SCIENTISTS AND 21ST CENTURY SCIENCE EDUCATION

Introduction

The critical examination of a nation's educational system is often a shock since education is deeply embedded in the culture of the nation. Nevertheless, it is a characteristic of our times that nation after nation is in the process of such a critical examination.

U.S. Experience

In the U.S., it often takes a major crisis to stimulate the kind of educational assessment that is required. The U.S. educational system and especially in mathematics and science, has enjoyed many decades of world leadership after the technological successes of World War II. Aided by wartime-induced prosperity, a strong pulse of European immigration and an awesome respect for the power of technology, the U.S. entered the post-war epoch with a determination to lead the world in science, mathematics and engineering.

The "G.I. Bill" sent millions of World War II veterans to college, strongly advancing the prosperity that an educated population can create. U.S. graduate schools attracted students from all over the world. Generous research funding also paid off. We achieved outstanding manufacturing productivity; new industries and new occupations with highly paid jobs were created. New advances were achieved in all fields of basic and applied research.

The 1957 success of the Soviet Union's first earth orbiting satellite, Sputnik, stimulated a huge U.S. response: the creation of NASA enabled the U.S. to put a man on the moon and put exploratory robotic vehicles on Mars. Revolutionary progress in microelectronics enabled the development of the personal computer, cellular phones, a huge expansion of software development leading to the explosive exploitation of the internet. U.S. advanced into the Information Age. Ingredients that made all of this possible were a cooperative Federal Government, an educational structure that, at its best, was hugely productive, and a continuing influx of talented foreigners.

However, by the late 1960s and early 1970s, the Vietnam War and accompanying social turmoil turned much of the nation's youth against established traditions and values. President Dwight Eisenhower had warned the nation about a "military-industrial complex" that seemed to encourage environmental degradation, energy profligacy and the acquisition of nuclear armaments sufficient to destroy the entire planet 10 times over!

Small wonder that the response of students was a decrease in their interest and their achievements in mathematics and science. National and international measurements confirmed the decline. A falling off of the immigration of future STEM workers added to the U.S. concerns.

By the 1980s, the nation became aware of an erosion of U.S. scientific and educational capacity. A report of a National Commission issued in 1983 entitled "A Nation at Risk" warned of the failure of the educational system. A long process of re-examination began then and continues with ever more intensity today. National Commissions, Panels, Workshops, Forums, Councils – public and private – produce eloquent and passionate analyses and criticisms of U.S. education. The involved communities touch every aspect of U.S. society: scientists, educators, business community, academic societies, teachers unions, parent associations, textbook publishers, foundations, federal, state and local governmental agencies – all studied the "system", analyzed the failures and recommended solutions. Today we recognize a colossal failure to implement.

We must be aware that, as opposed to all other nations, U.S. education is local responsibility. We have no Minister of Education. We have 50 states, divided into over 15,000 school districts, managed by Boards whose membership are mostly devoid of educators or scientists. A consensus has emerged which recognizes the slow but steady failure of the U.S. educational system to supply the nation's industries with a cohort of skilled, creative STEM (Science, Technology, Mathematics, and Engineering) people as well as a failure to create a general public, knowledgeable and sensitive on the role of STEM in the 21st century.

The conclusions were essentially unanimous as more and more of the nation's leaders articulated the problems. Indicted were the processes of teacher recruitment and training, the greatly diminished professional and social status of teachers, the increasing gap in educational achievement between the poor, the handicapped, English-deprived (about 30% of the population) and the rest. The curricula in the STEM subjects has not absorbed the scientific revolutions that took place in the 20th century, most notably the 1910-1930 revolution in the physics of atoms and molecules (quantum physics) and the discovery of the structure of DNA (1953) which led to the rise and dominance of molecular biology.

The International Scene

In studying the corresponding educational picture in other nations, we are aware of two crucial changes which describe these early 21st century times. One is the extraordinary pace of technological change which influences human behavior worldwide. A stone is thrown in Ulan Bator and it is posted on the internet in Macao and San Salvador within minutes. The other is globalization which has the effect of combining the human resources of the planet, wherever they may be located, for the sake of efficiency. Pre-globalization had a national enterprise manufacture all parts of a given product, say an automobile. Globalization seeks the least expensive and most efficient producer of a given part (say the wheels) wherever, in whichever country that part is made.

