

Five Challenges in Science Education

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The launch of Sputnik on October 4, 1957 triggered my nascent passion in tinkering into a full-fledged desire to become a scientist. My academic performance was spotty up until that time, having been identified as “mildly retarded” by one well-intentioned counselor in the days before ADD was recognized. But, with Sputnik, my apparent ADD vanished as I spent hours thinking about what it would take and what it would be like to spend a career exploring new frontiers of knowledge. For a fourteen-year-old growing up in Chicago, this was a great time to be alive. We had a splendid museum of science and industry, a planetarium, an aquarium, and a natural history museum. We were surrounded with resources to support any interest that young people had in the sciences.

By November of that year, President Eisenhower announced that our public educational system was in severe need of a complete overhaul if we were ever to produce enough scientists and engineers to keep up with the Soviets. By the time I started high school, the PSSC science curriculum was in place, and I found the educational climate needed to foster and develop my skills. In some ways, those were the golden years of education for me.

Today we hear a lot about educational reform, but our quest for accountability has resulted in many cases in the abandonment of quality educational practices and, in their place, we see what appears to some as perpetual testing in the midst of a curriculum devoid of excitement and the uncertainty of genuine exploration. But, as President Kennedy once said ¹, “Our

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problems are man-made, therefore they may be solved by man. And man can be as big as he wants. No problem of human destiny is beyond human beings.”

Looking at our current economic challenges, coupled with the loss of creative scientific and engineering work to other nations, it seems overdue to take a hard look at some of the challenges facing science education in the US, and to suggest ways these challenges might be addressed. As Intel's Craig Barrett says², “Anyone ... from the United States who says that the Chinese or Indians are not entrepreneurial, not creative, that they don't want to rival the United States in business startups has not been to India or China.”

Five of these challenges will be explored in the rest of this short document. These challenges are by no means the only ones facing us – you can come up with many others – but they provide a good starting point for conversations around this truly important topic.

The Shortage of Qualified Teachers

One of the highlights of the much-maligned “NCLB” act is the mandate that each student will have access to highly qualified teachers. And yet, in the areas of math and science, such teachers seem to be in short supply. This challenge has become so severe that some districts are importing qualified teachers from other nations – for example, schools in Wichita, KS are securing H1-B visas for Filipino teachers who come for three-year assignments (which can be extended)³ This experiment has worked well, but it is unclear if it has bought enough time for the domestic teaching force to add enough qualified science teachers to the pool to meet the needs of America's schools.

Much has been written on this topic. For example, the NAP report *Rising Above the Gathering Storm*⁴, explores this challenge in depth. The task is complex, but the penalty for inaction is to have even more teachers working outside their specialties. The following table from this report shows how big the challenge is:

Students Taught by Teachers with No Major or Certification in the Subject Taught, 1999-2000

Discipline	Grades 5–8	Grades 9–12
English	58%	30%
Mathematics	69%	31%
Physical science	93%	63%
Biology–life sciences	—	45%
Chemistry	—	61%
Physics	—	67%

In a followup document, *Rising Above the Gathering Storm Two Years Later*², the authors state “The strongest influence on the performance of students in a class is whether they have a teacher with a bachelor's degree in the subject they teach.”

Getting students through college in the sciences and engineering is a challenge that affects the pool of qualified teachers. In the area of engineering, for example, it appears that up to 50% of engineering undergrads in some schools change majors by the end of their sophomore year⁵. The number of US college graduates in physics in 1956, the last full year before the launch of Sputnik, was twice the number of graduates in 2004. The need to encourage teachers to work in the sciences must cut across all those interested in a future in education. No group can be left out in our quest to address this challenge.

Going back to my own experience as a student, I was lucky enough to have science teachers in high school who had their primary degrees in the sciences they taught and, in some cases, had worked in the field for years before becoming educators.

Learning about science as a vibrant human activity

Years ago, in my presentations, I would ask teachers to tell me the names of scientists. In general, the names they gave were of dead white men. Sometimes Madame Curie's name would appear, and Watson and Crick would be mentioned as living examples of famous scientists (at the time). But the idea of science being a vibrant field with participants of all genders and heritage was not reflected in most of the answers I received. It is as if we taught students about science without the scientists!

