Promoting K-12 Aerospace Education via Wind Tunnels Developed through an International Capstone Design Partnership

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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 Moonbuggy 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 2010 and 2013, Dr. Carmen 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.

Mr. Ben Groenewald, Cape Peninsula University of Technology

Ben Groenewald is Head of the EECE Dept. at CPUT in South Africa. He holds a Master of Science in Electrical and Electronic Engineering from the University of Cape Town and is currently studying towards his PhD. He is a panel member of the organizing and editorial committee of the Domestic Use of Energy and the Industrial and Commercial Use of Energy conferences. He is a reviewer for both of these conferences. Mr. Groenewald was the CPUT capstone design class coordinator for many years. His main interest, apart from managing his department, is the promotion of STEM education in South Africa and developing sustainable off-grid electricity supply micro-grid models for rural towns in South Africa.

Mr. Rhyme Kagiso Setshedi, Cape Peninsula University of Technology

Rhyme Setshedi is a physics Phd Candidate and a qualified educator/lecturer in the Department of Electrical, Electronic and Computer Engineering (DEECE) at the Cape Peninsula University of Technology in Cape Town South Africa. He has over a decade of teaching experience at tertiary levels and a deep passion for Science, Technology, Engineering and Maths (STEM). His research interest includes small angle scattering (SAS) and the use of informarion technology systems (ITS) in physics and in education. In is on this bases that Rhyme has partnered with Mr Ben Groenewaald (Departmental Head- DEECE) and Dr Christina Carmen (a capstone design class coordinator in the Mechanical and Aerospace Engineering department at the University of Alabama in Huntsville(UAH)) on this ALLiance for International Excellence among the future Space workforce (ALLIES). Rhyme has been involved in this international STEM outreach programme for three years now, coordinating CPUT students' involvement in the ALLICE STEM tool development with UAH students.

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Aysha Abrahams Born and raised in Cape Town, South Africa. Obtained a Bachelor's degree in Education (Honours) in 2002 and a Master's Degree in Education (2006) from the University of Cape Town. Lectured at the University of Western Cape, University of Cape Town and Cape Peninsula University of Technology (CPUT). Currently lecturing Communication Skills and Industrial Projects in the Electrical Engineering Department, CPUT. Additional areas lectured: Research Methodology, Professional Practice, Literacy First Additional Language Methodology, Environmental Education, Philosophy of Care & Health Promotion, Life Orientation, Religion and HIV/Aids. Departmental duties include: Teaching & Learning representative and first year coordinator. Projects: HEAIDS, Service learning in Education and STEM. Awards received: UCT Student Conference award- 2002 and 2004. Publications: one journal article and a chapter in a book. Two articles pending acceptance from accredited journals. Completed and passed Doctoral thesis awaiting graduation.

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ABSTRACT

In many nations, programs to grow the Science, Technology, Engineering, and Mathematics (STEM) pipeline are a priority due to the fact that advancements and innovations in STEM fields are indicative of a growing and progressive society. Within the United States (US), an aging National Aeronautics and Space Administration (NASA) and Department of Defense (DoD) workforce, as well as the need to create a more diverse STEM workforce, are impetuses for accelerated efforts that focus upon STEM education and careers. Such efforts are also continuously gaining traction in South Africa; a nation dedicated to overcoming the negative education disparities that resulted from apartheid. As the result of a mutual interest in promoting STEM education and careers among Kindergarten through 12th grade (K-12) students in the US and South Africa, an academic partnership was established in 2012 between the University of Alabama in Huntsville (UAH) in Huntsville, Alabama (AL), and the Cape Peninsula University of Technology (CPUT) in Cape Town, South Africa. The partnership is referred to as the **ALL**iance for **I**nternational **E**xcellence among the future **S**pace workforce (ALLIES). One of the primary goals of ALLIES is to design and develop STEM tools within engineering capstone design classes at UAH and CPUT. Upon completion, the STEM tools are donated to various K-12 schools in the US and South Africa. The STEM tools adhere to stringent curriculum and product requirements-with safety as a top-level requirement. Another critical goal of ALLIES is the enablement of international design efforts that provide engineering students opportunities to gain invaluable experience working, interacting, and communicating with, an international partner. The objective of the present investigation is to determine the impact of the international design collaboration upon the engineering design students, and the benefits of the STEM tools upon the K-12 students. In order to specifically promote aerospace engineering, the ALLIES partnership has focused upon the design and development of wind tunnels that are donated to primary and secondary education schools. Previously designed UAH capstone design class wind tunnels have proven to spark interest in aerospace related phenomena among K-12 students and, as a result, wind tunnels quickly became the preferred STEM tool developed via the ALLIES partnership. The most recent effort focuses upon the design of a wind tunnel that can be fabricated using materials, parts, and components available in most regions of the world, such that disadvantaged schools can easily replicate one. The present paper will focus upon the ALLIES wind tunnel design process, the educational impact upon the engineering design students, as well as the recipient K-12 students.