Matching the decline of U.S. performance in STEM, other nations are rising to create educational systems that will place them at the lead over the entire spectrum of science and technology.

The race for scientific and technological leadership is worldwide, competing even with soccer! In the U.S., the reports arrive regularly with mixtures of alarm ("Before It's Too Late") and perceptions of the new burdens on education, now classified as pre-K through grade 20. The 21st century world is dramatically more interconnected and competitive. U.S. workforce now must compete with workers anywhere in the world, including large numbers of highly educated workers willing to work for low wages. This places a higher responsibility on STEM education, which now requires much higher performance levels in creativity and innovation than ever. Yet the trends are in the wrong direction.

This presentation of an educational crisis from the U.S. point of view has its parallels in many nations. Attitudes depend upon the history and culture, on the leadership, and the industrial and scientific base of the nation. However, there is a common incentive: the need for an educational system that will encourage its graduates to innovate, to be creative, to create new services (FedEx), new communications devises, new kinds of software, new kinds of transportation (Segway), housing, medical advances. The education system then must provide a matching high level of preparation in mathematics, science, engineering, but also in reading, speaking, writing *and* history, economics, literature, the arts. It is interesting to note how similar are the education problems of South Korea and the U.S.[1]

In the U.S., the diversity of students presents a special problem for the educational system. This system must provide for a much higher level of scientific literacy for all students, yet raise the level of achievement for students with the greatest interest and aptitude for STEM. Yet among today's students are English language learners, those

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[1] *Science*, vol. 317, 6 July 2007, p. 76.

from low socio-economic backgrounds, those who have completed high school but are not capable of doing college work. Also creating a challenge to teachers and the system are students comfortable with the Internet, comfortable with Web 2.0; they learn from blogs, wikis and podcasts. Clearly, the teaching of such students must proceed quite differently from the teaching of "normal" students.

School systems differ greatly from nation to nation, even from district to district within a nation. However, there are common problems:

(1) the lack of training of teachers in STEM subjects;
(2) the lack of sufficient time for teacher-to-teacher communication;
(3) the inability of teacher to understand or even to have some grasp of current political issues which are based upon science;
(4) the lack of teacher grasp of the *process* of science, i.e. how it works, some history, the path to successful careers in science;
(5) a failure of teachers to understand the deep connections between the core disciplines of physics, chemistry, biology;
(6) the lack of an appreciation of the excitement and beauty of the scientific view of how the world works and
(7) knowledge of scientists is absent – their need for skepticism, open-mindedness, curiosity, who did what and when.

A Science Way of Thinking

A frequently debated issue in STEM education: How much science should non-science students know? An easy response is: they should have acquired a science way of thinking.

This seemingly exotic concept of a "Science Way of Thinking" was stressed in the 1930s by famed U.S. philosopher and educational theorist, John Dewey[2]. Science, said Dewey, was the most potent force in the modern world. He was disturbed by what he felt was an emphasis on rote memorization and mechanical routine at the expense of inquiry and creativity. Dewey urged scientists to convey the science way of thinking to all phases of education as a "SUPREME INTELLECTUAL OBLIGATION". Although this includes critical thinking, curiosity, skepticism, and verification by observation and measurement, its deeper meaning has to do with the sense of wonder and awe that emerges from the student's gradual realization that the natural world is orderly and comprehensible. The overarching laws of science enable predictions: sunrise, weather, the hour and day of the return of Halley's comet in 2061. The appreciation and respect implied here are

[2] John Dewey, 1859-1952.

tragically missing from our science classrooms.

The body of knowledge generally termed “scientific stuff” is the content of science – what we know about how the world works. There is also the process of science – the observation and measurements of a phenomena, the slow conversion of phenomena to knowledge via the process of testing and rational thinking.

The Teaching of Science

The fitting together of pieces of knowledge into a coherent framework is the art of science. This process goes on so that larger and larger elements in the domain get included. The whole is a “theory”, tentative until disproved by fact or, surviving extensive and repeated tests, accepted as a law. Unfortunately, scientists still call it a theory.

Essential to the process of science is the story telling. Who did what and why and how do we come to know? Science is a humane and accessible indulgence, carried out by humans called scientists. What they say they are doing, their personal and cultural perspectives, is the process of science.

