K-12 STEM Education: Bringing the engineering maker space, student-centered learning, curriculum, and teacher training to middle schools

Joan M. Banks-Hunt; Dr. Stephanie Adams; Dr. Susan Ganter; Juan Cruz Bohorquez
Virginia Tech University
Blacksburg, United States

Abstract—Encouraging our youth to pursue careers in science, technology, engineering, and mathematics (STEM) fields has become critically important to meeting needs for adequate and clean water, less pollution and an adequate food supply, along with needs for housing, communications, and sustained technology leadership. According to the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, the future of STEM fields is dependent on a steady workforce of talented and diverse individuals. Without a growing pool of STEM talent with emphasis upon the "E", the Bureau of Statistics projects that the U.S. will have a difficult time filling the demands for STEM professionals as near as the year 2018. In response to the need to develop a STEM proficient workforce with emphasis upon the "E", an industry leading high-tech corporation on the west coast developed a hands-on engineering maker space that exposes middle school students to an exciting one-day authentic learning experience. Announced January 2016, Virginia Tech and the high-tech corporation entered into a multi-year, multi-phase partnership agreement to develop programmatic curricula, teacher credentialing and professional development, hands-on engineering practices, activities for long-term student engagement, and ongoing research. The purpose of this work-in-progress article is to report on the first phase of the partnership agreement and its innovative practices of interest to stakeholders invested in the K-12 engineering footprint.

Keywords—*maker space, programmatic curriculum, teacher credentialing and professional development, hands-on engineering*

I. INTRODUCTION

Engineering plays a major role in shaping the world today. However, growing the talent pool of engineers in the U.S. raises concerns. Based upon national trends that report declining interest of U.S.-born students in engineering [1], the need for K-12 science, technology, engineering, and mathematics (STEM) educational solutions in the U.S. [2] [3], lack of gender and ethnic diversity [4], goals for internationally competitive achievement rankings in math and science [5], national standards [6] [7] [8] [9], state standards such as Virginia Board of Education Standards of Learning (SOL) [10] or California Common Core State Standards [11], and issues of technological literacy for all Americans [12]; there are many opportunities for research and innovative solutions. Even with STEM jobs in high demand, trends predicting millions of unfilled positions by 2018 because of the inadequate number of technology skilled individuals in the U.S. workforce [13] [14]; the value of engineering education struggles to nourish roots in K-12 education. Much of the concern for attainment of quantity, quality, and diversity of future engineering talent stems from solutions needed to bring engineering to K-12 education, teacher preparation and support resources, funding, and ways to increase students' awareness and interests in the contributions and importance of engineering careers in our global society. Expert reports address the landscape of opportunities and challenges for bringing a standards-based engineering education to K-12 education across the U.S. (ASEE [15]; NAE [6] [16]; NRC [17]; NSF [18]; and ITEA [19].

The Bureau of Labor Statistics, U.S. Department of Labor, describes an inadequate supply of workers with degrees in science and engineering fields in 2012-2022 employment projections [20]. These projections raise concerns for U.S. scientific, engineering, technological, and industrial leadership, with subsequent effects on areas such as economic growth, job creation, standards of living, and national security. To overcome this potentially looming shortfall, stakeholders invested in the K-12 engineering footprint are focusing on finding new ways to expose and excite kids to move toward STEM career choices.

It is a necessity in the 21st century to provide technology literacy for all children. "New technologies and STEM knowledge are at the core of our ability to manufacture better, smarter products, improve healthcare, preserve the environment, and safeguard national security. Individuals prepared with the skills and knowledge to invent, build, install, and operate new technologies are essential" [21]. However, many children are not exposed to STEM career opportunities in engineering fields at all during their K-12 studies. In a small percentage of U.S. schools, "Tomorrow's science, technology, engineering, and math workforce starts with early education" [22]. Typically, teachers have not been trained in engineering education and do not have access to course materials and instructional resources, which renders the teaching and learning proposition for many children nearly unattainable. These opportunities drive the partnership's contributions and innovative practices that target children in grades 6, 7 and 8.

High School can be regarded as one of the most sensitive periods for students' decision-making regarding selection of a college discipline of study and career direction.

On the one hand, pre-engineering could be a pipeline from high school to engineering disciplines in higher education. On the other hand, technology education programs are vulnerable beyond the middle grades, where interdisciplinary math and science courses and engineering courses, albeit attractive electives for college admission, are not consistently mandated to include the subject of engineering in high school graduation requirements and elective course offerings [23].

