Women Building the US STEM Pipeline

Dr. Christina L. Carmen, University of Alabama, Huntsville

Dr. Carmen obtained a Bachelor of Aerospace Engineering degree as well as a Master of Science in Aerospace Engineering degree from the Georgia Institute of Technology in Atlanta, GA. While at Ga. Tech she worked with Dr. Warren Strahle, researching solid propellants. She obtained a Doctor of Philosophy in Mechanical Engineering from the University of Alabama in Huntsville (UAH) with a focus upon turbulent combustion modeling. Dr. Carmen is the capstone design class coordinator in the Mechanical and Aerospace Engineering (MAE) department at UAH. She primarily teaches MAE senior design classes with a focus upon product realization – a class she has taught since 2002.

Several of Dr. Carmen's senior design teams have won national and international design competitions including the American Society of Mechanical Engineers (ASME) Safety Engineering and Risk Analysis Division safety competition, the International Aluminum Extrusion Design Competition, the American Astronautical Society/von Braun Symposium student poster competition, the NASA Exploration Systems Mission Directorate (ESMD) Systems Engineering design competition and the NASA Great Moonbuggy Race. In 2012, the UAH Moonbuggy team won 1st place in the NASA race.

Dr. Carmen is the UAH ASME student chapter faculty advisor as well as a Director of the North Alabama ASME section. Dr. Carmen has served as a National Science Foundation scholarship panelist, Department of Defense SMART scholarship panelist and as a delegate to the ASME Leadership Training conference. In 2015 Dr. Carmen was named the UAH College of Engineering Oustanding Teacher, and in 2010 and 2013 she was named the Outstanding Mechanical Engineer in North Alabama by ASME. In 2010 she was awarded a NASA Exploration Systems Mission Directorate (ESMD) faculty fellowship – one of 5 senior design class instructors selected from around the country to participate in the program. As a result of the fellowship, several UAH MAE senior design teams have been able to work with NASA engineers on projects that are relevant to NASA's mission. In April 2011, Dr. Carmen was selected as a Society of Automotive Engineers (SAE) Ralph R. Teetor Educational Award recipient.

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Deborah Fraley is an Aerospace Engineer from Auburn University with 38 years experience as a defense contractor. She is employed as the Business Development Manager for Quantum Research International, Inc., a small company headquartered in Huntsville, AL. She is also the STEM Director for the TN Valley Chapter (TVC) of Women In Defense (WID), a national security organization dedicated to the advancement of women in national defense fields. Ms Fraley coordinates the WID TVC STEM program in partnership with the University of Alabama in Huntsville (UAH). Ms Fraley was awarded the prestigious Joseph C. Moquin Award for Professional of the Year for 2014 by the Huntsville Association of Technical Societies for her STEM work in the TN Valley area. Additionally, Ms Fraley is on the Advisory Council for the Auburn University Huntsville Research Center.

Women Building the US STEM Pipeline

ABSTRACT

In 2009, a collaborative engineering effort to promote Science, Technology, Engineering and Mathematics (STEM) education in the United States (US) was initiated between women representing academia and industry. The industry contingent provided financial support and mentorship to the academic side that resulted in undergraduate engineering student teams designing and building educational products for use within primary and secondary education schools with the goal of encouraging younger students to pursue careers in STEM fields. Due to an aging workforce at the National Aeronautics and Space Administration (NASA), the US Department of Defense (DoD), and the US Aerospace Industry, as well as the need to improve diversity in STEM jobs, the need to grow the US STEM pipeline is critical. This national priority is informed by the fact that advancements and innovations in STEM fields are indicative of a growing and progressive society; for political, technological, and economic reasons, among others, it is imperative that the US maintain leadership in these arenas. Therefore, as a result of a shared interest in STEM outreach and education, the female led partnership focused upon the design and development of STEM tools that are subsequently donated to Kindergarten through 12th grade (K-12) classrooms for continued use. STEM tools allow for tactile learning of subject matter often presented in a solely theoretical manner. The effort, referred to as the STEM initiative (STEMi), partners a female Capstone Design Class (CDC) Coordinator and Instructor at The University of Alabama in Huntsville (UAH) and representatives from Women in Defense (WID)-a non-profit national defense organization. STEMi originated within WID as a means to encourage and inspire K-12 students to take an interest in STEM subject matter with the goal of motivating them to pursue higher education in STEM areas and use their education in the US defense workforce to replace retiring technical experts. The UAH CDC focuses upon Product Realization, whereby Mechanical and Aerospace Engineering (MAE) students, over the span of two semesters, design and develop a product that meets customer requirements. The STEMi effort enables the UAH students to create STEM tools under the guidance and support of representatives from WID acting as the project sponsor. The present paper will describe the STEM tool development process and assess the educational impact of the resulting STEM tools upon the K-12 students, as well as the impact of participating in a STEMi design project upon the UAH students.

Introduction

US citizens born post-World War II, roughly from 1946-1964, are often referred to as the "Baby Boom" generation. This demographic is reaching a peak in retirement numbers and the detrimental effects are being felt within numerous US sectors. Of great concern is the exodus of workers in critical scientific communities such as NASA, the DoD, major aerospace entities, and other technological centers. In 2015, The Space Foundation reported that the US civilian space workforce experienced a 14% decline in employees from 2006-2013 and approximately 17.6% of NASA's workforce was eligible for retirement, whereas only 15% were under the age of 35[1]. Almost half of NASA's employees at Glenn Research Center (GRC) in Cleveland, Ohio, were in their 50s in 2015[2]. In order to transfer knowledge gained by senior employees to a younger generation, NASA implemented a phased retirement program–initiated by the US Federal government in late 2014–that enables individuals to work part-time, receive half of their retirement annuity, and maintain many additional benefits, with the caveat that a minimum of 20% of their time is dedicated to mentoring younger employees[2]. Similar data regarding the aging US aerospace workforce was provided by the Aerospace Industries Association (AIA) in 2015[3]:

- At least 25% of workers are over the age of 55
- At least 10% of workers are over the age of 61

As a result, the AIA has actively engaged in efforts to encourage US youth to pursue mathematics and science degrees.