Introduction

For similar-yet profoundly different-reasons, the US and South Africa have placed a high priority upon developing the future STEM workforce of their respective nations. The most recently available US civilian space workforce data reveals a 14% decline in employees from 2006 to 2013[1]. Additionally, in fiscal year 2015 approximately 17.6% of NASA's workforce was eligible for retirement, whereas only 15% were under the age of 35[1]. In order to remain a world leader in space faring activities-as well as militarily, economically, and technologically-the US has accelerated efforts to continue to build the pipeline of young individuals choosing STEM careers. South Africa, on the other hand, is an emerging space faring nation. Similar to the US, South Africa desires to build its STEM workforce in order to advance the technological and economic backbone of the nation. However, the South African government imposed system of segregation-known as apartheid and lasting from 1948 to 1994-resulted in a majority of the population suffering from a 46 year long banishment from a mathematics or science based education. In order to overcome these educational obstacles, South Africa aims to integrate and accelerate STEM education among primary, secondary, and post-secondary education students.

In the US, numerous government, industry, and philanthropic based funding sources are providing the means necessary to address the critical need to inspire and motivate the K-12 population in regards to STEM education. In March 2013, US President Barak Obama announced a new initiative to prepare 100,000 new STEM teachers over a 10-year period[2]. The front line between K-12 students and STEM careers are teachers trained to provide students with hands-on, Problem-Based Learning (PBL) that has proven to generate interest in STEM[3-6].

In South Africa, the end of apartheid instigated a steady increase in postsecondary education enrollment of black students. The following statistics relay the facts[7]:

- In 1993, one year prior to the end of apartheid, black students represented only 40% of college students, even though blacks comprised 77% of the nations' population
- In 2011, black students represented 81% of college students

While these statistics appear promising, they belie an undercurrent of continuous difficulty in maintaining a healthy pipeline of blacks entering STEM fields. Attrition rates for black students in STEM majors remain high, blacks are still underrepresented in STEM fields, and black participation rates (i.e. people employed or actively seeking employment) are low, as the following statistics reveal[7]:

- In 1993, the participation rate for blacks was 9%
- In 2007, the participation rates for blacks increased to only 12%

The reasons for the dichotomy between increased black enrollment in South African colleges and the continuously low population of blacks in STEM fields, remains a source of continued discussion and analysis. However, illumination of these persistent struggles has resulted in acknowledgement by the South African government, although, perhaps, not enough proactive efforts to improve the situation. The South African National Planning Commission's Diagnostic Report[8] identified nine primary causes that continue to fuel racial inequality:

1. Poor educational outcomes
2. High disease burden
3. Divided communities
4. Public service performance is uneven
5. Spatial patterns marginalize the poor
6. Too few South Africans are employed
7. Corruption
8. Resource intensive economy
9. Crumbling infrastructure

The continuing struggle to provide the tools necessary for black South Africans to succeed in STEM fields seems to be rooted in the lack of will and government initiative[7]. The *National*

Development Plan 2030 is another report generated by the South African National Planning Commission, whereby 119 actions are identified in order to overcome persistent inequalities. Actions specific to increasing participation of blacks in the STEM workforce include, but are not limited to, the following[9]:

- Increase state funding to ensure 2 years of early childhood education before grade 1
- Teachers should be recognized for their efforts-teaching should be a highly valued profession
- Reward schools for consistent improvements in annual national assessments
- Strengthen and expand Funza Lushaka (i.e bursary to promote teaching as a profession)
- Additional training for university lecturers
- Build strong relationships between the college sector and industry
- Implement a National Program to develop the Next Generation of Academics for South African Higher Education
- Provide more support for universities to help students from disadvantaged backgrounds
- Provide all students who qualify for the National Student Financial Aid Scheme with access to full funding through loans and bursaries to cover the costs of tuition, books, accommodation and other living expenses-students who do not qualify should have access to bank loans, backed by state sureties

In order to accommodate the need to promote STEM education in the US and South Africa, two Capstone Design Class (CDC) educators from each nation initiated the ALLIES partnership in 2012. ALLIES enables students, faculty, and staff from UAH and CPUT to collaborate on the design and development of STEM tools that are subsequently donated to K-12 schools. The partnership was based upon existing, and successful, STEM tool design efforts at UAH. The design class instructors were eager to add an international collaborative design aspect to the STEM tool development effort. The present paper provides background information regarding the establishment and goals of ALLIES, the international design process methodology, and assessment results regarding the impact of the ALLIES partnership upon the CDC engineering students and the K-12 students.

