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The Relationship of Technology To Science and the Teaching of Technology

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INTRODUCTION

TECHNOLOGY EDUCATION NEGLECTED

"Technology" as parallel subject matter to "science" has never found any major place in our K-12 system. This is due to the enormous confusion surrounding the question of the relationships between the icon-words "Science" and "Technology." In the American public's belief system, "Science" is a uniform good. The American credo affirms "more scientific research" is certain to be good for the nation. In economic terms, it fails to distinguish between a "consumption good" and an "investment good." Without any thought or reflection, the U.S. public and its leaders base actions on the proposition that the supply of new "basic science" is infinite, that science leads to applied science which in turn leads to technology and jobs. ALL of which assumptions are now regarded as, almost certainly, egregious errors.

The U.S. attitude toward technology, on the other hand, is much more ambivalent. On the one hand, "high-tech" carries the same cachet as "science;" but technology as polluter, negligent cause of adverse health effects (from war to asbestos to "chemicals"), conjures up powerful negative images.

This situation was compounded by still a further mistake. This is the fundamental error made after World War II in America when victory was ascribed to the atom-bomb (less than one in a thousand in the population realized that Japan had offered surrender before the bomb), and the atom-bomb was hailed and celebrated as a product not of U.S. technology, but of physics!!! Thus was "science" ensconced in America's pantheon.

Finally, while "science" (now represented by its subdivisions of Chemistry, Physics and Biology) became firmly ensconced in the school system, vocational education carrying many other connotations was the only toehold which anything resembling "technology" had within the school system. Yet today it is possible that another historic shift will allow technology to be reentered into mainstream K-12 education.

IMPENDING U.S. DECLINE

The accelerating economic decline in the U.S. will provide this opportunity. And 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 proclaimed and reinforced at every opportunity by anyone concerned about better technology education.

OPPORTUNITY AND RESPONSIBILITY

Those concerned with technology education face an enormous challenge. First, they must clarify the relationships between science and technology, and clarify especially the place of both in the context of the economy and the political life of the country. Second they must re-think, "de novo," how and what one would teach the AVERAGE CITIZEN about technology, and secondarily what should be taught about science.

The purpose of this paper is to describe the muddle resulting from this linguistic confusion, and to present some basic definitions and relationships among science, technology and society. In addition, we address the two questions of what average citizens need to know about science and about technology.

THE PRESENT MUDDLE

TECHNOLOGY RESCUES THE U.S. AND IS MISLABELED "SCIENCE"

For 45 years since World War II, U.S. policymakers have survived on a series of historical accidents. Victory in war paid totally unexpected dividends in its aftermath. The U.S. was the only country with an enormous industrial machine running full tilt. This industrial momentum, with its overcapacity and its energized youthful leadership became the technological pioneer and monopolist to the world. But it did so on a strongly tilted (even if temporarily so) playing field, and with no opposition. The most significant policy impact occurred without planning. The many brilliant scientists -- physicists and chemists -- who had been doing amateur engineering in Los Alamos, emerged into the civilian sector with the assertion that it was "American science (especially nuclear physics) which had won the war." In the euphoria of the victory, no one even bothered to challenge this utterly preposterous claim. It was no time to point out that Japan even had, in effect, surrendered before the bomb, and it had surrendered because of superior U.S. munitions production technology. The modern physics which was needed for the bomb had all been done in Germany. If such scientific advances had anything at all to do with making bombs, virtually any country could make them. If science conferred any advantage, Germany should have won hands down. Making nuclear bombs was an enormous technological achievement, based on the U.S. enormous technology base in power, people, and resources. Yet the historical fact remains that just as Jacob stole Esau's blessing by sleight of hand (Genesis

27:27-34), a much more serious stealing of the birthright (the affection of the U.S. public) of "technology" by "science" occurred in the late forties. This misrepresentation -- this golden fleecing a la Senator Proxmire of stealing the kudos due to technology -- has, does, and will, until rectified, cost the nation very dearly. Shapley and Roy (1983) dealt with the impact on national policy. This paper focuses next on the impact on education.

WHAT SCIENCE AND TECHNOLOGY DO WE NEED?