While proactive efforts to build the STEM pipeline are crucial in order for the US to remain a world leader militarily, economically, and technologically, data still reveals major foundational issues with mathematics and science competency scores among US students. The US Department of Education National Center for Educational Statistics (NCES), in association with the International Association for the Evaluation of Educational Achievement (IES), has collected data every 4 years since 1995 in order to assess mathematics and science achievement. Metrics focus upon the scores of 4th and 8th grade students, as well as advanced studies–which have been gathered 3 times since 1995– focusing upon the mathematics and physics achievement of students in the final year of secondary school. The latest results were collected in 2015 and the following data pertains to US 4th grade students[4]:

- Average mathematics score was 539 (11th place)
- Average science score was 546 (8th place)

These scores place US 4th grade students behind students from Singapore, Republic of Korea, Japan, Russian Federation, China, Finland, Kazakhstan, and Poland. Similar results were obtained for US 8th grade students[4]:

- Average mathematics score was 518 (9th place)
- Average science score was 530 (8th place)

These scores also place US 8th grade students behind those from many other countries including Singapore, Republic of Korea, Japan, Russian Federation, China, Canada, Kazakhstan, and Ireland. On average, the 2015 US results have improved slightly since 1995. However, the improvement has not been significant enough to approach the scores of several nations and US policymakers should view this with continued concern.

Over the past decade, many approaches have been implemented with the goal of increasing US mathematics and science test scores by specifically focusing upon the promotion of STEM education and careers. Numerous academic, governmental and commercial institutions have also developed and/or participated in STEM endeavors that aim to inspire and motivate youth to seek a STEM education. One such program is the Arizona Science of Baseball[5] (ASB) that is managed by the University of Arizona. In 2012, the pilot program targeted 7th and 8th grade middle school students and incorporated the sport of baseball such that students could correlate fun, physical, and athletic activities to multiple STEM concepts. One activity would require the students to evaluate the mathematical and geometrical concepts conveyed via the baseball field itself; such as geometric angles and distances between bases. Other examples of STEM programs include those created by the American Institute of Aeronautics and Astronautics (AIAA), the International Space Life Sciences Working Group, and the National Space Biomedical Research

Institute (NSBRI). The AIAA pre-college outreach program aims to inspire K-12 students, parents, teachers, and schools via grants, educator mentorships, national workshops, and recognition programs[6]. The International Space Life Sciences Working Group created the Mission X: Train Like an Astronaut program[7] whereby 10 countries-including the US-participated in the pilot program in 2009. More than 4,000 students participated in activities that simulated astronauts' experiences. The hands-on, physical activities promote interest in STEM careers while also encouraging physical fitness, teamwork and interpersonal skills. The NSBRI has established partnerships to promote STEM education with various organizations including NASA, Morehouse School of Medicine (Atlanta, Georgia), and other international institutions as they aim to specifically focus upon space knowledge development[8]. Examples of space focused activities include arranging astronaut visits to K-12 schools, development and dispersal of teaching materials, professional development programs for teachers, and summer research opportunities in various nations.

The aforementioned STEM outreach efforts all focus upon motivating K-12 students to enjoy activities that implicitly convey mathematical and scientific concepts, in general. The UAH/WID partnership mimics this mindset by providing engaging, hands-on learning tools–referred to as STEM tools–to various K-12 schools. STEM tools provide K-12 teachers the opportunity to engage students in Problem-Based Learning (PBL) opportunities that have been proven to generate interest in STEM[9-12]. The tools provide students with a tactile learning experience that reinforces theoretical science and mathematics concepts presented in the classroom. The WID STEMi tools are designed and developed by UAH undergraduate engineering students with funding and support provided by WID. Upon delivery of the STEM tool to a K-12 school, data is gathered via surveys administered to the students which provide feedback regarding the educational value and impact of the tools. Additionally, feedback provided by the UAH students involved in the design and development of the STEM tools enables an understanding of the educational benefits and engineering skills garnered by the undergraduate students.

The UAH/WID STEMi partnership is comprised of women representing academia (UAH) and the defense industry (WID) who aim to promote an interest in STEM related subjects at the primary and secondary education levels. Specifically, this effort is led by a female CDC Coordinator and Instructor, who specializes in STEM outreach among various underrepresented groups, and a longtime female member of the Tennessee Valley Chapter (TVC) of WID who is also the STEM Outreach Director. Additionally, with respect to the 27 STEM tools that have been delivered as a result of the STEMi effort thus far, all but one were affiliated with female K-12 teachers. The teachers play a critical role as they specify the type of STEM tool desired and are the primary point of contact for the UAH students regarding product requirements, ergonomics, safety, and curriculum requirements, to name a few. In addition, numerous other women provide supporting roles via WID fundraising, and acting as CDC design reviewers and mentors.

Background

In 2009, the WID TVC decided to take an active role in supporting primary and secondary educational needs via the donation of STEM tools to K-12 schools. Since WID is a US defense affiliated organization, the effort was specifically targeted towards encouraging young people to pursue careers in US national defense and national security in order to, eventually, replace the aging DoD workforce. WID TVC realized that the aging technical workforce in the Huntsville, Alabama (AL) area (average age is 57) for both government and industry professionals, did not have a large number of young people trained in technical fields who would eventually provide replacement capabilities when senior level staff retires. The group decided to take on the mission of adding a new element to the already ongoing STEM activities in the Tennessee Valley area by providing STEM tools to science teachers in local schools that could be used to demonstrate scientific and mathematical principles. The tools supplement classroom lectures and standard teaching methods with a product that provides an element of participative fun to the students' learning process.

