

Science Education for 21st Century

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Abstract

We differentiate the two objectives of science education: (1) to recruit and train toilers in the gardens of mathematics, science and technology; and (2) to create a scientifically literate citizenry that will provide a consensus on the many public policy issues that have a scientific side. I will outline the evolution of progressive movements in the US science education, spanning the pre-K to year 14. The international aspects have been featured in the World Conference on Science (Budapest 1999), on June 2004 AAAS/UNESCO Conference in Paris, and on an international movement to train primary school teachers to teach mathematics and science. One must take note of three important developments in science education: the increasing sophistication of the best in educational research, the developments of educational technology which significantly surpass the convention of chalk and lantern slides, and the advances in neurosciences and cognition psychology. It is sad but fair to say that none of these has as yet influenced what goes on in the classrooms of the nation. Finally, we address the question of what graduates who will live and work in the 21st century should know about science.

Somewhere upwards of less than 1 million years ago, humans acquired the ability of handing down to succeeding generations, knowledge and skills acquired in families, groups, clans, ..., leading to exponential advances in human development. The invention of education had a huge diversity across the planet (eventually and very slowly homogenized by explorers, colonists, anthropologists and even more slowly by technology TV, radio, internet....)

Educational systems (*) in developed nations show an impressive resistance to change.

* The Education System: - Teachers, Unions, Supervisors, Legislators, Parents, Text Book publishers, Teacher training colleges, Others (all have > 12 years in schools)

Science education has two strong reasons for being emphasized:

1. To populate the 21st century work force (SMET).
2. To produce citizens who are “savvy” enough to help guide their families, community and nation in 21st century decisions and in 21st century culture.

This talk will deal largely with the science literacy of the general public, the family member, the voter and citizen of the world. I will address the following issues:

- What is different now? Or “why is this time different from all other times”?
- Why and how do our educational systems fail?
- What must be done to make them work better?
- Why is science so special?

And why in September 2004 do we stress “**Science and Science education**” and so invite scientists (ME!) to talk about education.

A word from my Mentor

SCIENCE is an adventure of the whole human race to learn, to live in and perhaps to love the universe in which they are part. To be a part of it is to understand, to understand oneself, to begin to feel that there is a capacity within humanity far beyond what it felt it had, of an infinity extension of human possibilities.

SCIENCE must be taught at whatever level, from the lowest to the highest in a humanistic way. It should be taught with a certain historical understanding, with a certain philosophical understanding, with a social understanding and a human understanding in a sense of biography, the nature of people who made this construction, the triumphs, the truths, the tribulations.

I. I. Rabi (1960)

Five Questions

1. Why are young students, in increasing numbers, avoiding courses in science, mathematics, mathematics – especially in developed nations?
2. Why is this a crisis of major importance?
3. How do we deal with the dichotomy of a rapidly expanding knowledge base at the same time as we have an increasing gap between the “haves” and the “have-nots”??

[The increasing gap between those with access (~ 1 billion) and those without access (~ 5 billion) to I.T. is a dire threat to our civilization]

4. Why is it that it makes no sense to take a year (or two) of science when the understanding of science rests on the connections between the three core disciplines of physics, chemistry and biology?
5. Is our present K12 system suitable for the 21st century? I am proposing a pre-K to 14 (20 yrs old).

The dominant themes in school science are the big ideas

ATOMS and their role in the creation of materials from oxygen to steel to gold to bacteria to silicon.....

Solar system of sun, planets, asteroids, comets and satellite probes, voyager, mars landerHELEOCENTRICITY

GERM THEORY	of disease
GENE MODEL	of inheritance
PLATE TECHTONICS	model of earth
COSMOLOGICAL	story of the big bang model of the universe

And the connectedness of all fields of knowledge: unifying themes e.g. Symmetry

What can the scientific spirit contribute to science education?

Following the great ones from Galileo to Feynman, we distil qualities:

- How do they think?
- Curious blend of curiosity and Ego
- Humility in the relationship to our scientific heritage
- An innate scepticism about the universal validity of what has been learned
- A liberating sense of freedom to question
- To do better: openness
- A faith in the ultimate beauty and simplicity of nature
- A confidence in rationality so that problems of baffling hopelessness yield and become miraculously simple
- A respect for qualities of mind independent of “race, creed or national origin”

Somehow we must try to embed these qualities into all students.