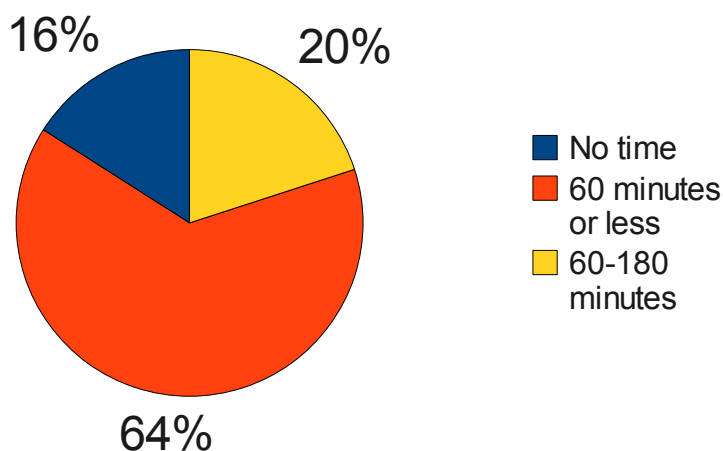
Also, I encountered many people who knew something about science, but not about why anyone would choose to spend his or her life exploring questions in a field that might not yield definitive answers in their lifetime. I even saw this in my own house when, shortly after my marriage, my younger step-daughter (who was in high school at the time) came to breakfast and saw a fractal pattern on my computer screen that was a result of a forecasting model I was doing for a client. The graph was quite pretty, and she wondered what it was. I told her it was a mathematical pattern. She has a strong artistic bent and shared that she never knew mathematical expressions could be beautiful. To her math was just calculations – not the exploration of deep ideas.

Now she had studied math in school, but she didn't realize that there were people who explored deep mathematical ideas outside the classroom – and that some of them did it just for fun!

By treating the sciences as abstract topics devoid of the incitement of human passion, we miss the chance to engage students in ways that might get them thinking of the sciences as a possible career path. In this regard, I was lucky. My father was (among other things) a bacteriologist. He would spend hours with his eyes glued to his microscope, looking at the pesky critters he'd found, and experiment with ways to knock them dead. There was a never-ending stream of experiments to do, and new discoveries to be made. While I had no interest in following in his footsteps, I respected the work he was doing in his own laboratory, and also got to meet other scientists who were engaged in amazing work in a variety of fields.

Cutting back on hands-on science

Hands-on science education seems to be in short supply in our schools. The following figure from the Lawrence Hall of Science 2000 study of elementary schools⁶ is sobering:



This chart shows the number of minutes per week spent on science education in K-5 schools in the San Francisco Bay Area in the year 2000. The fact that 16% of the students receive no science instruction at all in the heart of California's high technology enclave should be taken as a serious wake-up call.

Even in classes where science is being taught, too much of it seems limited to lectures based on textbooks. Now I admit to being one of those weird people who treats math as an experimental, rather than theoretical, science, and enjoy building complex computer models to explore topics as challenging as anticipating the emergence of new trends in technology. My approach comes from tinkering, and from a solid grounding in lab-based science in high school and college. I am saddened each time I walk the exhibit halls of a conference and see software that supports computer animation of experiments that should be done with real apparatus. Titrating a solution to neutrality is best done with a burette, not with a piece of

software that simulates the process.

To me the major benefit of doing actual experiments comes from observing those inevitable variations in experimental results from those predicted by theory. Experiments also allow students to observe non-intuitive phenomena they can then study in the course of resolving the gap between their intuition and the underlying physics or chemistry of an experiment. In this setting, a well-equipped laboratory can take advantage of versatile probe-ware and hand-held devices to capture real data that can be transferred to a computer for further analysis and inclusion in a report. In other words, students benefit when they *do* science, not just learn *about* science.

In addition to hanging out with my father, I was motivated to explore hands-on activities outside the classroom. When I was a kid, the Science Service produced and distributed *Things of Science*⁷ – a monthly kit of hands-on activities that was mailed to thousands of home subscribers. This product started in the 1940's. My subscription started at Christmas in 1957, a few months after the launch of Sputnik. My first slide rule was delivered by them the following year in one of the computation units. Each blue box, featuring a different topic, was eagerly awaited – it contained artifacts, and a manual of experiments to do with the enclosed items. I remember one month getting a box of fossil shells, getting a bendable plastic hinge another time, and a wide variety of other things to explore. Each box was eagerly awaited!

Tragically, kits of this sort have gone the way of the old chemistry sets. At least one can still purchase Erector Sets – but many of the other hands-on kits of my childhood have disappeared and, along with them, the chance for many kids to explore science topics with their hands *and* brain.

