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STEM is Not Just a Four Individually Lettered Word

Abstract

We have all heard combinations of the words *science, technology, engineering*, and *mathematics* or STEM bantered about throughout the halls of education. Unfortunately, most of the bantering takes place in individual, academic disciplines or silos with like-minded colleagues, all shaking their heads as to why the folks in the other silos just do not understand their approach. This is not surprising. As we specialize, we become more focused in "our own true and tried methods of teaching" and dig deeper into these silos. However, teachers that may have influenced their students the most were likely passionate about their field and the courses they taught. They worked hard to show the relevance and interconnectedness to what their students were learning. These teachers were there to wet their students' whistle by demonstrating how important it was to finish and succeed in *all* STEM-related sequences, not just the ones they were teaching. *These* are the teachers who should define STEM and who are needed to excite, not just the top 10% of students, but the next 70% of the entire student population.

One of the biggest challenges facing our nation today is the dwindling number of American scientists, technologists, engineers, and mathematicians at a time when we are facing increased competition from other countries. This critical shortage of STEM talent in the United States is occurring when technology reinvents itself every few years. Our country's economic competitiveness and prosperity depend on innovative STEM- educated young people that work together to solve our problems effectively and creatively.

Proposed herein is a strategy to weave STEM throughout the secondary curricula to engage and excite students. The strategy introduces engineering concepts into the curricula beginning at the middle school level. Then, in high schools, math and science teachers would be cross-trained in engineering and technology content so that they can inform and encourage their "mainstream" students of the benefits in pursuing these fields of study; in addition, these teachers would incorporate an activities-based, project-based and problem-based learning approach to engage and to stimulate student interest in the strategies used in engineering and technology. The model for this action is the Project Lead The Way® pre-engineering courseware. At the college level, the collaborative approach to learning and to problem-solving would be offered in summer camps which would encourage interaction between university and high school STEM faculty. For this approach to work, STEM must be embraced by all disciplines as not a single, stand-alone entity, but as an integral building block to a successful career for the student.

Importance of STEM

One of the biggest challenges facing our nation today is the dwindling number of American scientists, technologists, engineers, and mathematicians (STEM) at a time when we are facing increased competition from other countries. At the same time, there exists a vast untapped talent pool in those Americans who traditionally have been underrepresented in STEM fields, including women, Hispanic Americans, Native Americans, and African-Americans. This untapped talent pool includes the top 80% of high school students that are not being "excited" in their academic studies. This critical shortage of STEM talent is occurring when technology is reinventing itself every few years. The nation's competitiveness and prosperity depend on innovative, STEM- educated young people who work together to solve problems effectively and creatively.

In an effort to captivate student interest in STEM, all STEM disciples need to work together instead of being in their individual disciplines and silos to make the nation's education experience the best that it can for all students. High school math and science teachers should be cross-trained in engineering and technology content so that they can inform and encourage their "mainstream" classes of the benefits in pursuing these fields of study. At the same time, engineering and technology teachers can be cross-trained so they can apply the type of rigor in their courses to motivate students to further their knowledge and interest in formal mathematics and science. The STEM disciplines need to collaborate to tear their silos down and work hand-in-hand to educate and "*engage*" our young people. Hence, STEM is intimately woven together and should be embraced by all disciplines as not a single, stand-alone entity, but as the integral building blocks to a successful career.

A Sense of Urgency

The launch of Sputnik by the Soviet Union in 1957 caught the world's attention and made the United States feel left-behind in our quest for space superiority. A Presidential initiated national agenda created a sense of urgency to better educate and prepare our nation's young people to face the challenges presented by the emerging race to the moon. Not until the landing of the Lunar Module Eagle in 1969 did the United States feel that we had caught up and achieved technological superiority.

As a result of this urgency, the National Aeronautics and Space Administration (NASA) was created, as well as the structure of many of the engineering graduate programs that exist in the country today. The United States was educating young people to keep the country ahead of its competitors and the space race was on.

In recent years, many educators, scientists, politicians and business leaders have complained that the United States is on the verge of once again falling behind as the world's leader in science, engineering and technology. As a nation, we have become complacent in being able to generate the numbers of STEM educated young people to fill the jobs necessary to keep our competitive edge.