Studies indicate that interests in science, engineering, and mathematics as career options peaks during middle school years, especially for young women and minorities [24]. And historically speaking, technology education subscribes to the ideals of general education—education that is essential and beneficial to all [25]—a strong argument for engineering educational practices that target all students.

"It is critical to consider what is being done, and what might be done, in the educational system" [24]. Many approaches to bringing the "E" to K-12 schools have been introduced [26]. Some approaches provide STEM learning out-of-school time in afterschool programs. These "stand-alone," out-of-school time learning opportunities include familiar programs such as *TechBridge* or *FIRST (Robotics)* [27]. Other approaches are "integrated" during school and provide engineering or STEM embedded in science and/or math core curriculum, such as *Science and Engineering Practices in Next Generation Science Standards (NGSS*) [28] or (public) schools with an integrated STEM mission, such as the *High Tech High Learning Network* [29] [17].

However, bringing solutions in engineering to K-12 education continues to be a problem in search of curriculum, teacher training, instructional resources, funding, assessments, and support for all grade levels [30]. And these gaps exist in some locations more than others and challenge the aims of national standards, "All Standards, All Students" [9].

II. Motivation

As the first woman in space, Dr. Sally Ride (1951-2012) stated, "It takes years or decades to build the capability to have a society that depends on science and technology. You need to generate the scientists and engineers, starting in elementary school and middle school'' In making this comment, the *Trailblazing First Woman in Space* [31] recognized for her contributions in space engineering and motivational programs for young students, especially girls, urges us to explicitly bring engineering to earlier stage students.

However, it is commonly known today that many children who might thrive in a STEM-related career don't even know what an engineer does. This incongruence urges an importance upon increasing the visibility of engineering in the education of young students at early stages to increase the numbers of future engineers. To help children recognize engineering in the world that surrounds them, and the opportunities engineers have to make the world a better place, exposure to the STEM world and its career opportunities is important. "Corporations have pledged to help expand high-quality science and technology education to more than 1.5 million students across the U.S. More than 120 universities have pledged to help train 20,000 new engineers to tackle the toughest challenges of this technological century" [32].

Virginia Tech and the west coast corporation partnership agreement is focused on increasing awareness of engineering in middle school education by providing hands-on engineering activities for students and teachers, programmatic curriculum for teachers, and instructional resources for long-term engagement. Many shared interests motivate the partnership including: technology literacy for all students with emphasis upon engineering, K-12 national and state standards, STEM pipeline and career paths, bringing engineering to earlier stage students offering both integrated and stand-alone after school learning activities, and the hands-on "maker" approach to teaching and learning. Hands-on engineering is a project-based "Integrative STEM" discipline of study [33]. It integrates science inquiry practices, mathematics logic and problem solving skills, trial-and-error, creativity and visualization skills for students to collaborate, design, prototype, invent, optimize, and document unique project/product designs, the "maker" approach to authentic engineering teaching and learning.

The corporation in this partnership believes that it is their responsibility to increase awareness of STEM career paths, inspire, and encourage students to pursue STEM-related education in order to build the next STEM workforce. As an advanced technologies employer of a large number of individuals with engineering degrees, the corporation affirms that many careers in the future will require 21st century skills. This position is constructed from the corporation's volume distribution of products and services supplied to their customers across the U.S. and globally. March 2014, the corporation unveiled its one-day, hands-on engineering maker space, an authentic learning environment, for middle school students in a large public school district in California.

Virginia Tech believes in serving the community through a diverse range of research-driven disciplines critical to economic growth across Virginia, the nation, and the world. It is a research, teaching, and learning institution with a history of innovative programs for expanding the engineering student pipeline. Engaging two of its leadership academic programs, Engineering Education (EngE) and the School of Education (SOE), the university provides academic resources to bring engineering to middle school education. Leveraging research, theory, and real life applications for preparing Virginia Tech students to become scholars, teachers, innovators, and entrepreneurs in engineering, business, and numerous fields since 1872, with a growing footprint across the state and globally, are hallmarks of the university's cutting-edge Engineering Education research and

implementation leadership.

III. METHODS

Researchers have shown that an early interest in pursuing science and engineering is a better indicator of whether a student will pursue a career in STEM fields than a student's grades in school [34]. Because engineering is not currently a required discipline of the K-12 curriculum, there is a need for innovative practices for bringing engineering into schools. However, as a growing field of interest and source of optional coursework in many schools, engineering is the subject of discussion for state boards or education across the country. The Engineering Education (EngE) department and the School of Education (SOE) at Virginia Tech have combined experiences delivering cutting-edge Engineering Education research and implementation.