WID TVC focuses on securing financial backing from similar professional organizations, defense contractors, and local community organizations that will fund the creation of STEM educational tools for use in elementary, middle school and high school classrooms in the Tennessee Valley area. WID works with the Huntsville Space and Missile Defense (SMD)Working Group (part of the National Defense Industrial Association, Tennessee Valley chapter) to obtain the majority of funding ($5000 per year) that goes toward creation of the STEM tools that are donated to local schools. WID annually reports back to the SMD Working Group regarding the STEM tools that were developed with the funding and receives a recurring line item in the SMD annual budget.

At the start of the WID TVC STEMi in 2009, WID contacted a female faculty member in the MAE Department at UAH who is also the CDC department coordinator and an instructor of a CDC that focuses upon product realization. The UAH CDC class is a two-semester senior design class whereby student teams work with industry customers who require a particular product to be designed and fabricated. The customers typically have specific product requirements and often provide funding. The CDC instructor has taught the product realization class since 2002, and over 350 products have been successfully delivered to various customers including NASA, US Army, US Special Operations Command (SOCOM), Dynetics, Nucor Steel, Teledyne-Wah Chang, and numerous other entities. WID initiated the partnership with the UAH CDC class in order for the engineering student teams to design and build the WID funded STEM tools. On average, there are 10-12 teams per year in the UAH Product Realization CDC. Typically, 3-4 teams per year work on STEM tool projects funded by WID. All STEM tools are delivered to the K-12 classroom with complete documentation including an Operations Manual, Teacher Lesson Plan, Student Worksheet, and a Final Report that provides instructions for replication of the STEM tool for use in other classrooms or schools. All STEM tools are designed with safety as a top-level requirement, and durability as a close second. The tools are designed to be used indefinitely and with minimal maintenance. The STEM tools are also designed to be modular, such that parts and components can be easily replaced by the teacher.

To date, 27 UAH/WID STEM tools have been delivered to local schools in the Tennessee Valley area, as well as to a regional hands-on science center. A multitude of STEM principles are conveyed and demonstrated via the tools. Fig. 1 provides a sampling of recent tools. Additional STEM tools include, but are not limited to, the following: multiple tabletop wind tunnels, earthquake simulators, pulley systems, ballistic pendulum, solar system display, catapults, hybrid

Figure 1. UAH/WID STEM tools, clockwise from top left: fluid flow circuit, Wimshurst machine, mechanical and solar energy race track, dyslexic brain display, “Space Pong”-potential and kinetic energy display (*photo credits: C. Carmen*)

engine, water distillation system, and re-configurable learning stations equipped with computers. The type of tool is determined by the customer, which is typically the science teacher of the recipient K-12 classroom.

The present paper will focus upon the STEM tool development process–from initial contact with a K-12 school to final assessment of the educational impact upon the K-12 students, as well as the UAH engineering students. Specifically, metrics were gathered that addresses the following key questions:

- What are the K-12 student learning outcomes provided by the STEM tools?
- What are the benefits of working on a STEM outreach project (i.e. the design and development of STEM tools) for engineering students?

Methodology

The UAH/WID STEM tool project process can be categorized within 7 steps, as shown in Fig. 2. This process has been refined over the last 8 years and has been determined to yield optimum

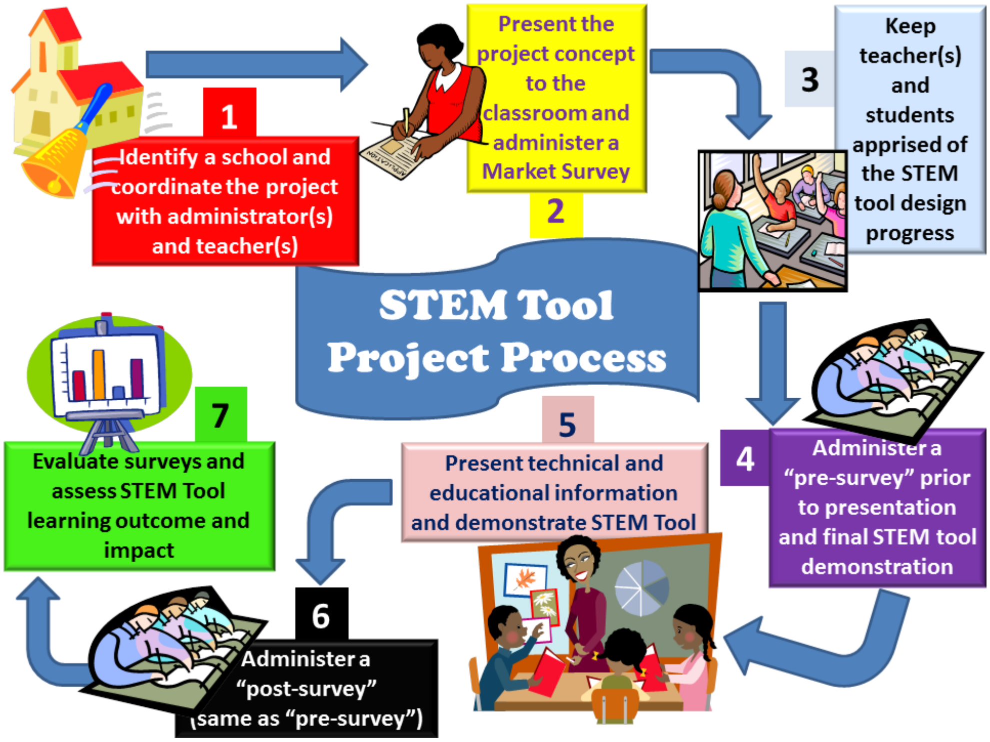

Figure 2. The UAH/WID STEM Tool project process (*credit: C. Carmen*)

results. Steps 1 and 2 occur during the first semester of the 2-semester UAH CDC sequence. Step 3 takes place during the first and second semester, while steps 4-7 are completed during the second semester.