During the last year or two, all policy analysts have agreed that U.S. technology is in deep trouble. Yet, without exception, the national response to the failure of U.S. technology is to demand more "science." This obviously assumes the absurdity that more or better science in K-12 equals better technology in the U.S. Paul Hurd (1989), dean of U.S. science education, in an elegant analysis of what is wrong with the myriad analyses of what is wrong with American science education, goes down all the alleged failures of the American schools, point by point, to show that in almost all cases it was the allegation that was incorrect. And soon, therefore, we shall be correcting mistakes that had not occurred. His central claim is that the American society's "contract with the schools" was for certain "services." It was not that the schools had failed in that contract, but that American society had changed radically and now wanted entirely different "services." Instead of better doing what was apparently required in the old contract, he suggests that the prior question is "What does American society want from its school system?"

In today's economic and political climate, my view of the tasks which society would like to have its schools help with, if not "solve," includes, at least, the following:

1. Maintain the U.S. living standards, as perceived by the public and experienced by a majority of the population, as being "the highest in the world." WHATEVER education is correlated with that, will be acceptable to the electorate.
2. Produce recognizably high achievers in all fields of learning: technology, art, humanities, sports, and science, who will contribute to a sense of national pre-eminence.
3. Help in the "socialization" of the minority populations, especially urban blacks and the new Hispanic and Asian immigrants; i.e. find meaningful work for them and thereby integrate them into American society.
4. Help in management of the social crises attendant upon major national failures -- widespread use of drugs, family structure dissolution, and so forth.
5. Educate a sufficient number of citizens to participate in, manage, and lead a complex technology-overlain society.

Hurd's point is that many of these are NEW goals for the school system, and the old school system cannot possibly "succeed" at them. In any case, no school system can contribute much to their solution.

All this bears directly on the issue of science and technology education because the #1 issue to confront the American populace and it's leaders in the next decade will be the economic issue. Most analysts agree that the speed of decline of the U.S. in terms of gross national product per capita, world economic hegemony, and so forth can only accelerate for the next several years. (See summaries in Roy, 1989; Roy, 1987). Without question the most significant immediate new task for the schools (and colleges and churches) is to prepare U.S. citizens, ON THE AVERAGE to LOWER THEIR EXPECTATIONS, while keeping hope alive. This may also, of course, require the upper third of the population to be "schooled" to accept even steeper declines to restore some equity after the Reagan years. Even the most enlightened political leadership cannot get elected on such a platform of managing economic decline, even if the alternative is catastrophe. But they can lead, if and when the groundwork has been laid in schools and churches to create a constituency. This is the magnitude of the task confronting ALL educators. But it does have a specific bearing on science and technology education.

EDUCATING AMERICANS IN TECHNOLOGY (AND SCIENCE)

This imminent national economic decline will present all educators with a tremendous opportunity because, for the first time in 50 years, the citizen will turn to new solutions. Among these solutions, there is a chance to rationalize the gross imbalance in the U.S. in interest, funding, and so forth favoring "science" at the expense of engineering and technology. But these educators also face an immensely more difficult question: What should be the goals, sequence and scope of content in technology and science?

WHAT NEW GOALS?

It is astonishing, as Hurd (1989) points out, that there is so little agreement on what the goals and priorities of science and technology education should be. It is our view that the broadest goal surely must be to educate citizens to cope with their present world. This means that the core of the curriculum must include TECHNOLOGICAL LITERACY (as described below) for every citizen.

Another goal at the other end of the spectrum would be the preparation of the professional college educated scientist and engineer workforce (about 10-15% of the population). Their curriculum would resemble most closely the present college-bound science tracks in our schools.

In the middle there should be radically new curriculum options which would combine much more hands-on practical learning -- not far from present Technology Education curricula, but with more science. This would put technology alongside more abstract science in a new "Applied Science" emphasis. And this option should be perceived as an equally prestigious and difficult option as any college preparation curriculum.

WHAT NEW CONTENT?

CLARIFY DISTINCTIONS BETWEEN SCIENCE, TECHNOLOGY, AND STS EDUCATORS.

In ALL the sets of options, a major emphasis must be placed on correcting old mistakes in the national perceptions of what science is, what technology is, and how they are related.