This has not gone unnoticed at the national level. During the 2006 State of the Union Address, the President George Bush called for bolstering the nation's mathematics and science teacher ranks and for equipping our nation's students with the skills they need to be competitive in the global economy. This mandate would be the foundation for a new 10-year, $136 billion education and research initiative. In order to keep America competitive, "We must continue to lead the world in human talent and creativity," said the president in his speech. "Our greatest advantage in the world has always been our educated, hard-working, ambitious people, and we are going to keep that edge." However, with other pressing national concerns, we have not seen significant national efforts targeted to help swing the pendulum in the right direction.

The National Academies, an organization that performs public service by bringing together committees of experts in all areas of scientific and technological endeavors, recently responded by asking for recommendations that federal policymakers could consider to enhance the science, engineering and technology enterprise so that the U.S. can successfully compete, prosper, and be secure in the global community of the 21st century. One of the four resulting recommendations focused on actions in K-12 education. The goal associated with this recommendation is to increase America's talent pool by vastly improving K-12 science and mathematics education.

The problems are being recognized, but can they be corrected before it is too late? The nation is playing catch-up: the pipeline of STEM talent is too small to feed the need in industry caused by retirements and general growth and change in technology. Giants in the aerospace industry such as Lockheed-Martin, Boeing, and NASA know the urgency. Lockheed-Martin expects to hire 140,000 engineers within the next 5 years, Boeing will employ an additional 60,000 engineers in the next 4 years, and NASA has stated that its "graying" workforce or half of its scientists and over one quarter of its engineers will be eligible for retirement in the next 4 years. To help offset the problem, both Lockheed-Martin and Boeing support systemic reform in public education, working in partnership with K-16 entities located primarily near major facilities to enhance education. NASA has encouraged retired engineers to continue working on projects during retirement. They have also allocated office space to support these retired engineers as they continue to work part time on projects to ensure they do not lose their engineering expertise until the void is filled.

Last century's space race brought about by Sputnik is today's global brain race that has resulted in a gradual and subtle globalization of competitors who live just a mouse-click away in rapidly developing nations such as China and India. The urgency associated with this issue cannot be solved with idle rhetoric but with concrete steps to solve the problem.

The STEM Players

Combinations of the terms *science, technology, engineering*, and *mathematics* or STEM are continually bantered about throughout K-12 and to a lesser extent in higher education. Unfortunately, most of the bantering takes place in individual academic silos with like-minded colleagues, with nodding heads as to why the folks in the other silos just do not “get it.” Engineering and technology tirades sound something like this:

“Those math folks! By the time the students get to us they have never even solved one equation using actual units.”

“Why can’t they apply those math concepts to real-life situations? Maybe then the students would be more engaged.”

“Those physics teachers! Why in the world are they solely using the International System of Units (i.e., meters, grams, Newton, and Joules) when no engineering company in the country does business that way? Feet, slugs, pounds-force and BTUs are the units used in the real-world.”

The engineering teacher boasts to the students. “Calculus, I can count the number of times I used calculus when I was in industry on my fingers!”

Through the halls of science, a lone voice can be heard describing his/her class compared to some engineering or technology-related class as – “well, this is a *‘science class’* and not that applications kind of stuff that is being taught down the hall.”

At a school budget meeting the other day, a math instructor made the comment that, “In order to save money, the school should just get rid of all the laboratories.” Then on the way out of the meeting, a philosophy instructor mentioned that, “The school could save even more money by getting rid of all the blackboards and chalk!”

Many parents and teachers who hear the words “technology or engineering” in the context of a high school class immediately stereotype it as a course that is watered down and does not have the rigor needed for a student who will pursue a bachelor’s degree; this unfortunately perpetuates the “blue-collar-ghetto” myth of what happens to students if they take such courses.

Although these quips are provided tongue-in-cheek, there is a dose of reality to them. The typical education of K-12 and university instructors has been through an educational system where teaching occurs in silos. As we narrow our specialty, we go even deeper within these silos. We understand the relationship that our specialty has with regard to the bigger picture, yet many times do not articulate that relationship to our students. Thus, only dedicated students get excited about their chosen STEM specialty because they have the inherent ability to connect the dots between subjects taught in the secondary schools.

Teachers in *our* high school days who influenced us most were likely passionate about their field and the courses they taught. They worked to show the relevance of what we were learning. They also did not go so "wide" or so far into "left field" that we couldn't learn the content. Science, technology, engineering and mathematics teachers were there to wet their students' whistles by demonstrating how important it is to finish and succeed in their technology, mathematics, and science sequences. These are the teachers who should define STEM, as they are needed to excite, not just the top 10% of students, but the next 70% of the entire student population.