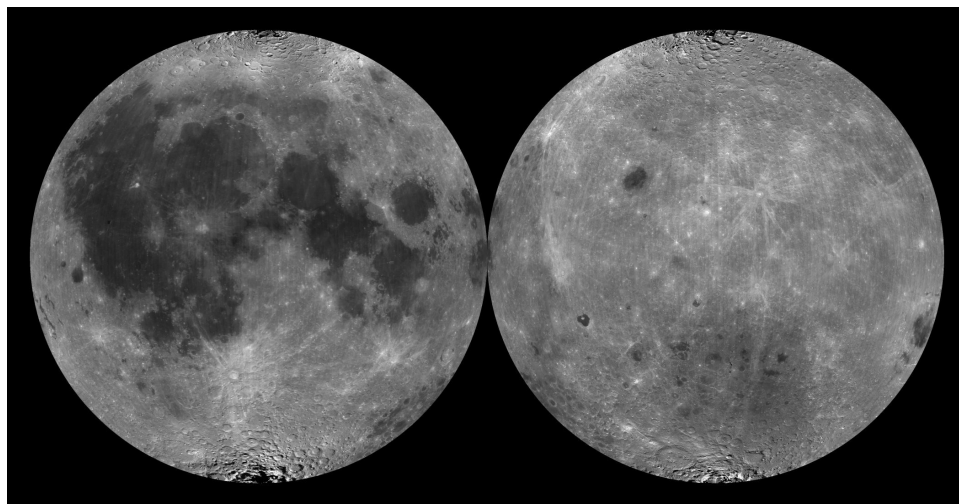
Science as process of inquiry and real projects

It seems to me that too much science instruction is based on imparting a body of knowledge to the students and then having them apply this knowledge to some pre-defined problems (complete with answers in the teacher's edition of the text!) The process of having students

explore new questions on their own falls outside most State standards, and thus gets left out of the curriculum. I think this is a mistake. I'd rather see students use a foundational knowledge of a field as a springboard to asking (and answering) their own questions. To start with, this is what real scientists do – they spend their lives answering questions that they ask of themselves. This move to a more student-directed approach is not trivial for teachers to make. To start with, there is still a need for basic knowledge to be shared. The challenge comes in finding the place for teachers to stop lecturing and the open the class up to student designed projects based on questions they ask themselves. To assist in this process, there is a rubric students can apply to their own questions to evaluate if they are worth spending time on to answer. (This rubric can be found in the inquiry handout on the Faculty page at www.tcse-k12.org).

What kinds of questions are worthy of student inquiry? Well, let's take an example: We know that we only see one side of the Moon from Earth – our Moon rotates on its axis at the same rate it revolves around the Earth. Why is that?

Rather than providing a canned answer, students will learn far more if they research this question themselves. Of course, this is an example of a question that has a known answer. A more complex question is based on the following two images:



The image on the left is the face of the Moon seen from Earth. That on the right is the “far side” of the Moon. There are striking differences in these two images – most notably the virtual absence of maria on the far side. How did these differences come about?

It turns out that this is still an open question. While a teenager may not come up with a definitive answer, this project provides a great deal of opportunity for research, and is sure to

result in students learning far more about the Moon than they would in any textbook-driven course.

A major challenge in transforming science studies into the inquiry-driven project-based learning domain is staff development. Our experience has shown that support needs to be provided on a regular basis until the teachers *and* the students become comfortable with the shift in methodology. The rewards, however, are amazing. Not only do students go beyond the material provided in their textbooks, they also develop an appreciation for the kind of work done by real scientists – perhaps leading more of them into the field.

The importance of this shift is reflected in a study done at Ohio State University⁸ in which students in China and the US were tested on science “facts.” The Chinese students outperformed the US students. But when both groups of students were tested on scientific reasoning, both groups failed. In other words, the knowledge of textbook delivered science facts does nothing to develop the capacity for scientific reasoning.

Connecting science to other subjects

Innovative educators have always made connections between science and other topics. Some science fiction provides a good starting point. Whether it involves reaching back to Jules Verne, or exploring more contemporary authors like the (late) Philip K. Dick, or Neal Stephenson, science fiction has always triggered some great “*what if?*” moments in our minds. Expanding beyond science fiction, the fine arts provide alternate pathways to thinking about science – and many scientific phenomena are esthetically pleasing by themselves!