A very effective way to make the distinction is to point out the three rather sharply separated human communities and their separate activities; scientists, engineers, and science-technology teachers. These distinctions have been well made by Harrison (1989). Similar distinctions must be made between the goals of science and technology. Baruch (1984) put it very well. For students, a tabular apposition of the characteristics of science and technology often achieves a firmer grasp of the distinctions than any argumentation. (See Table 1)

TABLE 1

SHORT FORM COMPARISON OF SCIENCE AND TECHNOLOGY

SCIENCE	TECHNOLOGY
Human study and understanding of nature (natural philosophy)	Human use of human and natural resources to attain a desirable goal. Obviously, technology is as old as human society: pottery bows and arrows, jewelry.
Observation and reflection was the main tool in classical science (partly for religious/ philosophical reasons). Modern science (300 years ago) added added experimentation	Empirical cut and try is the time tested method of technological advance. Technology is always part of nature + human + artifact system with manifold feedback.
Science is inherently reductionist (i.e. ilolate the portion of the universe for study) and can be done in complete isolataion with no feedback loops.	

MODERN SCIENCE	MODERN TECHNOLOGY*

Universal	Strongly influenced by local environment
Precise	Fuzzy
Simple truths, equations concepts	Complex aggregate of complex information
Transfers all content a light, to all parts of the world	Takes years, and is pointed at targeted audience
A single individual can understand and utilize new advances	Needs an entire system (=culture) to utilize new science or technology
Transfers relatively easily	Transfer is very complex
Many cultures do it well	MIGHT be highly tuned to cultures that value cooperation and community over individuals

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* Gestation periods are 10-20 years

DEVELOP CLEAR PICTURE OF RELATION OF SCIENCE AND TECHNOLOGY.

Next we must deal with the RELATION of

science to technology. It is imperative to undo the flat-earth ("science leads to technology") syndrome all the way through. It must be made clear with dozens of examples, starting with Galileo, that technology more often leads to science than the other way around. The accurate description of the science and technology relation is:

1. Technology leads to science more often than science leads to technology.
2. Technology and science are not in the same hierarchical plane in human learning. Technology integrates science's results with half a dozen other inputs to reach a goal.
3. Teaching technology and about technology is important for all citizens, while science is an equally important addition for a small (10-15%) subset.

This topic has been developed in detail in other papers (See, for example Roy, 1989; Shapley & Roy, 1983).

STRATEGY: PEDAGOGY FROM THE OBVIOUS, INSTEAD OF THE OBSCURE

From time immemorial, communicating "techne" 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 which 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 increasingly over the last fifty 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 science. 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 shows 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 last President of the U.S., the chairpersons of most of our largest corporations, the leading playwrights, poets, and university presidents have very little knowledge of the level of science some now demand of ALL students.

A technology-focused curriculum would eschew abstraction for obviousness. Every citizen would be expected to know about those parts of contemporary human experience which are obvious to all, which 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, 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 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, can form the connecting 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.

THE NATURE OF KNOWLEDGE OF TECHNOLOGY AND SCIENCE

Larkin (1989) has stressed the hierarchical structure of knowledge within physics. This author (Roy, 1986) has made the case that many applied sciences, such as materials research, do not lie in the same hierarchical plane as the basic sciences like physics and mathematics. In other words, materials research cannot be sandwiched in between physics and chemistry. The integration of several subject matters or disciplines, including engineering disciplines, combined with the purposive nature of the work, puts applied sciences and engineering into a higher hierarchical plane than the scientific discipline. In analogous vein, technology is not a subject alongside physics and chemistry (See Figure 1). It includes science as one among many inputs (See Roy's TWO TREE THEORY in Shapley and Roy, 1983).

The idea that learning science is the necessary pre-cursor to learning technology is absurd. All of human history is proof. Indeed the U.S. Department of Defense has shown that specific, even "high tech" tasks can be taught well, without any science. The entry points into the system of learning about technology are manifold. Figure 1 shows different routes which may be employed.

FIGURE 1. Hierarchical structure of knowledge, showing that technology is not on the same level as the sciences.

For THE MEDIAN LEARNER, we believe that the STS route -- entering via the interest in the societal problem -- is best. Moreover, it is the only innovation in CONTENT proposed for alleviation of the so called math/science crisis. For a 10 percent minority of the population, entering via science (the present tradition in the U.S.) MAY be the most effective. But for a larger minority, the entry through hands-on technology may be the best. The U.S. has been losing out on the "brains in the fingertips" of the artisan the "techne-ologist" by overstressing the abstract conceptualization as the ONLY way to learn the science which is related to technology, and technology itself. The next section omits the traditional route of more and better schools and improved BETTER SCIENCE CURRICULA, and focuses instead on the new options.