Step 1 of the process identifies the STEM tool recipient K-12 school. At the onset of the UAH/WID STEMi partnership, the WID STEM Director would contact a regional K-12 school in order to explain the purpose of the STEMi effort and recruit the school to participate. The contacted K-12 schools unanimously agreed to become involved. After the first few STEM tools were delivered and utilized, reaching out to solicit K-12 school involvement was no longer necessary. K-12 teachers began to reach out to UAH or WID as a result of their observation of existing STEM tools in use, either in their school or another. Presently, there exists a wait-list of schools desiring a STEM tool. After a school is identified, a K-12 teacher will act as the project "customer" and describe the type of STEM tool desired. Some customers have very specific product requirements, while others may have a general idea. However, under no circumstances will the UAH engineering team design a STEM tool that duplicates an existing product. The CDC requires the engineering student teams to design a product that is unique enough to be patented. While applying for a patent is not required in the CDC, it is encouraged and one patent has formally been pursued by UAH on behalf of a CDC team involved in the STEMi effort.

After a school and customer are identified, the UAH CDC instructor and WID STEM Director confer and discuss the various aspects of the requested STEM tool to ensure that the initial requirements are appropriate and can successfully be met. The project is then presented to the CDC students on the first day of class. Typically, the WID STEM Director will introduce herself and the overall project requirements. The CDC students complete a project request form as there are, on average, 2-4 additional project options, not related to the STEMi effort. The CDC instructor will attempt to match students to their first choice as project interest is very often indicative of the quality of the final product. On the second day of class, the STEM tool student design team is formed. The team commences an engineering design process that focuses heavily upon the use of the NASA Systems Engineering (SE) Handbook[13]. The design process utilized within the CDC has previously been described in detail[14-16]. The first semester requires completion of conceptual, preliminary, and detail design phases which results in a complete engineering description of a STEM tool that is ready for manufacturing. First semester activities include final resolution of requirements, initial system architecture concept, patent searches, functional and safety evaluations, concept of operations, preliminary functional baseline, risk assessment and issue mitigations, structural analysis, potential manufacturing methods, test planning, cost analysis, and three formal deign reviews, culminating in a Critical Design Review and a Detail Design Report. The second semester entails the fabrication, testing, refinement, and delivery of the STEM tool to the recipient K-12 school, along with extensive documentation. Three formal design reviews are also conducted during the second semester. Throughout the entire design process, the WID STEM Director will attend the 6 formal design reviews as well as mentor the engineering student design teams whenever needed. The WID STEM Director possesses 39 years of engineering experience as an Aerospace Engineer and defense contractor.

Step 2 of the STEM tool process takes place early during the first semester of the CDC. After the CDC team thoroughly understands the customer requirements and has completed some initial research–including patent searches and benchmarking–the team will visit the K-12 classroom. The intent is to introduce the CDC team to the younger students and discuss the early design concepts (i.e. design solutions) via a Power Point® presentation. Additionally, the CDC team will administer a market survey in order to engage the younger students in the design process and include their ideas and desires within the final product. Market survey questions are specific to the type of STEM tool, but may include questions such as “what color would you like the product to be?” and “what should the product be named?” The CDC team will always attempt to include the results of market survey responses within the STEM tool design.

Step 3 requires the CDC team to keep the K-12 teacher and students apprised of the design progress during the remainder of the CDC first semester and at the start of the second semester. The project customer (i.e. K-12 teacher) is always invited to attend the formal design reviews which take place at UAH. The teacher is also provided a Power Point® copy of the design review in order to show the younger students. Whenever possible, the CDC team will visit the school at the end of the first semester and at the start of the second semester.

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Step 4 takes place towards the end of the second semester and after the formal Product Readiness Review (PRR) at UAH. Again, the customer and sponsor (WID STEM Director) are invited to attend the PRR, whereby the CDC team demonstrates the completed STEM tool before actual delivery to the K-12 classroom. The product delivery presentation at the K-12 school requires approximately one hour. At the start, the CDC team administers a “pre-survey” to the younger students that is comprised of various questions, primarily technical, regarding concepts associated with the STEM tool.

Step 5 entails the CDC team conducting a brief presentation which provides details regarding the development of the STEM tool, as well as educational concepts conveyed via use of the product. The CDC team then demonstrates the STEM tool, often with K-12 student volunteers.

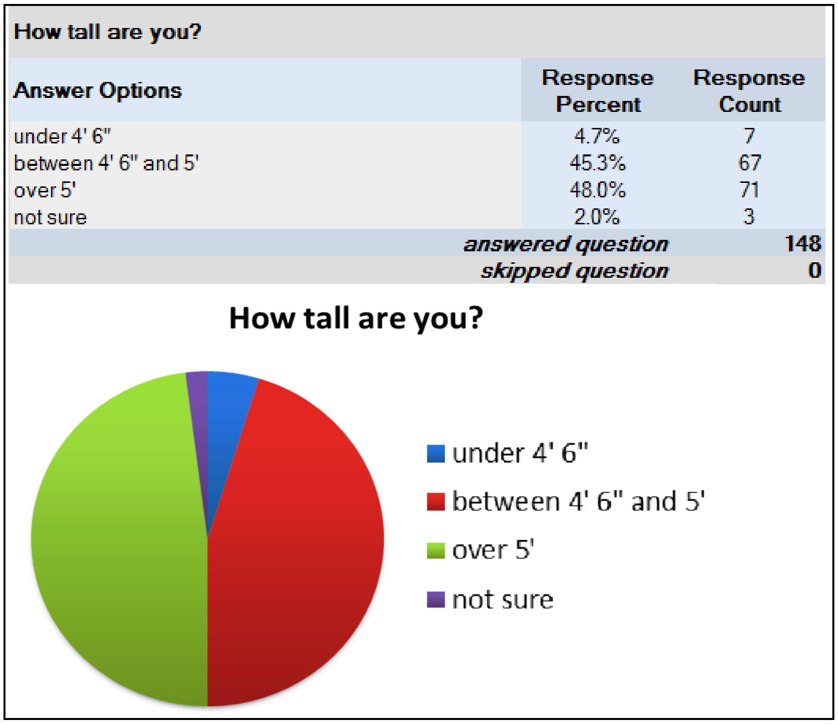
Step 6 is the administration of the "post-survey" which is comprised of the same questions as on the "pre-survey," as well as a few additional questions. Additional questions on the "post survey" may include whether the younger students would like other STEM tools for their classroom and, if so, what type.

