Beyond the Classroom: A Strategy for STEM Inspiration

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Abstract

Many studies have reviewed the shortcomings in STEM education in the US and have offered ways to improve it. Most of the studies have addressed traditional K-12 and undergraduate classroom methods. This article reviews the literature and identifies an emerging trend in "beyond the classroom" methods, which have the potential for inspiring more students to engage in STEM activities that can lead to valuable careers for the individual and society.

The Need for STEM Skills and Knowledge

PROGRESS IN SCIENCE, TECHNOLOGY, engineering and mathematics (STEM) fields provides the best opportunity for raising the quality of life of our society. Therefore, scientific academies have sought to "advance science, serve society" – the motto of the American Association for the Advancement of Science (AAAS). But surveys show that the demand for STEM graduates far exceeds the supply. Only about five percent of all employees are in STEM careers, including all the medical workers [1]. What can educators, parents and volunteers do to increase the supply?

Consider a random sample of K-12 students. The following paths to a STEM career might occur:

- Path 1 - Students are already inspired to pursue science early in life.
- Path 2 - Students get interested in STEM at some time in their school years.
- Path 3 - Students change to a STEM career at some time after they graduate.

Path 1 students are already motivated, and education can only encourage that path. For Path 3 students, some experience later in life causes a shift in career interests as adults; educators have little influence over those experiences. But for Path 2 students, inspiring educational experiences have the possibility of recruiting students toward a STEM career. As educators and STEM volunteers, we have the opportunity of creating those inspiring experiences.

We know from reports and our own experience that many children get "turned off" to science and math at some point in the middle grades. What causes these reactions to STEM subjects? Some of the most valuable insights came from the work of Sheila Tobias, one of the pioneers in the women's equality movement of the 1970s. She was an insightful advocate of improved math education, especially for girls and women. Tobias reinterpreted "math inability" as "math anxiety" [2]. In a traditional classroom setting, the task of solving a math problem in front of the class can be painful and trigger more fear and anxiety. This anxiety leads to avoidance of the subject. Since math is a system that builds in a logical sequence, any gaps in knowledge lead to further difficulties later on. This causes increased anxiety and avoidance, leading to a lifelong block and a feeling that "I'm just not good at math." By examining their feelings, not just the math problem, Tobias uncovered psychological barriers in math achievement caused by a restricted educational process. Tobias noted that math anxiety was particularly challenging for female students in this era.

Tobias later addressed a related question: "What makes science 'hard'?" In order to explore this question she created controlled experiments in which faculty in non-science fields were asked to attend a science lecture or take a science course. Her findings indicated that science ability was not a matter of intelligence, but of how different individuals process their perceptions of the world. Her conclusions were summed up in the book "They're not dumb; they're different" [3]. Tobias' books were bestsellers and helped to shake up the STEM education establishment. She is currently exploring the way engineering is taught, and she advocates that all students should be exposed to this subject, because of its importance in our technological world. [4].

STEM Education Gaps

The recognition of educational barriers and gaps became widely realized after the launch of Sputnik in 1957, a shock which provoked the United States government to focus attention on STEM education [5]. New federal initiatives were established to develop improved methods, equipment and textbooks. Ample new funding was provided by the National Science Foundation, and high-level studies were conducted among science educators, including the Physical Science Study Committee (PSSC) [6] and the Biological Sciences Curriculum Study (BSCS) [7].

These initiatives have since been followed by a continuing series of studies, curricula, and textbooks designed to improve science education and assess its results. Here we can only highlight a few of the more recent studies.

The Obama administration, via the Office on Science and Technology Policy, in 2010 launched the President's Council of Advisors on Science and Technology (PCAST).

Senior experts were invited to author a series of influential studies [8]. PCAST 2010 dealt with K-12 STEM education [9]. Under the heading "Troubling Signs", the Executive Report had this to say:

> "Despite our historical record of achievement, the United States now lags behind other nations in STEM education at the elementary and secondary levels. International comparisons of our students' performance in science and mathematics consistently place the United States in the middle of the pack or lower. On the National Assessment of Educational Progress, less than one-third of U.S. eighth graders show proficiency in mathematics and science.
>
> Moreover, there is a large interest and achievement gap among some groups in STEM, and African Americans, Hispanics, Native Americans, and women are seriously underrepresented in many STEM fields. This limits their participation in many well-paid, high-growth professions and deprives the Nation of the full benefit of their talents and perspectives.
>
> It is important to note that the problem is not just a lack of proficiency among American students; there is also a lack of interest in STEM fields among many students. Recent evidence suggests that many of the most proficient students, including minority students and women, have been gravitating away from science and engineering toward other professions. Even as the United States focuses on low-performing students, we must devote considerable attention and resources to all of our most high-achieving students from across all groups.
>
> Schools often lack teachers who know how to teach science and mathematics effectively -and who know and love their subject well enough to inspire their students. Teachers lack adequate support, including appropriate professional development as well as interesting and intriguing curricula. School systems lack tools for

assessing progress and rewarding success. The Nation lacks clear, shared standards for science and math that would help all actors in the system set and achieve goals. As a result, too many American students conclude early in their education that STEM subjects are boring, too difficult, or unwelcoming, leaving them ill-prepared to meet the challenges that will face their generation, their country, and the world."

Focus on Standard Assessments

In the recent decade, education studies have shifted toward a more business-oriented focus on measuring and evaluating results against national standards, the assumption being that over time, schools with learn what works and will migrate toward those practices. Initially a "Common Core" of standards were defined for STEM fields, but due to political opposition, today only standards for math and English remain. Currently the Common Core state standards initiative for mathematics has been defined and adopted by all but nine states. It is not a curriculum but a set of standardized goals in a sequence. The standards are evidence-based. They "draw on conclusions from the Trends in International Mathematics and Science Study (TIMSS) and other studies of high-performing countries.... the progression in the Common Core State Standards is mathematically coherent and leads to college and career readiness at an internationally competitive level." [10] However, the Common Core does not include science, technology or engineering standards.

Recently there has been increasing push-back on the business-like orientation on measurement of performance, from both teachers and students. The pressure to achieve numerical test scores has been questioned as the main goal. Moreover, it has proven difficult to devise performance metrics that are fair to all teachers.

A recent study has shown that behavior (*e.g*. number of absences and suspensions, grade point average, and on-time progression to 10th grade) of 9th graders is a stronger predictor than test scores of student success [11].

Education is not like a commercial business, where performance is easy to measure in terms of dollars. It should not be surprising that there would be ongoing challenges in educational assessment. Moreover, assessments alone do not guide educators into learning what works. There is still a strong need for experimentation and innovation.

Behavior-focused education emphasizes engaging students in "fun" and hands-on activities are part of a well-balanced exposure to science. And moving some of these activities outside the classroom setting may be especially influential for some of the “Path 2” students.

Technology Education Lags

Another PCAST report from 2013 [12] noted that

> "… our world today relies to an astonishing degree on systems, tools, and services that belong to a vast and still growing domain known as Networking and Information Technology (NIT). NIT underpins our national prosperity, health, and security. In recent decades, NIT has boosted U.S. labor productivity more than any other set of forces. .... In order to sustain and improve our quality of life, it is crucial that the United States continue to innovate more rapidly and more creatively than other countries in important areas of NIT. Only by continuing to invest in core NIT science and technology will we continue to reap such enormous societal benefits in the decades to come."

The client-side tools of information technology are converging: the desktop, laptop, smart phone, and the Internet. Practically everybody will need to use these technologies at home and work. They are getting smarter, smaller, and faster. Some human-based skills (visual pattern recognition, natural language understanding, delicate manual tasks) are difficult for machines to replicate, but the recent emergence of powerful machine learning tools and the advent of “big data” are rapidly overcoming many of these difficulties.

The tasks assumed for robots so far are often unimaginative and childish, such as contests, ball throwing, cleaning floors, etc. These are easy but not very valuable or marketable tasks. They may be giving the wrong image of robotics’ potential to both students and business people. Students working in robotics will increasingly aim toward the development of truly practical, money-saving or risky tasks. These will often lend themselves to inventions that can be developed and marketed. This prospect will continue to inspire some young people.

Traditional Education Can't Keep Up

These new and emerging technologies are evolving too fast for traditional educators to develop the knowledge, skills and materials needed to adequately inspire and engage young people in the classroom. The situation calls for a greatly increased engagement of professional scientists and engineers who are already using these skills and technologies. Hence, we believe that this kind of educational activity should extend beyond the classroom.