But why Education?

There is a connection of this list of qualities necessary for science and the art of science education.

Lets list:

- Resilience to change
- Scepticism
- Confidence
- Humility
- Universal tolerance
- Curiosity
- Independence
- All essential to science but also to any human activity where reason, judgement and a democratic spirit are important.
- Education, science education, must instil these qualities in the graduates of a 21st century school.
- Few of our students will become scientists but all can share in and prosper from the replacement or authority by reason that science thinking demonstrates. They will be better lawyers, policemen, poets, workers and citizens.

This is what we must do:

1. We must seriously examine new data from cognitive psychology and neuroscience “scientist in the crib” in order to enter the pre-K epoch (e.g. ages 1-4yrs). We need pre-K specialist and co-operation from parents, guardians etc
2. We must have primary school teachers or S&M specialists much better trained in teaching M & S in the Piaget style of inquiry, hands-on, “mains a la pate” used successfully in Chicago, Pasadena, France, ... These teachers need continuous professional development from scientists, mathematical and new curriculum developers.
3. We need new middle school teacher professional development and integrative curricula → solve local problems e.g. environment of the school, internet data, projects with world wide

collaboration. School inspired after school projects, technology of graphing calculators, keypads, simulation and imaging => ATOMS (e.g)

4. We need 21 century science curriculum for all students given by highly trained specialist teachers who spend ~ 20% of their time in collegial professional development sequence - 9th grade (15) conceptual physics; 10th grade chemistry and 11th grade modern biology of proteins, cells, DNA, genetics, structural (molecules) biology.
5. Teachers must also have weekly meeting to design coordinating and connecting strategy → story telling of science and technology success and failure. Visiting scientists. Key pad accountability. Contact with real world problems.
6. Bridges to the social scientists and the humanities. Pre-consilience activities. Science as culture.
7. 21st century workforce must be a thinking, problem-solving capability. Routine jobs will soon all be robotics driven. Thus schooling for all students must be extended to age 20-22. Professional lawyers, business types, journalists, artists, architects, media, etc must be science “savvy”.

In the extra two or more years of formal schooling, real world problems must be encountered including:

- Environmental remediation
- Natural resources
- Education in third world countries (science corps)
- Health care
- Forging connections to the arts.

Consilience

As the century closes, the quest for new fundamental laws in physics continues, encouraged by a powerful technology that enables more powerful tools for research, but also which creates the wealth that makes much a search affordable. A newer thrust is towards an understanding of complex systems. Edward O. Wilson, the Harvard biologist, writes (iv):

“This is the goal variously in the in the studies of the origin of the Universe, the history of climate, the functioning of cells, the assembly of ecosystems and the physical basis of mind. The strategy that works best in these enterprises is the construction of coherent cause-and-effect explanations across levels of organization. Thus the cell biologist looks inward and downward to the ensembles of molecules, and the cognitive psychologist to patterns of nerve cell activity... “No compelling reason has ever been offered why the same strategy should not work to unite the natural sciences with the social sciences and the humanities” This seminal idea should inspire educators to look at their offerings in the basic areas of knowledge: the natural sciences, the social sciences and the humanities as illustrating the fundamental unity of knowledge and to encourage changes which move in the direction of exhibiting this unity...”

One would perhaps be too idealistic to dream that some day, every high school graduate will be able to understand the relation between science and the humanities and why this is important.

The 21st century is different

It is a knowledge and information – based society which will produce new opportunities and new challenges in all dimensions of our lives.

- Change is inevitable
- Complete coverage is impossible
- Obsolescence is unavoidable

New technologies, new discoveries, new media, new social structures and new possibilities for quality of life make life long learning essential so that humans can think, create, learn and collaborate “forever”.

The divided lifetime- first with learning, then the rest of your life applying this knowledge - no longer works.

.....the world into which they emerge.....

Just how is the world changing??

- It is a world of unprecedented pace of change.
- It is a world of different and higher level requirements on participants.
- It is a world of information technology and of issues of access to such technology.
- It is a world of globalization – of a paradox of increasing global interdependence and, at the same time of defensive local cultures of nationalism separatism and community coherence. Also the threat to civilisation of fundamentalism projections of the human condition, the strength of family, the level of moral and ethical behaviour, economic health, social and political stability are all subject to the explosive advance of science and technology, impacting society.