Step 7 involves assessment of the "pre" and "post" surveys in order to determine whether the K-12 students gained knowledge as a result of the CDC team presentation and demonstration of the STEM tool.

Results

A recently completed UAH/WID STEM tool–specifically, a tabletop wind tunnel–will be discussed, in order to provide specific STEM tool process results. Due to the reputation of the UAH/WID STEM tool program, a female teacher at Mill Creek Elementary School (MCES), in Madison, AL, contacted WID in order to participate in the STEM initiative. Owing to a wait-list, the MCES effort began in August 2015, approximately one year after the initial request. The MCES teacher taught 5th and 6th grade science classes and requested a table-top wind tunnel that would allow her students to evaluate drag data exhibited by various scaled automobiles and other test articles. The project was presented as a CDC project option at the start of the fall 2015 semester and 6 MAE students were selected to work on the 2-semester project. As mentioned, due to the rigorous and thorough engineering design process employed in the UAH CDC, only the results pertaining to the STEM tool process represented in Fig. 2 will be provided.

As the start of the conceptual design phase, the CDC team visited MCES and introduced themselves to the 5th and 6th grade students that would be using the wind tunnel. Various aspects of the design requirements and initial design concepts were presented. Additionally, the CDC team administered a market survey to students at CES. The market survey enabled the design team to understand basic human factors and aspects of the design that the younger students desired to have incorporated within the final product. Several questions were posed to the students via a paper survey distributed to multiple 5th and 6th grade science classes. A total of 148 students completed the survey. The questions pertained to factors such as age, grade, ethnicity (optional), design features and ergonomic information. The results of an anthropometric question are provided in Fig. 3. The CDC team inquired about the height of each child in order to best design a wind tunnel such that all controls were accessible and optimal test section viewing could be achieved. Roughly 48% of the students were over 5 feet (ft) tall and over 45% were between 4.5-5 ft. The data resulted in the CDC team selecting a mobile cart upon which the wind tunnel could be secured. The anthropometric data conveyed that optimum ergonomic results could be achieved as well as a customer requirement that the entire wind tunnel be easily transported within the school.



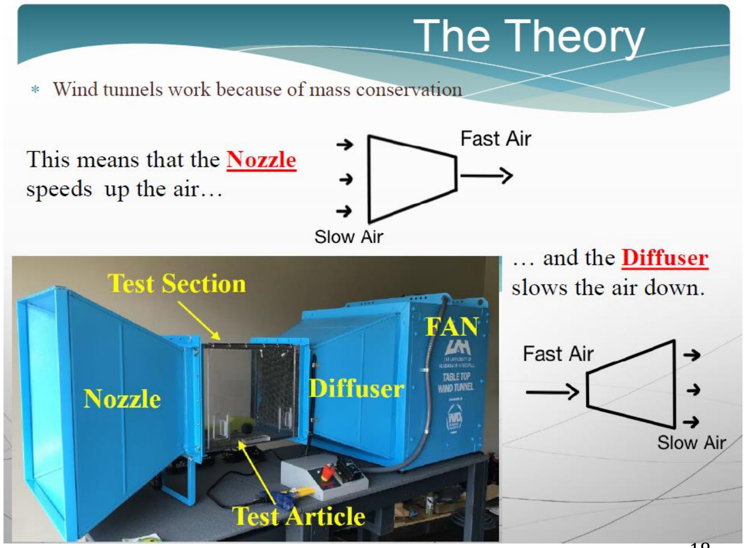
How tall are you?

Answer Options	Response Percent	Response Count
under 4' 6"	4.7%	7
between 4' 6" and 5'	45.3%	67
over 5'	48.0%	71
not sure	2.0%	3
	answered question	**148**
	skipped question	**0**

Figure 3. Anthropometric market survey results[17]

During the fall 2015 and spring 2016 semesters, the CDC team visited MCES on numerous occasions. The team members provided updates to the teacher and students, as well as participated in a STEM fair. Involvement in the MCES STEM fair was not a CDC requirement. However, the engineering students became so engaged with the elementary school children, that they volunteered to participate and enjoyed doing so. In fact, many UAH students who have worked on STEM tool projects have continued to volunteer at K-12 schools.

Upon completion of the wind tunnel, a PRR was conducted at UAH. The wind tunnel was demonstrated and the CDC instructor, WID STEM Director, and MCES teacher approved the product. The subsequent week, the wind tunnel was delivered to MCES and presented to a 5th grade class. As specified in Fig. 2, a pre-survey was first administered. The 12-question survey asked the younger students about their interest in various subjects as well as more technical questions pertaining to wind tunnels. The CDC team then presented an approximately 20-minute Power Point® presentation that included pictures taken during the wind tunnel fabrication and assembly, as well as general information regarding wind tunnel theory and usage. A representative slide, showing a labeled image of the wind tunnel, as well as theory regarding nozzles and diffusers, is provided in Fig. 4. To reinforce the understanding of nozzles and diffusers, the MCES students were provided with smaller versions constructed with poster board. Each student would place their hand at the end of the nozzle/diffuser and blow into the opposite end. They would subsequently rotate the nozzle/diffuser, and repeat the action in order to feel the difference in airspeed upon their hand. Next, the CDC team demonstrated the wind tunnel via the use of a scaled race car as the test article, as shown in Fig. 5. Upon start of the fan, the air would flow over the test article and the drag force would cause the test article to move back in the wind tunnel. A linear spring was attached to the test article such that the linear translation



