Why STEM Topics are Interrelated: The Importance of Interdisciplinary Studies in K-12 Education

David D. Thornburg, PhD
Executive Director, Thornburg Center for Space Exploration
dthornburg@aol.com
www.tcse-k12.org

Numerous reports, studies and pieces of Federal legislation have called for increased emphasis on STEM (science, technology, engineering, and mathematics) in K-12 education as a method of helping address shortfalls in these fields that are putting us at risk of losing our competitive edge. (For example see, *Rising Above the Gathering Storm* (http://www.nap.edu/catalog.php?record_id=11463) and the "Enhancing Science, Technology, Engineering and Mathematics Education Act of 2008" (H.R. 6104)). How were these four topics chosen as a focus of concern? How are they related to each other? Can they be explored in a cohesive way in K-12 education?

Unfortunately, except for defining the term "STEM," many documents do not explain exactly how these topics are related, and how they connect to other important topics relevant to preparing youth for their future. In fact, the connections between these four subjects are very powerful and make it easy to build a logical case for treating them together as an interdisciplinary whole. For example, our space exploration project for Middle and High School students (www.tcse-k12.org) is largely based on the seamless integration of these four topics, rather than treating each of them as separate or even as separable. This stands in stark contrast to traditional curricular programs that treat science and mathematics as distinct topics, while largely ignoring the areas of technology (as we will define it) and engineering. It is little wonder that relatively few students develop an early interest in these topics and choose to enter these fields in college. Worse yet, the dropout rate of those who do pursue degrees in these fields in college is quite high (www.purdue.edu/strategic_plan/whitepapers/STEM.pdf).

Role models in K-12 education are hard to come by. For example, our experience with educators has found that very few of them have primary degrees in one of the engineering fields, and, therefore, may lack an understanding of what engineers do, and how it differs from science. While some teachers suggest that engineering is "applied science," which contains a grain of truth, this definition falls short of telling the whole story.

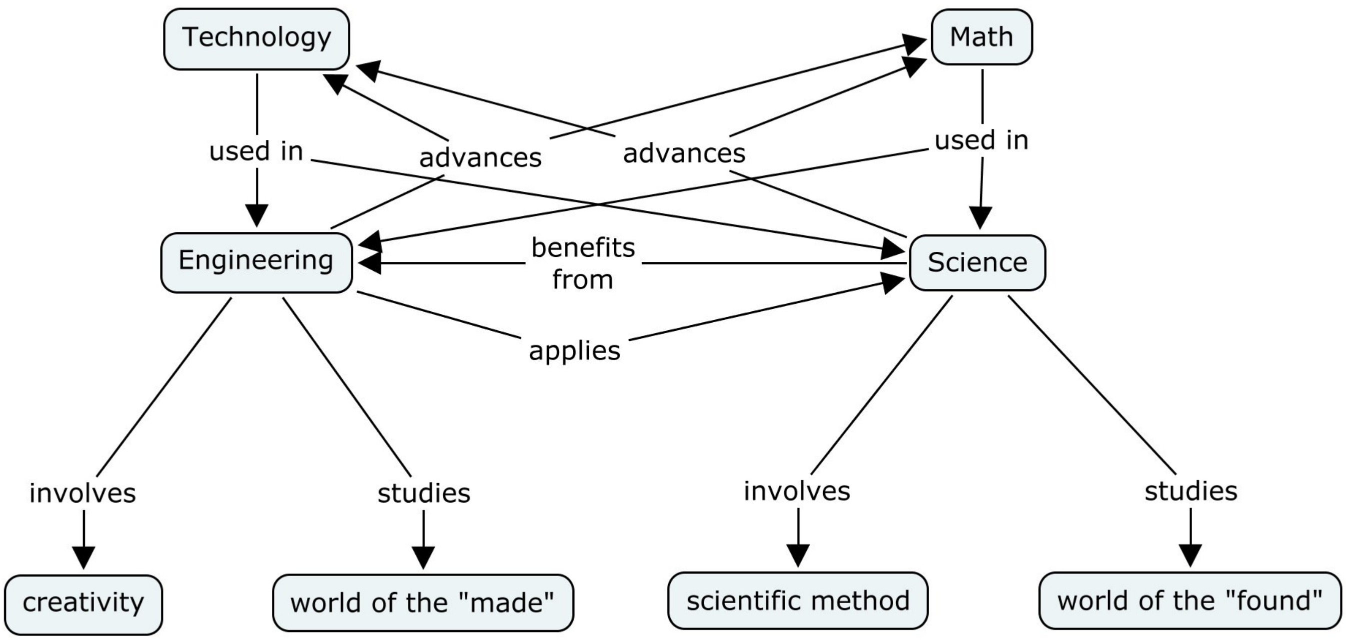
While it is the case that math, science and (some) technology are taught as separate subjects in school, the power of treating the STEM subjects in an integrated fashion strengthens the understanding of each of them. It is unlikely that this approach will be incorporated into traditional curricular areas, especially in high school, since they are so well-entrenched. This opens the door to electives, extracurricular, and after-school programs as possible means to address these subjects in an integrated fashion. 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.

The difference between science and engineering

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. A simplified view of some of these connections is shown in the following concept map:



While this map appears cluttered, it is actually fairly easy to read.

The interactions between science and engineering with the remaining STEM topics (math and technology) are also fairly clear. 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 19^{th} century when Peano showed it was possible to build a space-filling curve (a task that was previously thought to be impossible.) His thoughts were resurrected over a half-century later with 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 both science and engineering.

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 (http://www.spaceref.com/news/viewsr.html?pid=9910). 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.

For example, this recent image of the Carina nebula made with the HST shows details that have significantly advanced the understanding of molecular gas in this nebula. This scientific observation required advancements in technology facilitated by engineering and mathematics.

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, however, is not the only challenge.

Computers are technology, but technology is more than computers
In the K-12 world, our tendency is to think of “technology” and “computers” as synonymous. While it is true that personal networked computers *are* powerful technologies, there are myriad other technologies of benefit to education. Some of these (*e.g.*, telescopes) are high-tech marvels, and others (*e.g.*, duct tape) are not. The point is that they are all technologies. It is essential, when thinking about the development of STEM skills, to be sure that “technology” is not restricted to computers, but, in fact, expanded to include all kinds of devices, instruments, and tools that can be applied in both domains of science and engineering.

We do a disservice to students by misusing the word technology, rather than exploring the amazing role of technologies in the history of science and engineering dating back thousands of years, and reaching far into the future.

This brief look at the interrelationships among the four STEM topics reveals something of great power: they all reinforce each other in support of the overall growth of each topic. The result is an ongoing expansion of knowledge that can be applied to solve ever more challenging problems, and lead to a cleaner planet, higher qualities of life, *etc*. It is important to acknowledge that no one of these subjects can accomplish these goals by itself. For example, without engineering to produce new technologies, and the expansion of mathematical knowledge, advancements in science would, at some point, stop. The same can be said for the other three topics. They are all interrelated, and it is important that these relationships are understood by students. Even the student who, early on, shows great promise as a mathematician needs to understand the relationship between math, technology, engineering and science.