S. citizens. Science must again be connected to concrete experience; lemons and scrubbing ammonia must be connected to pH, toasters and irons must lead through fuses to amps, volts, and watts.

The metals, plastics, and glasses every human being uses must be the seedbed from which the periodic table and thermodynamics sprout. Global climate issues daily reinforce the reality of the Earth as a system from which can issue biodiversity, life forms, evolution, and so forth. Every illness, every pill, every surgical procedure, can serve as the "bait" for biology for another fraction of the students who have not responded to the abstract approach.

But—and this is of the utmost importance—it is not because one may entice more students into entering technology or science (or "appreciating" them) that this change must be made. It is much more fundamental than that. It is the repositioning and replacement of science back into its role as one among many human activities, potentials, values, ideologies, and so forth. Moreover, it is this reconceptualization that will ultimately rescue basic science, which is quickly running out of things to study at

a price the public (the only possible patron) is willing to pay. If science is not to become baroque, besides broke, the bridges to the everyday world must be strengthened. Fortunately for the world, the replacement of the British-American Nobel-prize-dominated economies by the Japanese economy as the dominant economic force with its technology-driven science, will bring home the point to the masses. Einstein once commented that if a culture's pipes did not hold water, neither would their theories. Yet thousands of graduate students in physics, chemistry, and even regrettably in electrical engineering, would be baffled by Einstein's claim of the close connection between our technology and our science because the reductionist paradigm has held that they can be paid from the public purse to do theoretical physics without any concern for their country's economic or technological base.

Role of Materials Scientists and Engineers in K-12

As in all scientific work, it is essential to stand as Newton did "on the shoulders of giants" by reading the literature.

Next it is essential to clarify what goals an individual or society wishes to pursue.

This will then determine the activities to be engaged in, which themselves fall into these categories:

1. Offering personal help in local school systems as aides (not experts) to the teachers who are the experts in teaching. This demands some training in approaching schools. It will necessitate coordination with a dozen other societies' members doing the same thing.

2. Working on changing the system to move toward officially substituting the applied sciences or real sciences of agriculture, materials, earth, health, or engineering for physics and chemistry as the representative subject matter called science wherever possible, with PCB courses offered for the small minority who want them.

3. Contributing new hardware, firmware, or software (giving special kinds of apparatus to schools), making TV teaching modules, making new print modules, etc. Before any such project is undertaken, what should first be worked out is how the product will be used in the schools. Who will authorize its use, pay for texts, etc.?

The materials scientist or engineer concerned about the state of the U.S. economy has many targets to aim at—the savings rate, Wall Street practice, the individualism of U.S. science, the gross exaggerations by scientists and journalists, and last, but not

least, the state of technological literacy in the country. For those who wish to work in the last-names area, this primer has attempted to help them avoid some pitfalls in entering the K-12 system.

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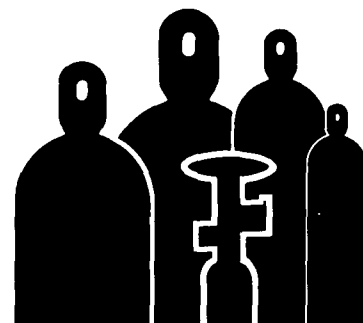
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