The partnership agreement is a multi-phase, multi-year implementation plan. Replication of the hands-on engineering maker space located on the west coast will be located on the east coast as one of the first phase deliverables. The maker space is strategic to providing authentic engineering learning experiences for middle school students, teachers, and school administrators. Also planned in the first phase is the ongoing research study to examine the existing one-day, hands-on engineering maker space on the west coast and the replicated maker space on the east coast.

- ***Maker Space***

The ***maker space*** provides the out-of-school engineering setting for student-centered engagement and teacher training. Unlike the traditional laboratory science classroom, the engineering maker space is more of an "entrepreneur's garage shop" with tools, machines to do work, project design and crafting materials, measurement technology, and work benches. Maker space teaching and learning activities taught by experienced instructors help students recognize engineering in the world that surrounds them, and the opportunities engineers have to "make" the world a better place [35]. The new maker space community hub, a replication of the west coast maker space, will be unveiled Fall 2016 in a large public middle school district located in the District of Columbia.

- ***Ongoing Research***

Research and assessment activities will include:

- Development of a strong and diverse portfolio of data on the current one-day, maker space experience.
- Quantitative Data Collection consisting of interviews, surveys, and observations
- Qualitative Data Collection consisting of interviews with previous participants
- Data capturing the number of students enrolling in STEM-related in-school time and after school programs pre-and post-program exposure
- Correlation of data captured from the west coast and east coast maker spaces.

IV. PRELIMINARY FINDINGS

Corporate instructors on the west coast are responsible for leading ***student engagement*** activities that begin with an introduction to the *Engineering World of Work.* The one-day experience combines mini-lectures with teamwork to facilitate awareness of engineering in the world that surrounds every person. Maker space activities are designed to specifically connect with middle school students. The instructors guide students to collaborate, create, write their first lines of codes, build, and test the functionality of their first engineering product, a small hand-held robotic toy complete with programmable microcontroller, servo motor, and simple electronic circuits. These activities expose one middle school (science) class per day to the high tech world of work—including engineering and non-engineering careers.

Figure 1 provides a visual interpretation of the typical middle school students' perceptions of engineering prior to exposure to the one-day, hands-on engineering maker space experience. Preliminary findings suggest that middle students' have very little connection to engineering. The middle school students' awareness of engineering, what engineers do, and engineering value-beliefs reflect preliminary interview data obtained from corporate instructors.

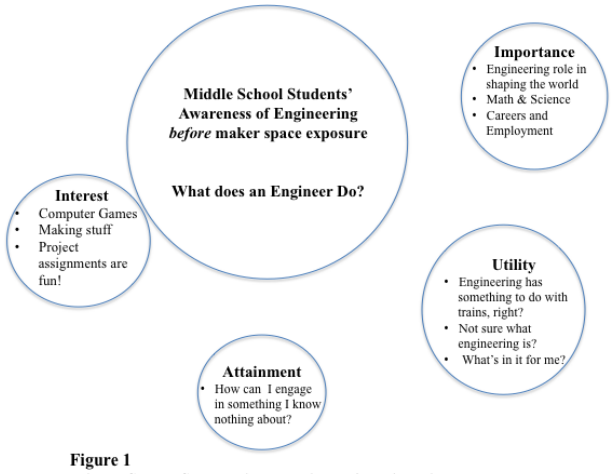

Figure 1
Middle School Students' Perceptions of Engineering
Engineering-value-beliefs

The next figure is a visual representation of the change in middle school students' awareness of engineering and what an engineer does after the one-day, hands-on engineering maker space experience. Again, findings displayed are preliminary.

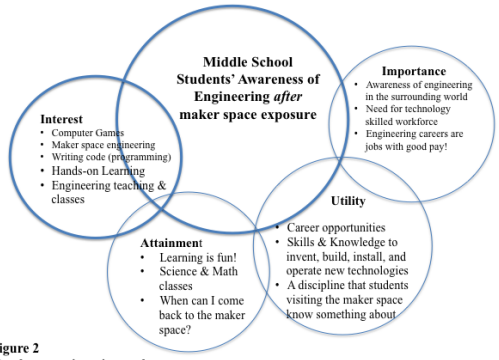

Figure 2
Hands-on engineering maker space exposure
- Engineering project collaborations are fun!
- Increased awareness of engineering and non-engineering careers
- Increased awareness of science & math in engineering
- Learning to make an electronic circuit and to write code was a lot of fun!