Changing the Emphasis

Teaching involves demonstrating skills and presenting knowledge; learning does not occur until the students "*engage*" and understand. One of the most powerful ways to change what happens in the classroom is for teachers to think about planning instruction from the perspective of student learning. An easy way to enable teachers to embrace this perspective is to design student work in the form of problems and projects that link standards and benchmarks from multiple disciplines. By using this approach, teachers are more likely to shift their focus and think in terms of student *learning* rather than focusing on *teaching*.

One philosophy about learning, labeled constructivism, proposes that learners need to build their own understanding of new ideas. A convenient format to view constructivism has been defined by Roger Bybee and the Biological Science Curriculum Study.[1] In this model, the process of learning is explained by employing the "Five Es." The Five Es are: Engage, Explore, Explain, Elaborate, and Evaluate. There are several "E" versions, such as 3E, 4E, and even Seven Es employed by the Miami Museum of Science[2]; the basic premise is that children have an experience with the phenomena in the learning of the concept or topic. In other words, the Learning Cycle applies the inquiry approach of teaching into a series of planning strategies.

It is widely accepted that curricular efforts to "*engage*" students, i.e., to involve them deeply in the process of *learning* and in the actual material they study, pays off. But as the number and proportion of underrepresented minority students and academically under-prepared students of all races in college grow, [3] educators and policy makers have lacked hard evidence that "*engagement*" practices work for students. Two recent studies,[4, 5] however, suggest that not only does "*engagement*" work for minority and academically under-prepared students, but such practices make a bigger difference for these students than for students in general.

What does it mean to "*engage*" students? A growing body of research supports the use of activities-based, project-based and problem-based learning[6] (APPB-learning). Schools that practice these modalities experience an increase in student motivation, an increase in cooperative learning skills and higher-order thinking, and an improvement in student achievement. The blending of APPB-learning is not simply an engaging alternative teaching method; it is a deliberate strategy to achieve high levels of rigor and relevance.
High school graduation must be viewed not as the end of learning, but as the jumping-off point for a lifetime of learning that will involve both acquiring new knowledge and applying existing knowledge to new situations. Lifelong learning skills will help students make informed and intelligent decisions regarding the direction and limitations of their chosen careers, technological developments, and the use of technology to alter their own lives, and other major financial, professional, and personal questions that they will undoubtedly face. These skills cannot be taught as discrete topics. Rather, students need to learn them through high quality, challenging lessons based on real world-problems that are unbounded by separate school subjects and unbounded by the silos that exist in our secondary educational system.

One of the implementation steps recommended by the National Academies to increase America's talent pool is to utilize "K-12 curriculum materials modeled on a world-class standard: [this would] foster high-quality teaching with world-class curricula, standards, and assessments of student learning. Convene a national panel to collect, evaluate and develop rigorous K-12 materials that would be available free of charge as a voluntary national curriculum. The model for this action is the Project Lead The Way® pre-engineering courseware." Project Lead The Way, Inc. utilizes APPB-learning methods in all of its pre-engineering curricula.

Why APPB- Learning Is Important

Activities are a method of instruction that involve directed teaching of a particular process or procedure. Activities "*engage*" students in learning skills that are later applied in more complex situations. *Project-based learning* is a comprehensive approach to instruction that presents a project or relevant activity that enables students to synthesize received knowledge and to individually resolve problems in a curricular context. *Problem-based learning* is both a curriculum organizer and an instructional strategy that presents a problem that is relevant and related to the context where students are the stakeholders; they synthesize and construct knowledge to help them actively grapple with the complexities of the problem. Students develop strategies to enable and direct their own learning. When students experience a problem in context, they are more likely to make connections and see the value in what they are learning.

Project Lead The Way, Inc. Weaves Science, Technology, Engineering and Mathematics Together

The national, not-for-profit corporation called Project Lead The Way, Inc. has developed a four year sequence of courses which, when combined with college preparatory mathematics and science courses in high school, introduces students to the scope, rigor and discipline of engineering and engineering technology prior to entering college. It is a model of how to develop curriculum and train teachers to use APPB-learning. The curriculum leads to rigor and relevance as the instructional goal and provides a means for teachers and students to better understand and apply their knowledge to practical real-life problems as well as the standardized state tests.