A 2012 National Academies study on discipline-based classroom learning [13] focused on research on undergraduate STEM teaching methods. Not the methods themselves, but the research on those methods. The conclusion was that we don't have much evidence on what works, and whatever we do know was not included in this report. Many educators have now realized that traditional classroom methods, no matter how well they are conducted, cannot keep up with the speed of change in STEM subject matter. A 2015 report by the National Research Council [14] concluded:

> "The ways in which young people learn about science, technology, engineering, and mathematics (STEM) has fundamentally changed in the past decade. More so than ever, young people now have opportunities to learn STEM in a wide variety of settings, including clubs, summer programs, museums, parks, and online activities. They spend more time in supervised programs outside of school, and they have greater access to on-demand learning resources and opportunities. At the same time, STEM learning outside of school has become a focal piece of the education opportunities provided by many national nonprofit organizations, statewide education networks, federal programs, and corporate and family foundations. And there is growing evidence that opportunities to learn STEM outside of school directly affect what is possible inside classrooms, just as what happens in classrooms affects out-of-school learning."

In 2016 the NAS published a study [15] that surveyed several examples of innovative practices in collaborative STEM education that could be widely adopted. This publication is pertinent to our concern. Here is an excerpt from the Summary:

> "Educators, policy makers, industry leaders, and others recognize the importance of strong college-university-industry collaboration in

preparing the STEM workforce of the future. Two recent reports from the President's Council of Advisors on Science and Technology (Engage to Excel, 2012 [16]) and the National Science and Technology Council (Federal STEM Education 5 Year Strategic Plan, 2013 [17]) emphasize the importance of encouraging stronger university-industry partnerships as vehicles to enhance student learning and diversify pathways to careers in STEM. The landmark National Academies report, "Rising Above the Gathering Storm" (National Research Council, 2007 [18]), also examined the essential relationships between university-industry collaboration and regional economic growth. The report suggested that partnerships among academia, governments, and industry succeed when all members of the partnership see the collaboration as in their best interests, and further, pursue these relationships in the spirit of mutual trust and appreciation of the value that each partner brings to the table."

Three overarching findings emerged from the 2016 NAS study:
• "Significant numbers of university students are graduating with STEM degrees, but many lack the right combination of technical and employability skills needed to thrive in the workplace. In short, we have many students with credentials, but fewer with the requisite skills to succeed early in STEM careers. This situation is particularly acute with minority students and female students, who are still significantly underrepresented in the STEM workforce and in STEM degree fields in most 4-year universities.

• "Employers are increasingly focusing on the skills and abilities new hires possess, rather than the specific field in which an individual has obtained a degree or credential. While there is a need for STEM graduates who will work as professional research and development scientists and engineers (so-called STEM narrow skills), there is a growing need for individuals who apply STEM knowledge and skills in technologically sophisticated occupations that require a facility with STEM concepts, but not necessarily a bachelor's degree (so-called STEM broad skills). There is also a growing need for students with a breadth of skills outside of their core STEM discipline, including skills that are perhaps best developed through a well-rounded liberal education that includes STEM courses, humanities courses, and experiences in the arts. These include problem solving, critical thinking, teamwork and collaboration, communication, and creativity.

• "A robust and effective STEM workforce development ecosystem requires proactive steps on behalf of university leaders, local employers, and intermediary organizations to build and sustain alliances that benefit students and regional economic development. Most of the concrete and high-impact strategies that surfaced during the course of the study—including those recommended in this report—do not require extensive policy change by governing boards, but rather can be undertaken at the classroom, department, or program level within a college or university, often in collaboration with a local employer. ...."

Diversity and Inclusion

A new 2019 report from the AAAS, "Levers for Change: An assessment of progress on changing STEM instruction" [19] emphasized the need for expanding outreach and access to the entire population, combined with innovative experiential methods. The report made frequent use of the term "research-based instructional strategies" (RBIS) to designate the set of active teaching and learning practices that support improved student learning. In general, such active, collaborative, and student-engaging strategies support learning, independent of discipline (Kuh, 2008 [20]; Pascarella & Terenzini, 2005 [21]; see also Fairweather, 2008 [15]). (A list of 32 such strategies is given in [22]).