- ***Programmatic Curriculum*** and Workshops

The goal is to provide teacher training to equip teachers and administrators with hands-on engineering experiences in the maker space as well as techniques and instructional resources for inserting engineering into the middle school curriculum. A teacher-training center will be available in the new maker space community hub to be located on one of the Virginia Tech campuses located within proximity of the District of Columbia.

- Workshops for teachers: An annual workshop series for middle school teachers in the District of Columbia region will be led by Virginia Tech faculty and staff beginning Fall 2016. Teachers will be enrolled in teams of 2-4 per school. The series will include a one-day experience three times per year (one each in fall, spring, and summer), to expose teachers to the maker space experience, how it can be used to promote learning, and ways in which modules of the experience can be integrated into the core science curriculum. Specifically, teachers will:
  - *Explore* hands-on engineering maker space activities with a wide variety of classroom instructional materials
  - *Create* engineering robotic projects that display integrative STEM
  - *Learn to write lines of code* for robotic projects using one of the most popular multipurpose microcontrollers used in STEM design projects and real-world engineering products (Arduino)
  - *Collaborate and Present* engineering projects in small teams of teachers
  - *Develop* hands-on engineering lesson plans

- Workshops for school administrators: Support for school administrators (i.e., counselors, principals, and superintendents) will be fostered through one-day experiences in the maker space, one-on-one conversations and team discussions focused on incorporating engineering into the school curriculum.
  - *Initiate* discussions with school administrators
  - *Incorporate* observation opportunities for school administrators during workshops for teachers and the students' one-day, hands-on, engineering maker experience.
  - *Offer* one-day workshops for school administrators to participate in and learn about the benefits of the maker space
  - *Discuss* with school administrators the important logistics and teacher training necessary for successful engineering in-school implementations

V. DISCUSSION AND FUTURE WORK

Feedback from west coast middle school teachers, principals, school administrators, and over 7,000 middle school students inspires the focus of this partnership for innovative practices to bring engineering to middle school communities. What gets taught in K-12 STEM classrooms is often a function of what gets emphasized in national and state content standards, together with what is assessed on state-mandated achievement tests, the resources and teacher training to support integrated and afterschool learning activities. Partnerships such as this one can contribute to curriculum expansion and fostering successful K-12 STEM education [36]. Bringing engineering to middle schools can begin to address our nation's challenges to create a well-prepared STEM workforce. This endeavor will only be successful if teachers are properly trained.

Preliminary findings from west coast instructor interviews on the topic of middle school students' perceptions of engineering and engineering value-beliefs are significantly different prior to and after exposure to the maker space. Prior to maker space exposure, middle school students have very little knowledge of what an engineer does. Preliminary qualitative themes suggest students have curiosity about what an engineer does, but little or no value-beliefs as identified by interest, attainment, utility, or the importance of engineering. However, after maker space exposure, value-beliefs change considerably. Students are excited, engaged in hands-on engineering, taking risks, interested in all engineering project design activities, and requesting to return to the maker space for more project activities.

Programmatic curriculum for teachers and school administrators are in development to enrich coursework in other areas of study (such as Educational Leadership), providing teachers and school administrators with the necessary skills to incorporate engineering into the middle school classroom. A teacher's credentialing program is also planned to provide professional development opportunities for teachers and administrators.

References

[1] NRC, "Engineering In K-12 Education: Understanding the Status and Improving The Prospects," *National Academies Press*, 2009.

[2] P. s. C. o. A. o. S. Technology, "Report to the President Prepare and Inspire: K-12 Education in STEM for America's Future," pp. 12-15, 2010.

[3] NRC, "Successful K-12 STEM Education," *The National Academies Press*, 2011.

[4] NSF, "Women, Minorities, and Persons with Disabilities in Science and Engineering: 2013," pp. 1-20, 2013.

[5] U. D. o. Education, "Highlights From TIMSS 2011, Mathematics and Science Achievement of U.S. Fourth- and Eight-Grade Students in an International Context," *NCES*, vol. 009, p. 56, 2013.

[6] NAE, "Standards for K-12 Engineering Education, Committee on Standards for K-12 Engineering Education," *National Academies Press*, 2010.

[7] R. Carr, Bennett IV, D., Strobel, J., "Engineering in the K-12 STEM Standards of the 50 U.S. States: An Analysis of Presence and Extent," *Journal of Engineering Education*, vol. 101, p. 26, 2012.