APPB-learning as used in the Project Lead The Way® curriculum:

- Helps students develop skills for living in a knowledge-based, technological society. Solving highly complex problems requires that students have both basic skills (i.e., reading, writing, mathematics) and foundation skills (i.e., teamwork, problem-solving, research, time management, information synthesizing, and technology tools usage).
- Adds relevance to the learning. By bringing real-life context and technology to the curriculum through projects and problems, teachers encourage students to become independent workers, critical thinkers, and lifelong learners. If students learn to take responsibility for their own learning, they will form the basis for working cooperatively and effectively with others in their adult life.
- Challenges students to high rigor. Complex, messy problems cannot be solved without the application of reading, writing, mathematics, and science. When working toward a solution to a problem, students often find themselves acquiring higher levels of academic skills and knowledge than if they were taught them in isolation.
- Promotes lifelong learning. Exposure to activities, projects and problems teaches students to take control of their learning, their first step as lifelong learners. It promotes meta-cognition and self-knowledge. Students generate strategies for solving problems by gathering, analyzing, and testing their data, sharing their findings with peers, and determining their solutions. Thus, students develop the abilities to work with peers, work in teams, and develop group skills.
- Meets the needs of students with varying learning styles. Students are expected to experience and to use multiple modalities in the process of researching and solving a problem and then communicate the solutions. This active learning takes advantage of student differences in interests and learning styles, giving each student a chance to excel in various learning activities.

Using the activity-project-problem modalities, students are engaged in three levels of thinking: the cognitive, the novice meta-cognition, and the expert meta-cognition as described in Fig. 1 below.

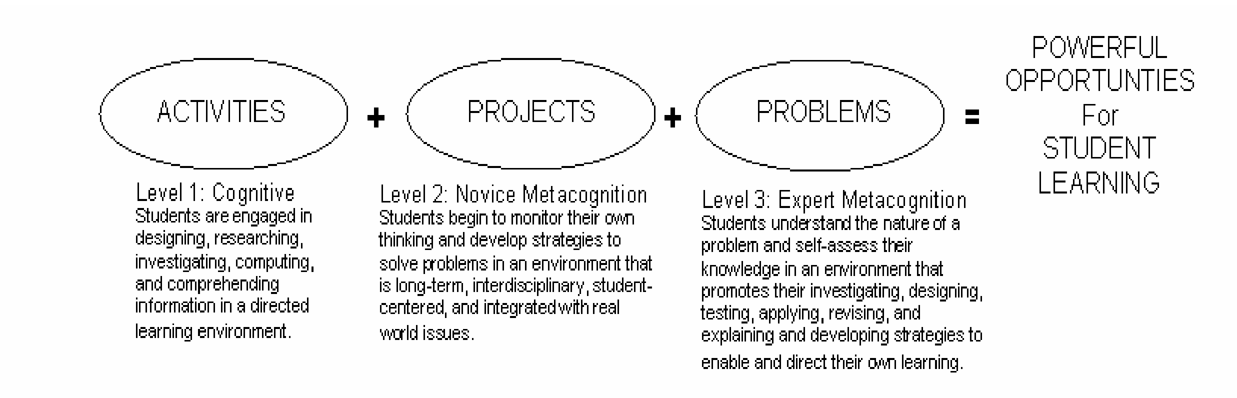

Fig. 1: APPB-learning model of curriculum development.

In addition to the high school courses, Project Lead The Way, Inc has developed a middle school program, Gateway To Technology®, which may be taught from grades 6 - 8. One of the major goals in the middle school is to increase interest and awareness of female and minority students in technology and also encourage increasing numbers of students to elect the high school program.

Conclusions

It is apparent that the United States is lagging behind in our efforts to educate enough young people to fill the ever-increasing pipeline of necessary STEM talent that is demanded by industry in order to sustain economic growth. Just as the space race in the 1960's motivated political, educational, business, and the population to act, so must today's global brain race create a sense of urgency to address this issue. Concrete steps must be taken to curtail the tide. A change in emphasis must be enacted in K-12 as well as higher education with all the players in STEM working together. Numerous efforts are being implemented across the United States to address the concern in K-12 and post secondary education. Some efforts have had limited success while others are making a bigger impact. However, we are not seeing a significant national effort or an urgent concern tied to any of these independent initiatives. Therefore, the challenge must be posed: Have we reached a point that another technology or engineering related crisis will have to push the United States to ramp up our collective efforts? If so, what are we going to do about it?

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