The following excerpts are findings drawn from the 2019 report:

"Women, minorities and persons with disabilities remain underrepresented in STEM professions while they are an increasing percentage of the overall U.S. workforce. Alternative and diverse approaches to excellence in education and mentoring " - NSF Strategic Plan [23].

"To meet the demands of a global economy and foster technological innovation, the United States needs more well prepared and diverse workers in science, technology, engineering and mathematics (STEM) fields (PCAST, 2012) [16]. National studies reveal racial and ethnic disparities in science literacy, as well as in educational achievement, employment, and health outcomes that depend on STEM education [24]. All Americans should have equitable opportunities to enter the high-paying, high-status, and high-employment jobs typical of STEM careers, and to learn, enjoy, and use science to make informed decisions in everyday life, in the voting booth, and in their communities Access to STEM learning opportunities begins in childhood and requires well-prepared preK-12 and informal educators to teach and inspire young people in mathematics and science (PCAST, 2010). High-quality STEM education for all undergraduates is essential to achieving all of these national goals. A large and ever-growing body of education research demonstrates that pedagogical approaches that foster active and collaborative learning can enhance student learning, attitudes, and persistence in STEM educational paths."

"Yet most students do not experience these engaging pedagogies. Indeed, students from underrepresented racial and ethnic groups, as well as low-income and first-generation college students, are more likely to benefit, yet least likely to experience them …. Policymakers view improving instruction as a "best bet" [23] and as the "lowest-cost, fastest policy option to providing the STEM professionals that the nation needs" [16]."

Fairweather [15] reviewed the literature on promising practices in STEM undergraduate instruction and concluded that the problem was not a lack of knowledge about which teaching practices were effective, but rather insufficient use of these practices: The key to improving STEM undergraduate education lies in getting the majority of STEM faculty members to use more effective pedagogical techniques than is now the norm in these disciplines. (p. 13)"

"…[M]ore effort needs to be expended on strategies to promote the adoption and implementation of STEM reforms rather than on assessing the outcomes of these reforms."

"…The problem in STEM education lies less in not knowing what works and more in getting people to use proven techniques (p. 28)."

"Thus, it is crucial that we learn how to lower these barriers and promote adoption of effective evidence-based teaching practices…."

"There is sufficient evidence from education research in and across the disciplines to indicate that active learning experiences are good for students and support their learning, attitudes, sense of belonging, and persistence in STEM. (We know that ongoing studies will further detail these benefits and how they vary among different student groups and settings.)" (p. 9).

Mentoring is also prescribed as a strategy for improving the retention rates in STEM education for Latina women, as shown in a recent paper by Staveley [28]. She recommended nine suggestions for effective mentoring of Latina women.

The AAAS “Levers of Change” report studied undergraduate college instruction in classrooms. But the evidence indicates that successful inspiration of students in STEM hinges on their experience in early K-12 grades, in experiences both inside and outside the classroom. Therefore, we believe that some of the most important “Levers of Change” will be located in these experiences. Hence, to get a more complete picture of the scope of RBIS education, it will be necessary to widen the scope of the research to cover these activities, many of which are occurring "under the radar" of formal educational systems and assessments.

STEM Support in the Classroom

One way to fill the STEM gap is to bring scientists into the classroom. A local ongoing STEM program that has been doing this is the AAAS Senior Scientists and Engineers (SSE) STEM Volunteer Program that is managed by Betty Calinger at AAAS headquarters for schools in the DC, suburban Maryland and Virginia (DMV) area [29]. The volunteers, led by Dr. Don Rea, recruit other professional scientists (either working or retired) to attend a local school regularly once or twice a week to guide and support the teacher in that classroom.

After-School Activities

A transitional move from the classroom is through after-school activities or out-of-school time (“OST”). These are of course traditional activities, especially for sports, but also for school clubs, science fairs, school plays, projects etc. There is a growing interest in such activities among many community stakeholders (including home schoolers and an emerging movement called “community schools”). In this way teachers can receive up-to-date and refresher training for in STEM in after-school settings [30]. But teachers alone cannot be expected to perform all the STEM education responsibilities.

Science fairs and STEM fairs

Science fair and STEM fair competitions are very popular and widespread. Competitive fairs are supported and standardized by a number of national organizations, including the Regeneron Science Talent Search, the National Science Bowl, Broadcom Masters (for middle school students), the International Science and Engineering Fair (for high school students), FIRST Robotics [31], the Biology Olympiad, the Physics Olympiad, the Google Science Fair, and many more. In our area federal employees support and mentor students in many of these science fair projects. A summary of local science fairs and programs has been compiled on the website of the Washington Academy of Sciences [32].