Education in the 21st century

The components of the digital revolution - radio, TV, wireless-ness, cell phones, internet - each with its own evolution, joining, merging morphing provides access to knowledge, learning across a lifetime in the humanities, sciences.....

Lack of access adds a crucial burden to the standard pains of poverty: hunger, disease, hopelessness.

- Some 80% of the population of the planet has never heard a dial tone. => The Digital Divide.

Yet cell phones and computers can be provided to families for pennies. A digital “peace” corps of a few B.S volunteers per village can instruct.

Why must scientists be involved in education?
AND
what can the scientific spirit contribute to science education?

Following the great ones from Galileo to Einstein to Richard Feynman, we distil the qualities that make science:

What is Science Thinking??

- Blend of curiosity and ego
- Humility in relationship to the heritage
- Scepticism about the universal validity of what has been learned
- A liberating sense of freedom to question authority
- An open mindedness towards new ideas
- A confidence in rationality
- A faith in the ultimate beauty and simplicity of nature
- A respect, no, a requirement for diversity in minds and cultures that have made science.

Somehow we must try to embed these qualities into all students as we teach science.

Education Technology

The possibilities are breathtaking.

History: Mass-produced textbooks
 Workbooks
 Pencil (with erasers for theorists)
 Cheap paper
 Blackboards (now white)
 Classroom clock
 The bell
 Electric lights
 Central heating

Admittedly a factory model but each of these was a transforming technology for school for the 18th and 19th century.

Now: the laptop, Internet, simulation and visualisation, information access, remote learning, web-enabled content, student centred learning (self funded instruction).

Yet, a few years ago, we had, in Chicago, closet computers.

PRIMARY SCHOOLS (Ages 5 – 10)

There is an internationality invariant problem that primary school teachers are untrained, ignorant of and fearful of science and mathematics.

The shame is that cognition science has stimulated “new” curricula that is engaging to children. Hand-on (mains a la pate) techniques stress the process of science. When teachers are trained in this, it is very successful.

Beijing conference (Nov 1-4) on primary school science education

- Story of TAMS and the French connection.
- If Chicago, why not Calcutta? CCBS and the international connection.

Primary schools

In grades one through three, US tends to introduce seven times the number of science topics as are typically intended in TIMSS countries that outperform the U.S. (This is typical) “mile wide and inch thick”.

Additionally, the collection of topics taught in US are a large and mostly arbitrary collection of what the district, state or even the teacher believes are interesting for children to do in science.

Local inference: teachers never have time to do anything in depth or to reach more demanding topics. Up to eight grade there is rarely more than descriptive aspects of Biology and little coverage of fundamental concepts in physics and chemistry.

WAR ---- GET THE PRIORITY AND THE LIMITLESS BUDGET

THIS IS A WAR ON IGNORANCE

ITS OUTCOME MAY BE AS SIGNIFICANT TO THE FUTURE OF THE NATION AS ANY IN OUR HISTORY.

“The measure of a nation’s success in the 21st century will not be on its military budget but on how much it spends on education”. *A. Einstein or somebody*

And in 99% of US High schools Biology is taught before Chemistry and Chemistry before Physics!

Here is the relevant history:

17th century Newtonian epoch – still valid (NASA uses Newton to guide voyager satellites around the solar system)

18th Century Thermodynamics, energy

19th century Electricity, magnetism

1890 -1930 Radioactivity, electrons, nuclei, atom, birth of quantum science, relativity

1930 – now Quantum chemistry

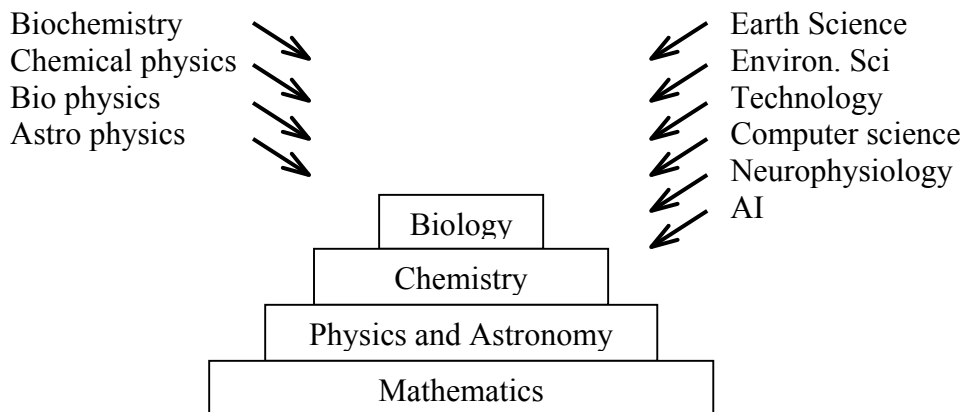
1953 - now DNA: biology becomes molecular

