

Hands and Minds: Why Engineering Is the Glue Holding STEM Together

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We live in a time when we need for our educational system to transform its approaches to the exploration of STEM (science, technology, engineering and mathematics) subjects. The motivation for this concern is largely economic, but other considerations are driving the push as well^{1,2}. But, for all the intense conversations surrounding STEM education in K-12 settings, there are still many people who feel that the topic should be addressed by perpetuating the traditional separation of each of these topics, rather than having at least one course that explores all four of them in an integrated manner. For several years, I have argued that all four of these subjects should be explored as a whole.

One of the challenges in this approach is that academic schools have a focus on science and mathematics, while, historically, career and technical education (CTE) settings have focused on technology and engineering. Rarely have the two focus points come together. This is changing, though, now that CTE schools are mandated to provide a fully integrated academic program along with traditional CTE courses. These institutions are in a good position to integrate all four subjects. But these integrated programs are typically in high schools, leaving the K-8 students to the mercy of a curriculum that generally keeps science and math in their perspective stovepipes, and largely ignores the subjects of technology and, especially, engineering. As a result, many students graduate from high school with no clear

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understanding of what engineering is, nor how it differs from science, for example. I encounter students today who associate “engineers” with the people who drive railroad trains. This challenge is not limited to the United States; it exists in other countries as well.

The fact is that the continued recovery and long-term growth of the global economy is dependent on highly educated people who understand the increasing complex technical issues that confront us daily: energy independence, global climate change, etc. Also, as numerous international space programs are being advanced, humans will soon colonize the Moon and Mars. The skills needed by these intrepid explorers and their huge Earth-bound support team are heavily loaded in the STEM domain.

Leaving aside, for the moment, the paucity of K-12 educators with backgrounds in engineering, consider this: Virtually all elementary and middle schools have libraries. Libraries are important – they are feeding places for the mind – support havens for intellectual development. Libraries provide rich resources for the exploration of grand ideas and can be a source of stimulation for the development of deep thinking on virtually any subject you can imagine. If our schools were to close their libraries, they might as well shut down.

Shops, on the other hand, are virtually non-existent in our elementary and middle schools. Students rarely have a place on campus to tinker with tools – to build devices of their own design – to learn how to make stuff with their hands. This, to me, is tragic. While we may think with our minds, we express our ideas and our creativity through the artifacts we build. A student who does a paper or Powerpoint report on electricity may get an “A” for a beautiful presentation, but this same student may not know how to connect a motor to a battery and a switch. The only way to find out if students actually know how to build things is for them to build things, and our K-8 schools are tragically under-equipped for this task.

And, just as the real power of a library comes from the librarians, the real power of a shop comes from the person who runs it and teaches the kids how to use tools, how to solve problems, and how to fix things if they don't work as planned.

It is a challenge to find engineering programs in K-12 schools. A recent report³ by the National Academies explores this topic. The committee who prepared this report had this to say:

The presence of engineering in K–12 classrooms is an important phenomenon, not because of the number of students impacted, which is still small relative to other school subjects, but

because of the implications of engineering education for the future of science, technology, engineering, and mathematics (STEM) education more broadly. Specifically, as elaborated in the full report, K–12 engineering education may improve student learning and achievement in science and mathematics; increase awareness of engineering and the work of engineers; boost youth interest in pursuing engineering as a career; and increase the technological literacy of all students. The committee believes engineering education may even act as a catalyst for a more interconnected and effective K–12 STEM education system in the United States. Achieving the latter outcome will require significant rethinking of what STEM education can and should be.

They estimated that since the early 1990's when K-12 engineering education programs were recognized as such, fewer than six million students have had some kind of formal education in the area. When we think about a total school population of 56 million students, this number is amazingly small.

Why should we teach engineering in the K-12 setting?