The science fair is a venerable tradition across the US. But the quality of student projects in these activities is uneven, and their concept of the "scientific method" has a narrow definition that has been carried along as part of the tradition. Also, they give students a very limited exposure to the range of STEM research in modern practice. At one science fair I recently attended, I noted that ***not one*** of the projects required the students to go outdoors (*e.g.* "Which detergent cleans the best?"; "Mold growth in bread".). Science fairs could provide an opportunity for inner-city students to engage with nature – there are many local parks, rivers, and the Chesapeake Bay where field trips could be done. The Smithsonian's Nature Center, the National Arboretum, the National Zoo, and the Botanical Garden are all located in the city.

Many fields of science – such as astronomy, archaeology, botany, ecology, geology, meteorology, oceanography, paleontology, and zoology – require careful exploration of the natural environment. Unfortunately, many school science fairs do not take advantage of opportunities for helping children to encounter the natural world in a scientific way. The lack of exposure to nature outdoors may give urban students a limited view of the real world, as well as of their opportunities in scientific careers.

Despite these limitations, the fact that science fairs are deeply embedded in the culture and curricula of most public schools means that they should continue to be encouraged and promoted. We only need to help teachers to improve and leverage this tradition.

STEM activities beyond the classroom

The conclusion of the Levers of Change report and earlier studies is that there is likely to be increased student engagement, inspiration, and commitment to STEM education outside the traditional classroom environment, in less formal, unstructured activities that feel more like "fun" to the student.

Some of these STEM-related non-formal activities include:

- Activities in "maker spaces", in which children of diverse ages engage in hands-on design and construction of various devices.
- Robotics clubs, such as FIRST Robotics [31], which have recruited a nationwide team of robot design engineers and a hierarchy of competitions.
- Special-interest clubs for high school age children, including Explorers Clubs, Boy and Girl Scouts, Red Cross first aid units, mathematics and chess clubs, etc.

Many of these activities are largely student-run, so by definition they are engaging to students. They develop confidence and leadership skills as well as technical skills. And most of them lead directly in career-relevant directions.

STEM Activities of the Washington Academy of Sciences

The preceding sections of this article have reviewed the general findings of educators and policy makers regarding STEM education. These scholars have arrived at several consistent recommendations regarding improvements that should be made in STEM educational activities, both inside and outside the classroom. At this point we wish to describe closely one specific case as an example of what is being done – the STEM activities in which the Washington Academy of Sciences has been directly involved.

The Washington Academy of Sciences assumes its jurisdiction to cover the District of Columbia and surrounding suburbs in Maryland and Virginia within a radius of 50 miles. Most members live in this region, and this is the region covered by our awards program, board members and volunteers [32].

The Academy benefits from the abundant scientific facilities and professionals in this area. In addition to some leading universities, we have several institutions that treat specialized branches of science. This region includes the National Institutes of Health (NIH) – the presence of which partly accounts for the growing number of other medical research companies in our area. There are major government scientific headquarters, including the National Institute of Standards and Technology (NIST). There is the Office of Science of the Department of Energy, and we have the National Ocean and Atmospheric Administration (NOAA). There is the National Aviation and Space Administration (NASA). The Applied Physics Lab of Johns Hopkins University is an individual lab. On the military side there are three major naval facilities: Naval Research Lab, the US Naval Observatory, and the Naval Surface Warfare Center (at Carderock). There is the Army Research Laboratory, Walter Reed Army Institute of Research, and Fort Detrick, which is in Frederick. There is also the nation's cryptographic installations around Fort Meade and the National Security Agency (NSA). And many more.

Programs that use experienced scientists and engineers inside the school setting can supplement the educational work of teachers and the standard academic curriculum. But as the reviews of STEM education above show, in recent years there has been increasing recognition that for many reasons, classroom methods are limited in their ability to engage students and attract them to consider the many STEM career opportunities in government and industry. For example, a 2016 report identified the high priority areas of technology that are needed by NASA [33]. Two of NASA's High Priority Technology Areas are:

- TA 4, Robotics and Autonomous Systems
- TA 11, Modeling, Simulation, Information Technology, and Processing

These fields are specifically relevant to the activities of young people in maker spaces and robotics programs. Research and development in these areas is ongoing at the local NASA Goddard Spaceflight Center, Johns Hopkins Applied Physics Laboratory, and elsewhere in the Academy's region. The activities described below are limited to certain areas of Maryland and DC. However, there are also a number of similar programs and activities in northern Virginia.