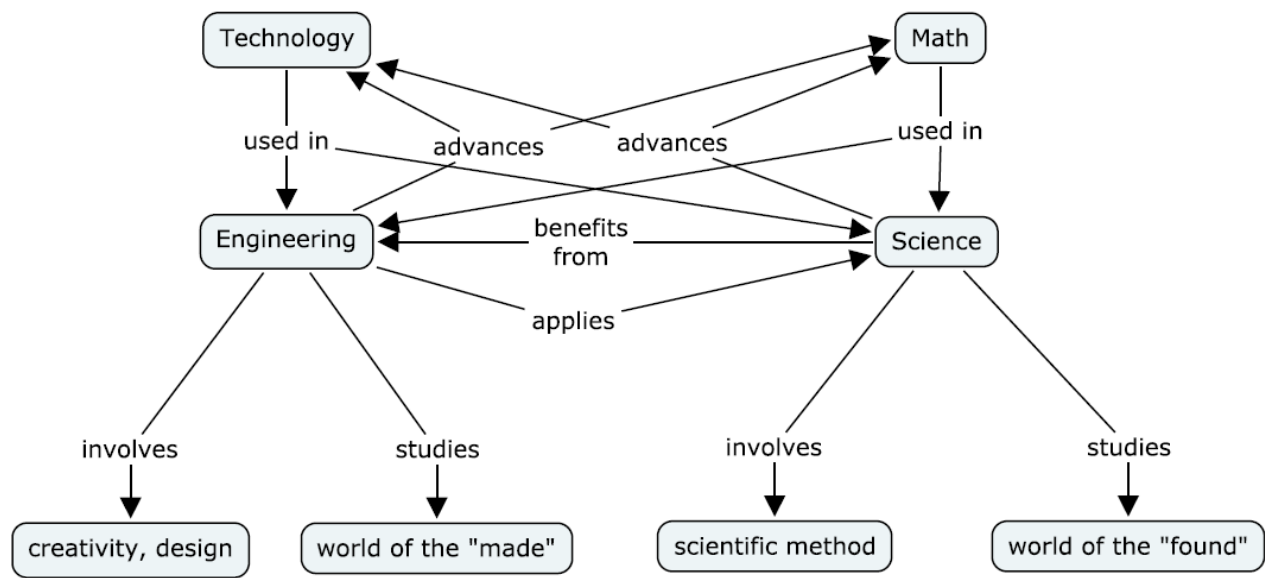
Today, for some very solid reasons, we are hearing more and more about the need for STEM skills (Science, Technology, Engineering and Math.) Unfortunately, much of the work in this area treats these four topics as stovepipes, functioning independently from each other. I think this is a mistake. As Kristina Johnson from Johns Hopkins University has said², “Today the problems are more complex than they were in the 1950's, and more global. They'll require a new educated workforce, one that is more open, collaborative, and cross-disciplinary.” Students should be provided opportunities for cross-disciplinary work before graduating from high school.

Here's the challenge:

While math, science and (some) technology are taught as separate subjects in school, the power of treating the STEM subjects in an integrated fashion strengthens the understanding of each of them. This is essential because technology and engineering are more likely to be found in

career academies than in purely academic high schools. The benefit of this approach is that, when students see (and understand) the interconnectedness of these four fields, they may find themselves more motivated to explore the individual subjects in deeper ways than they do now.

Consider the following chart:



At a high level, it is useful to think of science as the study of the “found,” and engineering is the study of the “made.” Scientists concern themselves with the advancement of knowledge in the realm of natural phenomena. Even the most abstract theoretical scientists are concerned (at their core) with the explanation of natural phenomena that might be observed under the proper conditions. Engineers, on the other hand, use scientific knowledge for another purpose: the design and fabrication of objects for the advancement of mankind. Whether it is the design of a new telescope, or crafting a more flexible space suit, engineers generally have a specific goal in mind when they start their projects: a goal that relates to having something fabricated (rather than discovered as naturally occurring).

At the core, science involves the “scientific method,” a process of hypothesis formulation and verification that is taught to students at multiple grade levels. Engineering, on the other hand, has at its core the more flexible notions of creativity and innovation – attributes that are harder to quantify and teach, but that are essential in the engineering domain nonetheless. The creative process can be nurtured, but it takes a special effort and classroom climate to

stimulate creativity. This does not mean that the scientific method is not of value to engineers, nor that scientists can not benefit from creative insights. Links of this sort are legendary in both fields. It is just that, at the core of these fields, each of these ideas has a strong role to play.