The Theory

- Wind tunnels work because of mass conservation

This means that the **Nozzle** speeds up the air…

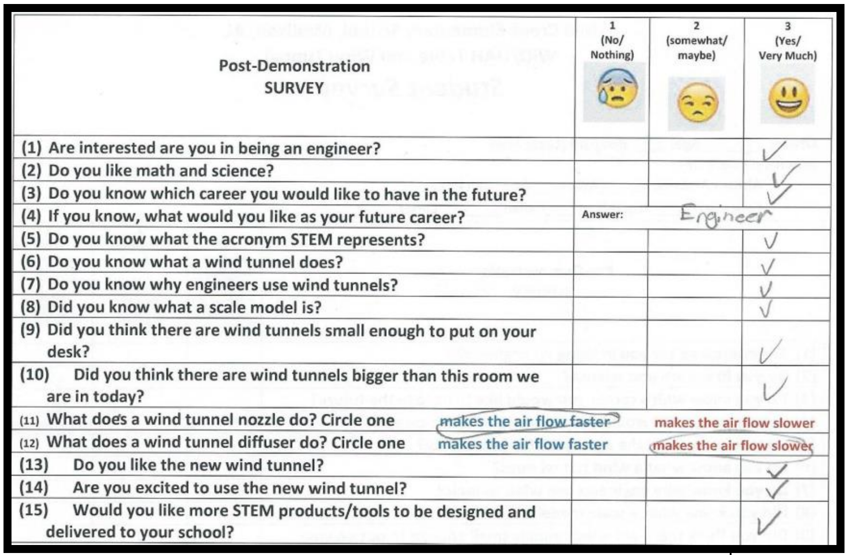
… and the **Diffuser** slows the air down.

Figure 4. Wind Tunnel STEM tool presentation slide[18]

Figure 5. A CDC team member explains the functionality of the wind tunnel to a MCES 5th grade class (*photo credit: C. Carmen*)

experienced by the scaled race car could be used to calculate the drag force, via use of Hooke's Law. This law states that the drag force on the test article is equal to the linear travel distance of the test article multiplied by the spring constant (a provided value). Hooke's Law provides an appropriate, yet simple, mathematical calculation that 5th grade students can comprehend.

After the wind tunnel demonstration the MCES students were administered a post-survey. The post-survey included the same 12 questions as the pre-survey and 3 additional questions, as shown in Fig. 6. Twenty-five 5th grade students completed the survey. Five students were 10 years old, sixteen students were 11, three students were 12, and one student did not provide an age. Eight students were female, 15 were male, and 2 students did not specify a gender. As shown in Fig. 7, only 3 of the 25 students initially understood the purpose of a wind tunnel. However, after the CDC presentation and demonstration of the wind tunnel, the number increased to 24 of the 25 students. The average pre-demonstration score was 1.76, with a jump to 2.96, post-demonstration. The wind tunnel presentation and demonstration accounted for an increase of over 68% regarding the 5th grade students' knowledge of the purpose of wind tunnels.



Post-Demonstration SURVEY	1 (No/ Nothing)	2 (somewhat/ maybe)	3 (Yes/ Very Much)
(1) Are interested are you in being an engineer?			✓
(2) Do you like math and science?			✓
(3) Do you know which career you would like to have in the future?			✓
(4) If you know, what would you like as your future career?	Answer:	Engineer	
(5) Do you know what the acronym STEM represents?			✓
(6) Do you know what a wind tunnel does?			✓
(7) Do you know why engineers use wind tunnels?			✓
(8) Did you know what a scale model is?			✓
(9) Did you think there are wind tunnels small enough to put on your desk?			✓
(10) Did you think there are wind tunnels bigger than this room we are in today?			✓
(11) What does a wind tunnel nozzle do? Circle one	[✓ makes the air flow faster]	makes the air flow slower	
(12) What does a wind tunnel diffuser do? Circle one	makes the air flow faster	[✓ makes the air flow slower]	
(13) Do you like the new wind tunnel?			✓
(14) Are you excited to use the new wind tunnel?			✓
(15) Would you like more STEM products/tools to be designed and delivered to your school?			✓

Figure 6. Post-survey responses provided by a MCES 5th grade student

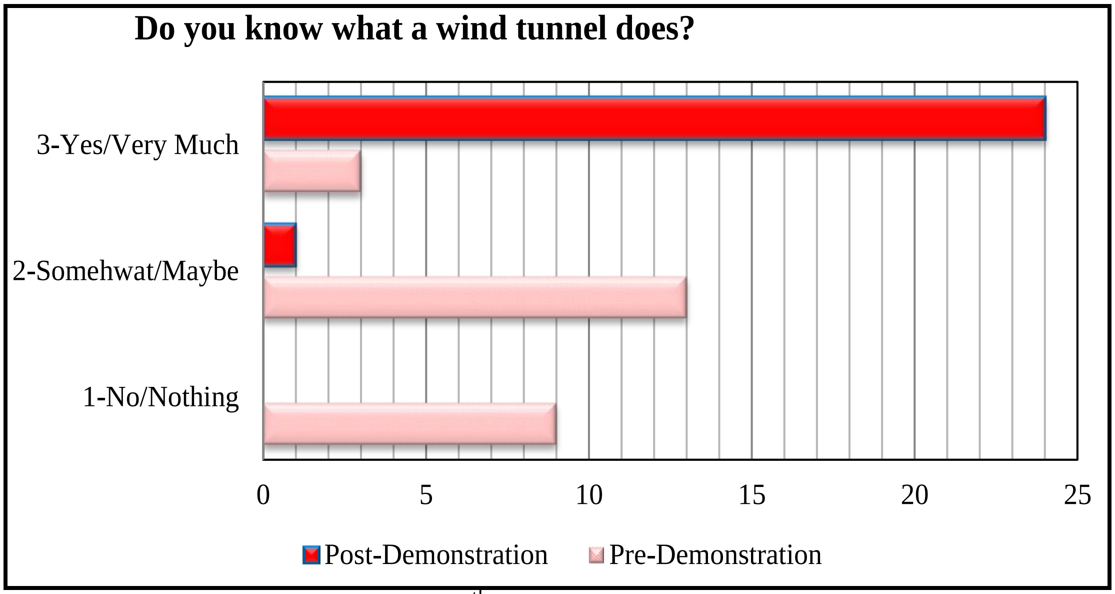


Figure 7. Survey results regarding 5th grade students' knowledge of wind tunnels

Another survey result is provided in Fig. 8 and regards the 5th grade students' knowledge of scale models. Only 7 of 25 students knew what a scale model was prior to the wind tunnel demonstration, whereas only 1 student indicated they did not know what a scale model was post wind tunnel demonstration.