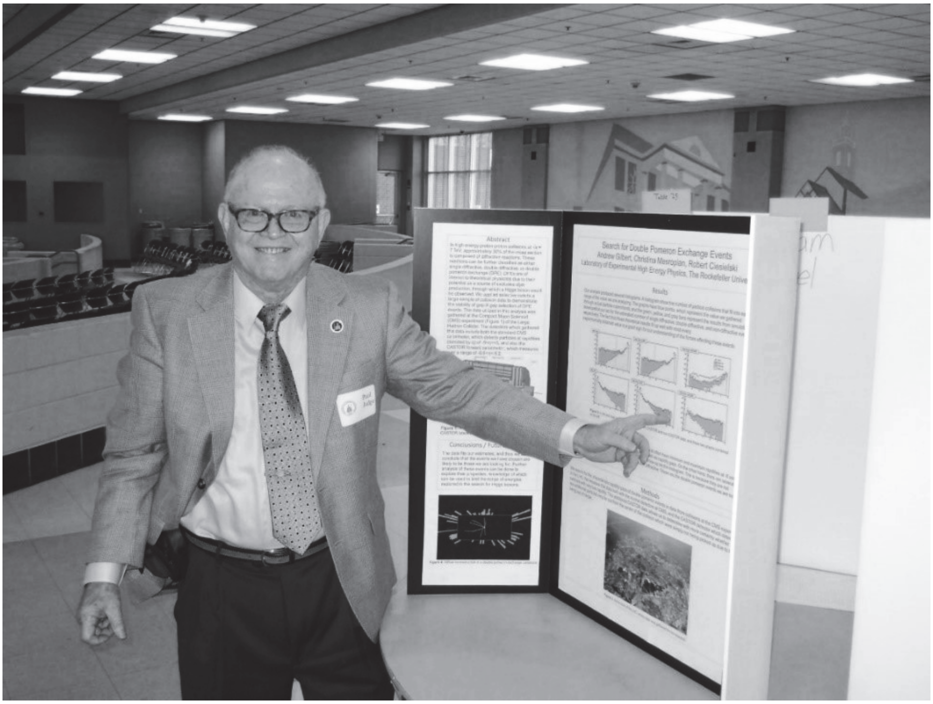

Figure 1. Dr. Paul Hazan judges a project at a science fair (photo by the author)

The Washington Junior Academy of Sciences has managed a program since the 1940's to provide science fair judges to various schools hosting K-12 STEM fair conferences and events in the DMV region. In the 1990s, Dr. Paul Hazan (see Figure 1) served as the judges' coordinator and offered leadership to grow the number of judges and events in which we participated. David Moran in Maryland and Jim Egenreider in Virginia helped to expand the recruiting of judges, including the participation of other members of the Academy's Board of Managers. Dick Davies assumed leadership of the Junior Academy in the early 2000's and continued to broaden the reach of our STEM programs. He recruited Kevin Brogan as a partner in organizing teams of judges. In recent years Dr. Vijay Kowtha and the author have led judging at the Blair Magnet High School and other STEM events (see Figure 2).

Figure 2. Winners of the Blair Magnet HS STEM Fair, 2020 (photo by V. Kowtha)

Maker Spaces

"Maker spaces" are large rooms dedicated to the creation and construction of devices such as robots by children of all ages. These constructions require special tools and products. Many new types of technical devices are being widely adopted in industry, and school systems struggle to keep up with an awareness of these devices and the skills needed to control them. These devices include small low-cost computers (*e.g.* Raspberry Pi) and microprocessors (*e.g.* Arduino) that are integrated into and shaping many industries, such as robotics, drones, and the Internet of Things (IoT). Other tools that are finding increased applications are 3D printers, laser cutters and CNC routers. The engineering skills to effectively learn and use these devices include CAD (computer-aided design), coding, cybersecurity, soldering and wiring, electronic sensors, network communications, etc. These are the kinds of skills taught in maker spaces and robotics clubs, such as the ones established by FIRST Robotics, Inc.