[8] N. A. o. Engineering, "Standards of K-12 Engineering Education," 2010.

[9] NGSS, "Appendix D - "All Standards, All Students"; Making the Next Generation Science Standards Accessible to All Students," pp. 1-21, Appendix D 2013.

[10] C. o. V. D. o. Education, "Race To The Top," vol. January 2010, p. 354, 2010.

[11] C. S. B. o. Education., "California Common Core State Standards (CA CCSSM)."

[12] E. Arthur, "Retrospective analysis of technological literacy of K-12 students in the USA," *International Journal of Technology and Design Education $V 20*, pp. 277-303, 2010.

[13] B. Casey, Senator and Chairman of Joint Economic Committee Chairman's Staff, "STEM Education Preparing for the Jobs of the Future," *April 2012*, pp. 1-17, 2012.

[14] J. Rothwell, "The Hidden STEM Economy," *Metropolitan Policy Program at Bookings*, p. 38, 2013.

[15] C. Mendoza-Diaz, "An Overview of Literature: Research in P-12 Engineering Education," *ASEE*, vol. 03, pp. 1-37, 2012.

[16] NAE, "Educating the Engineer of 2020, Adapting Engineering Education To The New Century," *The National Academies Press*, p. 209, 2005.

[17] NRC, "Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics. Board on Science Education and Board on Testing and Assessment, Division of Behavioral and Social Sciences and Education.," *The National Academies Press*, 2011.

[18] N. S. Foundation, "Engineering in K-12 Education," p. 595, 2009.

[19] ITEA, "Standards for Technological Literacy: Content for the Study of Technology," vol. 3rd Edition, p. 260, 2002.

[20] J. Sargent, "The U.S. Science and Engineering Workforce: Recent, Current, and Projected Employment, Wages, and Unemployment," *Congressional Research Service*, vol. 7-5700, 2014.

[21] N. S. a. T. Council, "Federal Science, Technology, Engineering, and Mathematics (STEM) Education, 5-Year Strategic Plan," p. 143, 2013.

[22] ReadyNation, "Toorrow's Science, Technology, Engineering and Math Workforce Starts with Early Education," *ReadyNation*, p. 5, 2013.

[23] T. Lewis, "A Turn to Engineering: The Continuing Struggle of Technology Education for Legitimization as a School Subject," *16*, vol. 1, 2004.

[24] S. Brophy, Kelin, S., Portsmore, M., Rogers, C., "Advancing Engineering Education in P-12 Classrooms," *Journal of Engineering Education*, p. 19, 2008.

[25] J. E. LaPorte, & Sanders, M. E. , "TSM Integration project: Integrating technology, science, and mathematics in th middel school," 1993.

[26] NGSS, "Appendix F—Science and Engineering Practices in the NGSS," pp. 1-33, Appendix F 2013.

[27] A. Alliance, "STEM Learning in AfterSchool: An Analysis of Impact and Outcomes," *STEM & Afterschool*, vol. Sept 2011, p. 20, 2011.

[28] N. Framework, "Science and Engineering Practices in the NGSS," pp. 42-43, 2012.

[29] H. Research, "Best Practices in Elementary STEM Programs," *hanoverresearch.com*, p. 30, 2012.

[30] H. C. Kimmel, J., Burr-Alexander, L., Rockland, R., "Bringing Engineering Into K-12 Schools: A Problem looking For Solutions?," *American Society of Engineering Education*, pp. 1 - 16, 2006.

[31] K. Reader, "First Woman in Space: Sally Ride," *K12 Reader*, p. 2, 2014.

[32] B. Obama, President of the United States, "President Obama on STEM Education," *AIP Bulletin on Science Policy News*, 2015.

[33] J. G. Wells, "Integrative STEM Education at Virginia Tech," *Technology and Engineering Teacher*, p. 8, 2013.

[34] R. H. Tai, Liu, C. Q., Maltese, A. V., Fan, X, "Planning Early for Careers in Science," *Education Forum*, p. 2, 2006.

[35] C. Anderson, "Makerspace & Curriculum, The Overlap of Standards and Curriculum, K-12," p. 35, 2015.

[36] S. Committee on Science, and Technology House of Representatives, "What Makes For Successful K-12 STEM Education: A Closer Look AT Effective STEM Education Approaches," *Committee on Science, Space, and Technology*, vol. One Hundred Twelfth Congress, p. 85, 2011.