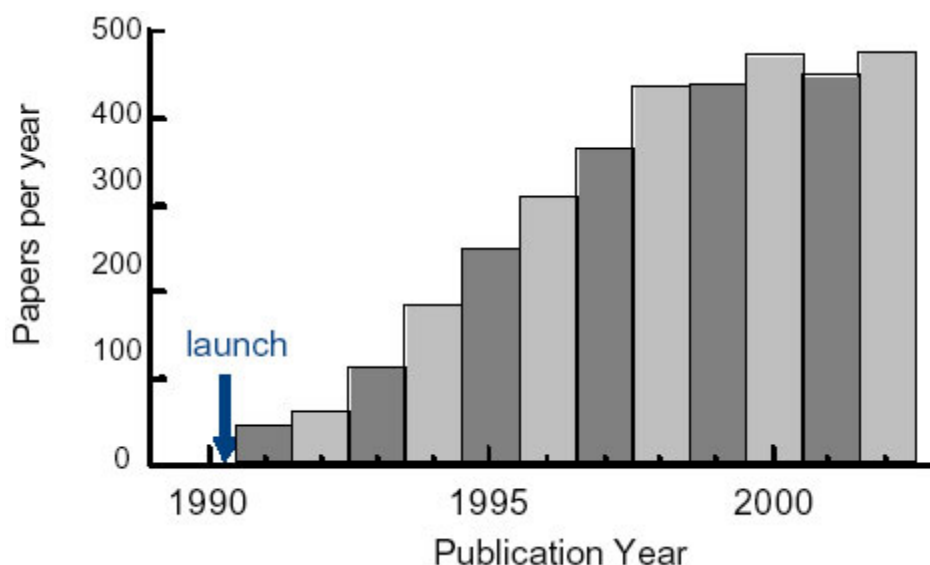
Science benefits from engineering, and engineering applies science – the two are linked. In fact, the linkages between these topics and the remaining STEM areas (technology and mathematics) are dynamic, highly interconnected, and constantly evolving over time.

Math skills are essential for both scientists and engineers. By the same token, advances in science and engineering can stimulate the development of new mathematical techniques. For example, Newton's contributions to physics and the calculus are tightly linked. Calculus provided the computational framework through which the laws of motion could be quantified and applied. This has always been the case. Geometry, for example, literally derives from “measure the earth.” While there are branches of mathematics that have yet to find application in science and engineering, this does not mean that applications will not be found at some time in the future.

To take a recent example, the foundations for chaos and fractal theory were laid at the end of the 19th century when Peano showed it was possible to build a space-filling curve ⁹ (a task that was previously thought to be impossible.) His thoughts were resurrected over a half-century later as a consequence of the active development of chaos and complexity theory. These branches of mathematics were helped along by the invention of the digital computer, and have since found application in science and engineering, as well as fields as disparate as economics.

Unfortunately, many students don't see a strong connection between mathematics and the other three STEM topics until they take advanced math classes in college. For many students, this is too late – without the requisite math courses under their belts in middle and high school, college-bound students are blocked from studying STEM subjects, thus contributing to the shortage of people in these fields.

The relationship with technology is similar. For example, the Hubble Space Telescope (HST) is a technology that has advanced our scientific understanding of the cosmos greatly. This telescope was the result of a huge engineering effort that relied heavily on science, and is providing new insights that not only advance science, but have had an impact on the engineering of newer, more powerful, telescopes. In fact, the Hubble news coverage in 2002 represented 44% of all stories emerging from programs of the NASA Office of Space Science ¹⁰.



The bulk of these stories related to scientific discoveries made with the HST technology – discoveries made possible by the tremendous applications of mathematics, and engineering required to design, build and maintain this telescope.

A problem with traditional curricula that treat the STEM topics as separable and, in fact, separate subjects is that powerful connections among the topics are easy to miss. Information on curricular connections are sometimes seen as supplemental, rather than lying at the core of the overall enterprise.

This brief paper set out to identify five challenges facing K-12 science education today. As you look at these challenges, and identify more of your own, I hope you will think about ways to address them in your own schools.

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About the author

David is the Founder and Director of Global Operations for the Thornburg Center. He is an award-winning futurist, author and consultant whose clients range across the public and private sector throughout the planet. His razor-sharp focus on the fast-paced world of modern computing and communication media, project-based learning, 21st century skills, and open source software has placed him in constant demand as a keynote speaker and workshop leader for schools, foundations, and governments.

As a child of the October Sky, David was strongly influenced by the early work in space exploration, and was the beneficiary of changes in the US educational system that promoted and developed interest in STEM (science, technology, engineering, and math) skills. He now is engaged in helping a new generation of students and their teachers infuse these skills through the mechanism of inquiry-driven project-based learning. (For details, visit www.tcse-k12.org.)

His educational philosophy is based on the idea that students learn best when they are constructors of their own knowledge. He also believes that students who are taught in ways that honor their learning styles and dominant intelligences retain the native engagement with learning with which they entered school. A central theme of his work is that we must prepare students for their future, not for our past.

David splits his time between the United States and Brazil. His work in Brazil also is focused on education, and he is currently part of a team redesigning curricular practice for some schools in and near Recife, his home city.