If science is the study of the “found,” engineering is the study of the “made.” Artifacts of human design are essential components of everyday life. Every time we turn on a light, ride a car, view a television, use a computer, or do virtually anything else, we reap the benefits of engineering. But this is not the only reason for the topic to be explored.

Our own work with students in K-8 settings has convinced me that engineering is the glue that holds the other STEM subjects together. As the NAP report says:

During the course of this project, the committee focused increasingly on the potential of using engineering education as a catalyst for improving STEM education in general, about which serious concerns have been raised among policy makers, educators, and industry managers. So far, the role of either technology education or engineering education has rarely been mentioned in these concerns. The STEM acronym is more often used as shorthand for science or mathematics education; even references to science and mathematics tend to be “siloes,” that is, treated largely as separate entities. In other words, as STEM education is currently structured and implemented in U.S. classrooms, it does not reflect the natural connections among the four subjects, which are reflected in the real world of research and technology development.

The committee believes the “siloes” teaching of STEM subjects has impeded efforts to increase student interest and improve performance in science and mathematics. It also inhibits the development of technological and scientific literacy, which are essential to informed citizens in the 21st century. The committee believes that increasing the visibility of technology and, especially, engineering in STEM education in ways that address the interconnections in STEM

teaching and learning could be extremely important. Ideally, all K–12 students in the United States should have the option of experiencing some form of formal engineering studies. We are a long way from that situation now.

In fact, one can have a phenomenal career as a scientist without using mathematics or engineering, and using only a limited domain of technologies. Mathematicians are in a similar situation and, in some cases, don't even need technological expertise to explore their domain. But, as important as these topics are, they represent only 50% of the STEM subjects.

Engineering is a different kind of craft – to be done properly requires extensive support from the sciences, mathematics and technology. For this reason an effective STEM curriculum in the K-12 world is ideally approached through engineering – the one subject that traditional academic schools around the world largely ignore.

This situation can be changed, and changed easily. K-12 engineering classes do not need to be watered down versions of college courses. They can evolve from experiences where students are free to tinker and build things of their own. While the shop classes of the past have largely been reduced to shadows of their former selves, a new kind of shop can be developed in which the students not only learn to use their hands to fabricate things, they learn how to design the very things they are fabricating.

This aspect differs from the shop class of old where students were taught how to fabricate things designed by others. Through the design/fabrication process, students not only learn the proper use of tools, they learn how to apply their science, math and technology skills in the development of an artifact of their own design.

From a pedagogical perspective, the K-12 engineering classroom becomes home to the constructionist ideas of Seymour Papert⁴, in which students experience the “flow” state of consciousness⁵ where they become fully engaged in their work.

How do we bring engineering into the K-12 school?

Just as we learn to talk fluently without much formal instruction in grammar, engineering can be first explored in flexible ways through the use of guided inquiry. We don't teach children how to build with blocks, nor should we. In the case of engineering, details can be filled in later as the projects grow in complexity or specialized knowledge is required.

For example, working with 4th-7th grade students in a workshop setting, we told the class that

they will be building a robot – from scratch. (Tools for this project include wire cutters, various pliers, scissors, duct tape, and hot glue. Any soldering is done by the facilitator when working with young children. The raw materials for the robot are either recycled, or purchased in bulk from surplus outlets. This means that, unlike projects built with commercial kits, students can take their finished projects home.

Students are told the robot will use a motor, so the first task is to explore how to connect a motor, a switch, and a battery so that, when the switch is turned on, the motor shaft spins. With students working in small groups (3-4 per group) they will try to puzzle out the problem. It can take a half hour of false-starts and pondering (usually with diagrams they draw on paper) for them to all understand that the motor, switch and battery need to be hooked up in series.