The 5th grade students' survey results demonstrated a positive educational impact as a result of the CDC team presentation and wind tunnel demonstration. Three additional post-survey questions inquired whether the students liked the wind tunnel, were excited to use the wind tunnel, and whether they would like additional STEM tools to be designed and delivered to MCES. For all three questions, the students unanimously replied "Yes/Very Much."

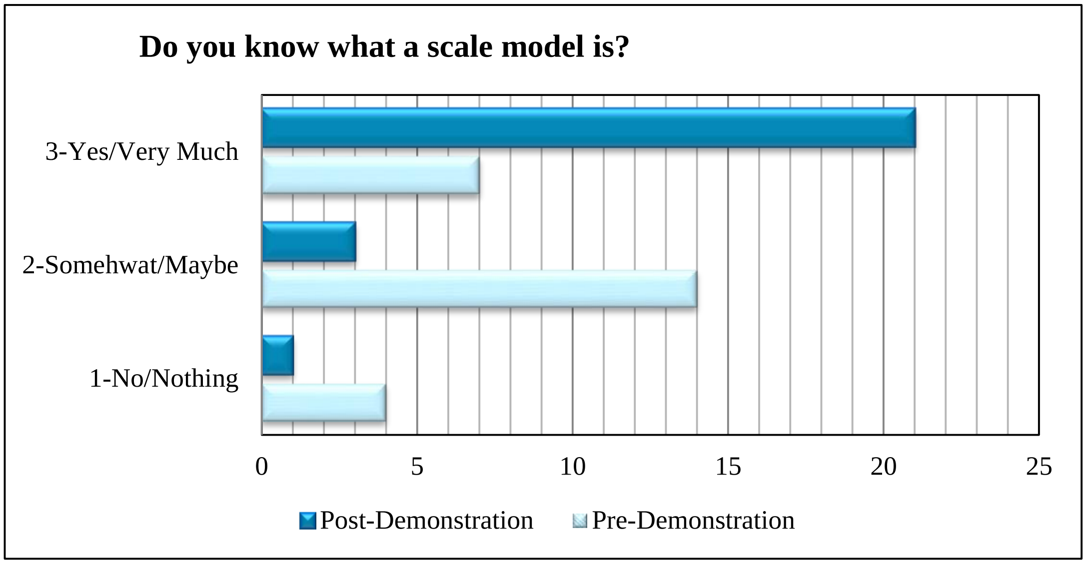


Figure 8. Survey results regarding 5th grade students' knowledge of scale models

Of the 25 students surveyed, five initially indicated that they would like to be an engineer and maintained that stance from pre- to post-survey. However, 4 of the 25 students changed an initial career preference to "engineer" after the CDC team presentation. This equates to 16% of the 5th grade students changing their career choice to a STEM field as a result of the UAH/WID effort.

Engineering Student Team Assessment

The CDC team consisted of 6 Mechanical and Aerospace Engineering students, all of whom selected the wind tunnel project as their first choice among all project options. Five members of the team were male, one was female, and the ages ranged from 22-29 years old. One student was Hispanic, one Asian, and the remaining were Caucasian.

The CDC team was administered a 25 question survey at the end of the 2nd semester, in April 2016. Most of the survey questions pertained to various processes and tools used within the CDC. The results for 7 questions, which are most applicable to the STEM tool project, are provided in Table I. According to the results, all 6 CDC team members considered STEM outreach (i.e. sharing engineering knowledge with non-engineers) to be important. Most of the team believed that their public speaking skills had improved–only one student disagreed and this particular student was known to already have great confidence in these skills as a result of numerous past public speaking experiences. All team members indicated that their technical writing skills had improved, with only one student responding that the improvement was "Very little." Technical writing skills are emphasized within the CDC and teams must complete thorough documentation including, but not limited to, the following: 6 formal design presentations, market survey, detail design report, final design report, product operations manual, STEM outreach presentation, teacher lesson plan and student worksheet. With respect to "team member" skills, half of the team indicated that their skills had "somewhat" improved and the

Table 1. CDC team survey results

Question	1 No/Not at all	2 Very little	3 Somewhat	4 Fairly well	5 Yes/ Very much	Ave. Score	Standard Deviation
1. Do you think that STEM outreach is important?	0	0	0	0	6	5	2.68
2. Do you think the CDC has improved your public speaking skills?	1	0	1	1	3	3.83	1.10
3. Do you think the CDC has improved your technical writing skills?	0	1	1	3	1	3.67	1.10
4. Do you think the CDC has improved your team member skills?	0	0	3	3	0	3.50	1.64
5. Do you think the CDC has improved your confidence as you enter the engineering workforce?	0	0	0	4	2	4.33	1.79
6. Are you proud of the final product?	0	0	0	2	4	4.67	1.79
7. Did you enjoy working with the customer(s)?	0	0	2	0	4	4.33	1.79

remaining responded “fairly well.” It is interesting to note that the CDC team was observed by the instructor to have significant communication issues during the first semester. However, during the second semester, the team performed with much greater cohesion. When the students were asked if working on the wind tunnel project had given them more confidence prior to entering the workforce, 2 students replied “yes/very much” and 4 replied “fairly well.” All CDC team members were proud of the final product with 4 responding “yes/very much” and 2 responding “fairly well.” Finally, 4 students responded “yes/very much” when asked whether they enjoyed working with the customers (teachers and students) and 2 responded “fairly well.”