“Atoms explain chemical activity and binding then molecules explain DNA and life”.

The point of the history is to establish a hierarchy of disciplines.

There isn’t one unique perfect H.S. science curriculum. But lets look at the progression of learning by very young children and by the developments in modern science.

=> **This is the way it is** <=



The pyramid of science (Biology on top! “Capstone”)
This hierarchy is intrinsic to science.
Why isn’t it relevant to science Education?
I believe it is... (The time traveller)

Comment on High School Science

The existence of a hierarchy in the relationship of the sciences is, I believe a profound cognitive statement.

Physics as the foundational science and its unique role in idealisation dictates: P-C-B

A year of PHYSICS gives students a good sense of how SCIENCE works especially when we include stories.

CHEMISTRY broadens the study of matter and energy, drawing explanations from physics, at the same time deepening the student’s grasp of concepts, more stories.

BIOLOGY provides a more cognitive challenge, building on the chemistry and physics that undergird biological order.

The Rapture of Mathematics in 9th Grade (15)
It is the solution of the conceptual equation, which confronts nature
Or
 $x = vt$

WAIT! THERE'S MORE

In designing the 21st century H.S. Science curriculum we must ask:

What do we want them (all of them) to remember in 10 years? They will have forgotten $F=ma$ and $E=mc^2$.

In this H.S. science for ALL students, each discipline must sacrifice; say 20% of content to teaching the process of science

- How does it work?
- How messy is the process of discovery
- The need for open mindedness, scepticism, some sense of history, science as a humanistic activity, story telling
- The social and economic results
- Science as the only universal culture, the same everywhere
- Science as a way of thinking and knowing
- Science and values..... ethics, morality, and the bridge to the humanities.

Today, in 99% of all U.S. high schools, students take the sequence

BIOLOGY* - CHEMISTRY – PHYSICS

Taught usually as separate, independent subjects, having very little to do with one another.

This sequence was started in 1893 by a “committee of ten” which set out to standardise the H.S. science curricula. Ok in 1893, not in 1930 and we now know that the new biology (after the discovery of DNA structure and function) is molecular-based. And molecules are made of atoms.....

Ninth grade biology has more new words than 9th and 10th grade French.

HOW ARE WE DOING?

21st century schools have a vastly more complex mission than earlier to prepare graduates for life in the age of the internet; to be able to earn a living, to enjoy leisure, to be an active and engaged citizen, to raise a family.....

Evidence of failure of our educational system abounds:

- Nation at risk – 1983
- TIMSS 1998 →
- Alan Greenspan congress testimony 2002
- Glenn commission 2002 (Before its too late)
- PCAST report 2003

Evidence of the public understanding of science is dismal. Growth of junk science.

- Creationism
- UFO
- Alternative medicine
- Peach Pits
- Astrology
- Perpetual motion

→ IT IS TIME TO DECLARE WAR!!

Our Curricula are over 100 years old and at least to 70 years out of date!

WHY DO OUR SCHOOLS FAIL?

1. Teacher training! Too many teaching out of field, etc..
2. Teacher morale
3. Lack of continuous professional development
4. Inadequate teacher evaluation (Chicago: 0.2% rated unsatisfactory)
5. Teachers are not rewarded for being good teachers or for teaching more demanding subjects and conversely...difficulty in firing poor teachers
6. Outdated and largely irrelevant curriculum (see industry managers and college admission officers)
7. A dysfunctional school management system
8. Poverty, lack of pre-school preparation low parental education, motivation *But.....
9. Not nearly enough parental choice e.g. charter schools, suburbs...
10. Social promotion problem, retention in grade? Summer schools
11. Inability to use educational technology