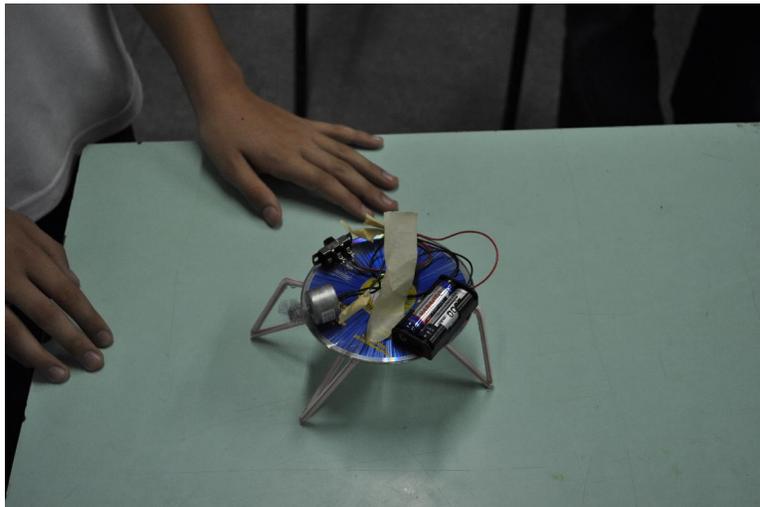
Once this task is complete, the students are told that the robot can't use any wheels – it has to move along a straight line by vibration of the motor. At this point they try to find a way to make the shaft unbalanced enough for the motor to vibrate noticeably. This sends them on a quest for different materials that can be glued to the motor shaft to make it unbalanced.

Students are then given a discarded CD to use as the robot base on which they can glue the switch, motor, and battery pack. Once this is done, the disk should vibrate when the motor is turned on. The problem is that the robot has no direction of movement. So the students need to fashion some kind of “feet” on the bottom side of the CD so that when the disk vibrates, the robot moves in one direction. The facilitator provides soda straws, wooden sticks, plastic forks, and other things that might be used for feet. Again, the task is a creative one, often with a few false starts.



Finally, each team has a working robot (typically after 2 hours) and they can enjoy having them move across table tops, the floor, etc. When students look at the other designs of their class, they find quite a range of solutions to the “feet” problem, showing that an engineering task can have many “right” answers.

During the whole process, the facilitator can be on the lookout for teachable moments when a scientific or mathematical principle can be applied. For example, one group wanted to use bent plastic soda straws as legs. The problem was that the weight of the robot caused the legs to collapse. After a few more tries, the facilitator saw that an intervention might be needed. He took a soda straw and bent it into a quadrilateral and asked the team to push at the diagonally opposite corners to see what happens. Students saw that the structure was flexible. Next, the same straw was bent into a triangular shape and the students were asked to repeat the experiment. They saw that the triangular shape was rigid. In about a minute, one student said: “That’s it! If we use triangles it won’t fall down!” The result worked and they also learned why triangles are used in many structures ranging from buildings to bridges. The challenge for the facilitator was being on the lookout for such moments, and then proposing an experiment that would help the students resolve the problem while learning a valuable piece of (in this case) mathematics.



Similar approaches to problems can increase student understanding in the areas of science and technology as well. The point is that, through engineering projects, students not only learn math, science and technology, but understand the application of these fields in the realm of invention and problem solving. STEM programs based on engineering have a tremendous advantage over those that keep the subjects in their own silos.

References

1. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. at <http://www.nap.edu/catalog.php?record_id=11463>
2. Rising Above the Gathering Storm Two Years Later: Accelerating Progress Toward a Brighter Economic Future. Summary of a Convocation. at <http://www.nap.edu/catalog.php?record_id=12537>
3. Engineering in K-12 Education: Understanding the Status and Improving the Prospects. at <http://books.nap.edu/catalog.php?record_id=12635>
4. Papert, S. & Harel, I. Situating Constructionism. at <<http://www.papert.org/articles/SituatingConstructionism.html>>
5. Csikszentmihalyi, M. *Flow: The Psychology of Optimal Experience*. 303(Harper & Row: New York, 1990).

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.