THE NEW PEDAGOGIC STRATEGY: STS - TECHNOLOGY - SCIENCE

It is the author's contention that the entire student body being exposed to STS will benefit them in several ways:

1. Students will be much more informed and aware of the most significant current issues.
2. They will have been exposed to a method of critically analyzing such issues.
3. They will have been made aware of how technology affects their lives, and how they may interact with technology.
4. A higher percentage than at present may choose to enter engineering, some because they perceive it as a means of controlling their own futures.
5. A higher percentage will become interested in the scientific background behind the engineering, and this could result in more candidates for science degrees.

Thus the STS approach to "science" education has two separate benefits; making better educated citizens and possibly increasing enrollments in science and engineering.

The STS route can be summarized by Figure 2.

FIGURE 2. The STS route.

At the conceptual level, this technological literacy requires a knowledge and understanding of the key generalizations of STS, all thoroughly explicated through numerous examples involving national problems from global climate change to liver transplant allocations to high-tech flight from the U.S., and so forth.

To acquire technological competence in this culture, one can take the route through high school science. This is certainly appropriate as a part of this POTENTIALLY deeper understanding of technology culture for the 5-10 percent who will major in technical subjects in college. How technologically literate typical science graduates actually are, is not clear. Nor is it clear how much science is optimal at this level. What has been established as a result of the "new Math," "PSSC," and "Chemstudy" approaches, is that having more and more sophisticated courses in physics and chemistry in high school has been counterproductive. Moreover, AIP data show that the percentage of physics majors who took no physics in high school is rising and now approaching 25 percent. It would appear that BROADENING THE BASE OF SCIENCES taught in K-12, by requiring the applied sciences (earth, materials, and medical) is a strategy which has not been tried. Moreover, this has the intrinsic pedagogic rationale that learning science through contact with applied science is certainly invaluable in itself, and may make much better basic scientists also.

Finally we turn to the citizens who will use more technology and less science in their life's work; the factory workers and the repair/service persons of sophisticated machines from automobiles to copying machines.

What mix of traditional science and modified technological education courses is optimal? The need for students with this kind of training becomes apparent when the U.S. is compared, for example, with West Germany.

EDUCATING AMERICANS IN TECHNOLOGY

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 necessary. 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 be re-reified -- 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 sprouts. 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 re-positioning and replacement of science back into its place as one among many human activities, potentials, values, ideologies, and so forth. Moreover, it is this 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 being 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.

It is not appropriate here to try to develop and justify an optimum scope and sequence of the courses in science, technology, and STS, which could optimally educate the MEDIAN STUDENT. An appropriate mix of K-12 teachers, professors of education, and school administrators needs to be assembled to do just that. Yet, from the foregoing one can summarize some of the elements which should be present in any new curriculum for an STS and applied science approach to education of the median student. Listed below are some of the key content which would be brought together under any such curriculum. And Figure 3 provides a VERY VERY rough sketch of the kind of sequence one could imagine for educating Americans about and in TECHNOLOGY.

KEY ITEMS TO BE INCLUDED IN NEW CURRICULA

1. Require STS components throughout 6-12
   a. Distinction between science and technology
      Relation of science and technology to Society:STS
   b. Role of Science and Technology in the interaction of Science, Technology, and Global Society.
2. Introduce formal science via applied science courses (Materials, Earth, and Medical Science).
3. Require some "technology" of every student in parallel to the science requirement in junior and senior high.
4. Shift emphasis of special programs from very science-talented, to science-alienated (a fraction of whom are also talented).

IS STS OPTIONAL IN COLLEGE AND/OR HIGH SCHOOL?

The place of STS in formal education is slowly becoming clear. It is, as Figure 4 attempts to show, the interactive heart of general education. For fifty years the fissiparous dominant reductionist model, based on a misunderstanding of good science, has cut the heart out of general education by dividing it up among watertight disciplines.

FIGURE 3. Possible STS and technology education emphases in the new sequence

STS has emerged today as THE unifying (across the two-culture divide of S/T and the Humanities) force. It obviously also emerges as that central core of general education which is NOT handed over to a "discipline". In that respect, STS is a re-invention of the idea of the UNI-versity as a part, indeed the very intellectual core, of the Multi-versity.

FIGURE 4. STS has become the CORE of

integrative general education, thereby taking over the core function of the UNI-versity, but doing it within the MULTI-versity.

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