But the teacher, properly trained, brews the magic, colors the learning, and resonates with the students. “Yes! This is the way it works”. The chart of the periodic table glows with meaning. DNA, a once secret code, is now a user’s manual for human genetics. Gravitation guides planets, comets, falling apples. Superconductivity, so neatly demonstrated in classrooms labs, is a key to technologies that bring comfort and wealth – magnets for MRI, filters for city water systems, rings for giant atom smashers. “How else, class, can we use this invention?”

The tragedy is the rarity of this epiphany. Yet the “Science Way of Thinking” encapsulates the goal of science education for non-science students.

In education, the importance of inquiry, of students stimulated to engage actively in the process of learning, has been accepted widely in principle but only rarely put into practice. The profound concepts developed by John Dewey but traceable back to the Swiss educator, Jean Piaget, were aimed at establishing, as the goal for all students, of a science way of thinking. Dewey was so impressed by the power of curiosity-driven inquiry that he urged these educational principles on all aspects of education.

Proposal

Up to something like grade 14, we believe that future scientists, mathematicians and engineers and future citizens in democratic societies may be subject to fairly similar curricula. The output should yield a general population that can grasp a “science way of thinking”. It is here that scientists can help enormously by joining some kind of school/laboratory association where teachers and scientists can communicate for serious periods of time, e.g. 3-5 hours per week.

Until teacher recruitment, teacher training and teacher professional development all advance to the level required by the needs of 21st century STEM education, working scientists should be used in the schools. Scientists as mentors will, in fact, always be useful as teacher mentors in the schools. Here we are considering teachers in training and teachers in service from K- through grade 14.

We propose that all graduate students planning to achieve PhDs in science – all post-doctoral scientists, mathematicians, engineers – for the first 3 years of their post-doctoral career, be required to spend an average of about 3 hour a week in schools working with STEM teachers. This is a form of tax for 5-6 years, in return for the national infrastructure which provides the scientists and engineers a livelihood. This vital assistance to the teacher corps will also result in a science literate general public, again, shoring up the infrastructure for the 21st century economy and general culture.

Adding this conjoining of teacher training and teacher professional development with young scientists, mathematicians and engineers is not a single cure-all. Its success rests on an educational transformation that supplies us with outstanding teacher prospects, a much more rigorous program of teacher training and a greatly increased allocation for teacher professional development which allows for the kind of teacher-STEM interactions we have described. It depends on teachers being allocated a much greater fraction of their time to classroom work and a revolution in the respect that the administrative systems, and indeed the entire society, have for the professional life of the teacher.

Employment, citizenship, parenthood, leisure will all be profoundly influenced by 21st century developments, making Dewey’s quest for education embedding a science way of thinking ever more crucial.

The cost of this proposal would be chiefly in the preparation of the scientists-as-teachers-of-teachers. They will need to understand the limitations of the teachers. Here, we think mostly of the middle, high school and early college teachers. Thus, a 3-4 week summer course must be designed, much of which can be online.

Primary school teachers are another burden since these teachers are crucial in shaping the attitude of the young students. Fortunately, there exists excellent materials that have been developed (Lawrence Hall of Science, Berkeley or TAMS in Chicago) and the level of the teachers-of-primary-school-teachers need not be so high.

STEM Education in a "Liberal Arts" World

As our concerns about STEM education begin to influence educational systems around the world, we must keep in mind the age-old conflict between the role of science and that of the other liberal arts subjects. The transformation we seek in our educational systems must include the need for communications, for all citizens to have a grasp of history and geography (they must easily be able to find South Korea or Nigeria on a map!), must be critical thinkers, must understand in general terms how governments work, must have some initiation into global problems such as the environment, poverty, terrorism, law, energy, democracy, public health. Thus, again in the spirit of John Dewey, knowledge of science can be used to integrate all young people into the beauty and wonder, but also the fragility, of our planet. The science way of thinking can and should enhance relationships among people, appreciation of the cultural heritage in national literatures, music, art without which life is drab and dry as dust. That science is a universal culture, the same everywhere on our planet and, we believe, everywhere in the universe, must be a primary product of the new education we must adopt.

The new education should not be static, rooted in the past, passive inculcation but dynamic, evolving, based upon a respect for universal humanness and care for our environment. The proper teaching of science adds wonder at what we humans have discovered, adds mystery and awe at what we still have to learn. These spiritual aspects can infect all aspects of our human capabilities. That is the deepest goal of science-based 21st century education.