The CDC team members provided written answers elaborating on Question #5, and the comments are as follows:

- “It prepared me for presentation of a product”
- “It has helped me to be able to be part of a team and to accomplish the goals we set”
- “This class required me to make decisions and stand behind them”
- “The lessons learned and design confidence are invaluable”

An open-ended question posed to the CDC team queried them about why they chose to work on the wind tunnel project. The replies are as follows:

- “Working with elementary school kids”
- “I think STEM outreach is very important and, particularly, having women visible in STEM encourages younger girls to explore their talents in those areas”
- “Previous work with UAH’s wind tunnel”
- “It touched upon areas of design directly associated with my current employment”

Conclusions

Thus far, the UAH/WID partnership has resulted in 27 STEM tools and has provided CDC students at UAH the opportunity to collaborate on the development of products that are subsequently donated to K-12 classrooms. The STEM tool effort has proven to generate excitement among the UAH students as well as provide K-12 students with hands-on tools to reinforce classroom lectures.

Upon completion of the latest STEM tool wind tunnel project, surveys completed by 5th grade students indicated a positive learning impact. Initially, only 12% of the young students understood the purpose of a wind tunnel. After the wind tunnel was discussed and demonstrated, 96% of the students indicated that they understood the purpose of a wind tunnel (only one student indicated that they had a "fairly well" understanding). Additionally, only 28% of the 5th grade students initially knew what a scale model was, compared to 84% after the CDC team members demonstrated the tool. After discussion and demonstration of the wind tunnel, 100% of the young students indicated that they were excited to use the product and desired more STEM tools for their classroom.

The female led collaboration in the development of STEM tools has proven beneficial to UAH students as well. The CDC team members successfully involved the elementary school children in the requirements development of the table-top wind tunnel, and included the recommendations in the final product. The UAH students appreciated the opportunity to work on a STEM tool design project and voluntarily took part in a STEM fair at MCES. A survey indicated that 100% of the CDC team members believed that STEM outreach was important. The CDC team also indicated their communication skills were improved as a result of numerous design reviews and documents generated.

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Bibliography

1. The Space Foundation. "The Space Report 2015: The Authoritative Guide to Global Space Activity."
2. Soder, C. "Mentoring, Half-Time Work Help NASA Glenn Address Aging Workforce, August 2, 2015. http://www.crainscleveland.com/article/20150802/NEWS/308029986/mentoring-half-time-work-help-nasa-glenn-address-aging-workforce, accessed January 23, 2017.
3. "Aging aerospace workforce seeks young talent in Aurora," The Associated Press, June 6, 2016, http://www.denverpost.com/2016/06/05/aging-aerospace-workforce-seeks-young-talent-in-aurora/, accessed July 12, 2016.

4. Provasnik, S., Malley, L., Stephens, M., Landeros, K., Perkins, R., and Tang, J. “Highlights from TIMSS and TIMSS Advanced 2015,” US Department of Education, NCES 2017-002, November, 2016.
5. Valerdi, R., Monreal Jr, J., Valenzuela, D. and Hernandez, K. “Measures of Effectiveness for S.T.E.M. Program: The Arizona Science of Baseball,” Conference on Systems Engineering Research, Georgia Institute of Technology, Atlanta, GA, March 19-22, 2013. *Procedia Computer Science* 16 (2013), p. 1053-1061.
6. Bering, E. A., Bacon, L., Copper, K. K., Hansen, L. J., Sanchez, M. J. “The American Institute of Aeronautics and Astronautics pre-College Outreach Program,” *Advances in Space Research*, Volume 42, Issue 11, p. 1869-1878.
7. Lloyd, C. W. “The Mission X: Train Like an Astronaut,” *Acta Astronautica*, 81, 2012, p. 77-82.
8. MacLeish, M. Y., Akinyede, J. O., Goswami, N. and Thomson, W. A.. “Global Partnerships: Expanding the Frontiers of Space Exploration Education,” *Acta Astronautica*, 80, 2012, p. 190-196.
9. Matarić, M.J., Koenig, N., and Feil-Seifer, D. “Materials for Enabling Hands-On Robotics and STEM Education.” *Proc. AAAI Spring Symposium on Robots and Robot Venues: Resources for AI Education*, Stanford, Calif., March 26- 28, 2007.
10. Williams, K., et al., “Enriching K-12 Science and Mathematics Education Using LEGOs.” *Advances in Engineering Education*, Vol. 3, No. 2, Summer 2012.
11. Haury, D.L. and Rillero, P. “Perspectives of Hands-On Science Teaching.” ERIC Clearinghouse for Science, Mathematics and Environmental Education, Columbus, OH, March 1994.
12. Garrity, C., "Does the Use of Hands-On Learning, with Manipulatives, Improve the Test Scores of Secondary Education Geometry Students?" 1998.
13. NASA Systems Engineering Handbook, SP-2007-6105, http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080008301.pdf
14. Carmen, C., “Integration of a NASA ESMD Faculty Fellowship Project within an Undergraduate Engineering Capstone Design Class,” *62nd International Astronautical Congress Proceedings*, Cape Town, ZA, Oct. 2011.
15. Carmen C. and Groenewald B., “Initiation and Development of International Collaboration Among the Future Space Workforce Via the Design and Development of a STEM Tool,” *63rd International Astronautical Congress Proceedings*, Naples, IT, Oct. 2012.
16. Groenewald, B. and Carmen, C.L., “Establishment of a Multi-National University Effort to Promote International Cooperation and Develop the Future Space Workforce,” *64th International Astronautical Congress Proceedings*, Beijing, CN, Sept. 2013.
17. Dulz, D., Henslee, A., Hoang, T., Marks, D., Moreno, A., Latham, J, and Peusch, A., “Preliminary Design Review: Table Top Wind Tunnel,” MAE 490 Introduction to Engineering Design: Product Realization, The University of Alabama in Huntsville, Huntsville, AL, Oct. 2015.
18. Dulz, D., Henslee, A., Hoang, T., Marks, D., Moreno, A., Latham, J, Peusch, A. and Carmen, C., “STEM Outreach Product Delivery: Table Top Wind Tunnel,” MAE 491 Product Realization, The University of Alabama in Huntsville, Huntsville, AL, April 2016.