Dr. Kowtha has served for many years as a creator and coordinator of robotics and maker space clubs in College Park, Greenbelt, Landover, Maryland, and in DC, with an emphasis on outreach to underrepresented students in STEM. In 2017 he established a branch of FIRST Robotics (Team Illusion 4464) in Greenbelt, MD. Using the acronym MASER-DC (Mentors Advancing STEM Education and Research in DC) [34], he has organized maker spaces for K-12 students in DC and Prince Georges County, Maryland.

Figure 3. Beltway Plaza Mall maker space, 2017. (photo by the author)

For several months, the maker space for Team Illusion 4464 was housed in a storefront in Beltway Plaza Mall (see Figure 3). This enabled passersby to see the activities ongoing and many new students were recruited in this way.

Figure 4. Dr. Kowtha in the new maker space for *Bladerunners.* (photo by the author)

Recently Dr. Kowtha established an all-girls robotics club called *Bladerunners* that operates out of a space he rented in College Park, Prince Georges County, MD (see Figure 4).

Rockville Science Center, Maryland

The Rockville Science Center [35] is a volunteer outreach organization to inspire an interest and knowledge of science in the local community. Under the leadership of Robert Eckman, the Rockville Science Center hosts a variety of maker groups, including MoCo Makers, which presently meets in a room in Rockville Library. Access to this space is limited to library hours, and the space is limited (see Figure 5).

Figure 5. MoCo Makers participating in a project (photo by the author)

In the library space MoCo Makers leader Matt Zamora offers weekly presentations to the public on a wide range of technologies. In the past three years, the following technologies have been explored and discussed among the participants: Field-programmable gate arrays, cluster computing, Raspberry Pi, Verilog syntax, modular electronics, MakerBot for telescopes, glove sensors, 3D printers, prototyping, stepper motors, servo motors, drones, MIDI streams, solar sensors, git, digital radio, MicroPython, Kickstarter, GPS, Chromecast, fractals, microcontrollers, Slack, Fusion 360 for CNC manufacturing, cryptocurrency, blockchain, Arduino, neural networks, diodes, algorithms, encryption, navigation, sun tracking, self-propelling spheres, compiling C++, LEDs, operating systems, mobile apps, reverse engineering, electrical power grids, robot analysis, torque, oscilloscopes, resistors, touchscreen LCD, Beaglebone, car transmissions, temperature sensors, robotic mounts, and the Vagrant software development tool see Figure 6).

Figure 6. Rockville Science Center storefront, opened in 2020 (photo by R. Eckman)

Recently Rockville Science Center has acquired a store-front STEM program maker space in the center of the city. This large space, which gets ample public traffic, will provide high visibility for many planned science and engineering activities every day, including scientist panel discussions, a planetarium and a biology workshop. Also, it will allow student access to the space at times when the library is closed.

Rockville Science Center also hosts a monthly Science Cafe, a Young Adult Science Cafe, several robotics programs, and tours of local science and engineering labs. They provide summer camps and hosts an annual Rockville Science Day in April (but not this year!)

Other beyond-the-classroom programs similar to these are being conducted in DC and Virginia. As the "baby boomer" generation is now reaching retirement, we can expect to have an increasing reservoir of experienced people from whom to recruit and engage in STEM educational efforts, and as Academy members increase their engagement in tutoring, judging, and mentoring, we can expect to report more success stories in the future.

These programs are successful at attracting students because they leverage the time that is available for after-school activities, and likewise they leverage the time that is available to retired senior scientists and engineers. The programs bring these two groups together for STEM activities that are fun, challenging, and career inspiring. Moreover, the hands-on activities in building robots, programming computers, operating and constructing drones and other machines provides students with ample opportunities for creativity and experiences not available in the classroom.

Although these activities are called "beyond the classroom", by no means does this imply that schools are not involved. Partnering with local schools and school systems is essential. Partnering has mutual benefits including:

- Schools provide the pool of students who may be recruited for beyond-school programs
- Interactions with teachers are necessary to avoid duplication and fill specific gaps in instruction
- Teachers help identify students who are academically prepared to benefit from beyond-school programs

Local science and engineering businesses and government agencies are also stakeholders in beyond-the-classroom programs. They often recognize these programs as a potential source of talent for employment, and in some cases, they support these programs for that reason (see Figure 7).

Figure 7. Typical activity in the Beltway Plaza Mall maker space with a diverse group of students and mentors.
(photo by the author).

Summary

The reports cited above indicate that education researchers are increasingly recognizing the potential of beyond-the-classroom programs to increase the quality, quantity and diversity of STEM students. The Washington Academy of Sciences has a unique position and opportunity to greatly enhance the effectiveness of STEM education in the DC area. There are already several beyond-the-classroom programs that are open for business, but they need more volunteer mentors, more equipment, and more financial support.

Recommendations

The current pandemic experience is reminiscent of the Sputnik experience in the US: it has shocked us into recognizing a new existential threat to survival. One of the logical outcomes of this experience will be the demand for an increased number of STEM graduates, as scientific research is the only strategy we have to mitigate such threats in the future. This will require further removal of psychological barriers to STEM education as well as the creation of many new kinds of opportunities for young people to engage in STEM activities.

All of the US states have an Academy of Science (or Sciences), and they are affiliated with the National Association of Academies of Science. the Association's stated policy is "... to ensure that their students shall conduct original research and technological or engineering design projects that contribute to a fuller understanding and enrichment of the world rather than simply repeating previous research or template experiments." [36]

This policy emphasizes the value of originality and creativity in STEM activities. Academies of science have a unique vantage point for assessing the quality of STEM education activities, and for direct participation in making improvements in ways that are appropriate for their particular location and environment.

The case study above reviewed the current STEM education activities of one local region of the US. Similar activities are replicated all over the country; science fairs, in particular, are a venerable and widespread activity, but they tend to be unoriginal and uninspiring. There is an expanding interest in hands-on activities centered around maker spaces and the creation of microprocessor-based devices and 3D printers. These items have now become affordable to many students. Currently, with stay-at-home orders in place, many students are able to continue their construction activities at home. Some are fabricating 3D-printed face shields and other PPE for use in medical and other settings. The NIH has encouraged this practice and has even created a website where individuals can post new designs for 3D printing – even including 3D models of the SARS-CoV-2 spike protein molecule [37]. Undoubtedly our current home-based education experience will lead to more useful ideas and products.

Here are some examples of ways in which the academies can support STEM education:

1. As the saying goes, "a crisis is a terrible thing to waste". The management and resolution of the current pandemic must be guided by scientific knowledge, some of which does not yet exist. Governments at local levels are now recognizing their increasing dependence on specialized technical guidance, equipment and institutions. Constituents in a local jurisdiction are likely to be willing to increase their investments in STEM education to meet future crises. The local academy of science could play an important role in advocating for these investments.

2. Establish partnerships with nonprofit organizations (such as FIRST Robotics) that operate maker spaces with high outreach potential. Provide publicity and financial support to these organizations and recruit mentors to serve as participants for their programs.

3. Create a Committee for Encouragement of Science Talent. This committee will be responsible for developing procedures for monitoring and evaluating the effectiveness of activities to encourage young people outside the classroom setting. The committee can provide recommendations for awards and recognition to individuals, such as an award for Leadership in STEM Inspiration to be include among the awards offered by the academy.

4. Partner with other local scientific societies (such as Sigma Xi and IEEE) in volunteer activities and sponsorships.

5. Offer a formal call for papers from high school and undergraduate students. Submissions will be peer-reviewed and qualified papers will be published in the academy's journal, or in Sigma Xi's Chronicle of the New Researcher, which already has in place a peer-review and editorial process.

6. Replicate the work of the AAAS STEM Volunteer Program, which recruits volunteer professional scientists to serve in public school science classrooms in the DC area [29].

7. Ask WAS members to donate supplies, such as surplus scientific equipment and furniture, to help equip the maker spaces.

8. Recruit STEM fair judges for school events by reaching out to local scientific institutions and companies.

9. Create a network to recruit senior STEM Fair awardees to serve as tutors and mentors for younger students.

10. Establish partnerships in STEM projects between students in different countries, using Internet collaboration tools. This will allow students to experience the increasingly international character of professional research activities.

These are just a few examples of strategies and activities of an academy that can be developed into detailed plans to fit the particular needs and resources in a particular state or metropolitan region.

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Bio:

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