Background

After meeting at an international aerospace conference in 2011, a Mechanical and Aerospace Engineering (MAE) CDC instructor at UAH and an Electrical, Electronic and Computer Engineering (EECE) CDC instructor at CPUT formed a partnership, referred to as ALLIES. Both UAH and CPUT have active and ongoing research programs affiliated with the space industries of the US and South Africa, respectively. ALLIES is intended to develop the future space-and broader STEM-workforce by focusing upon the following specific objectives:

1. Establish collaborative efforts between universities in various nations
2. Provide undergraduate engineering students the opportunity to work on international engineering projects
3. Encourage K-12 students to pursue careers in STEM fields

It was determined that the optimal method of achieving the ALLIES objectives would be via the collaborative design of STEM tools that would be donated to K-12 schools, or educational centers, in both nations. STEM tools are hands-on, interactive products that convey educational phenomena associated with STEM fields, and that properly align with age and grade appropriate topic(s). Since 2009, UAH CDC teams have produced numerous STEM tools that have been donated to K-12 schools and science centers. Examples of the previously designed STEM tools are shown in Fig. 1.

Figure 1. UAH capstone design class STEM tools-clockwise from top left: dyslexic brain display, fatigue and beam bending apparatus, pulley system, velocity/motion tracks, mechanical and solar energy race track (*photos courtesy of C. Carmen*)

Methodology

At the start of the international partnership, UAH and CPUT CDC instructors aimed to create a partnership that would answer two primary research questions:

1. Would CDC students in the US and South Africa benefit from working together during the development of STEM tools?
2. Would US and South African K-12 students benefit from utilization of the STEM tools in the classroom?

In order to understand the differences between the two CDC programs, the instructors first shared class schedule details, and information regarding design methodologies and processes. Prior to commencing the collaborative design of a STEM tool, the UAH CDC instructor shared pedagogic information regarding the use of quantitative evaluation matrices by student engineering design teams. Evaluation matrices are commonly used trade study tools that enable teams to make decisions when exploring various design concepts. Within the UAH CDC, the NASA Systems Engineering Handbook[10] is used as the foundation for the engineering design process. The NASA handbook provides guidance regarding the use of quantitative evaluation matrices. Details, with respect to how UAH utilizes evaluation matrices, was shared with the CPUT CDC students, and survey data conveyed that use of the matrices were beneficial to the CPUT students when making design decisions. Details regarding the benefits and use of evaluation matrices, both at UAH and CPUT, have been previously reported[11, 12].

In order to concentrate upon the aforementioned research questions, the focus of the ALLIES partnership quickly shifted to the design and development of a STEM tool. Again, since UAH had experience in the creation of STEM tools for K-12 students, the ALLIES partners did not deviate from the previous processes employed-other than modifications required for an international effort. The UAH CDC STEM tool development steps typically employed, as well as the modifications needed for international STEM tool development, are provided in the Appendix. Thus far, 3 ALLIES STEM tools have been designed and delivered to K-12 schools- one in South Africa and two in the US. The modifications shown in the Appendix are derived from lessons learned during the design and development of the 3 STEM tools- referred to as Phase I, Phase II, and Phase III.

The STEM tool engineering design process spanned two semesters. During the first semester, the design requirements were defined, conceptual designs explored, a preliminary design developed, and a final design described in detail with manufacturing ready drawings. The second semester entailed parts procurement, fabrication, assembly, testing, and refinement of the product. A thorough Operations Manual is created, as well as teacher lesson plans and student worksheets appropriate for K-12 students. The aforementioned process has been previously described in detail[13].

Phase I STEM Tool

At the onset of the ALLIES partnership it was decided that the first STEM tool design effort should not be too complex in order to aid a successful initial collaboration. Therefore, the Phase I STEM tool was a table-top catapult. The goal of Phase I was for UAH and CPUT CDC participants to collaborate during the 2-semester design process and, ultimately, deliver the catapult to South African K-12 school. The UAH student team would fabricate the catapult in fulfillment of their CDC requirements, in which a final product is delivered to the project customer. A top level requirement for the catapult, as stipulated by CPUT, was that the STEM tool "shall be easily replicated, assembled, and disassembled." Many additional requirements were defined early in the design process by the ALLIES partners as well as potential users of the product. For example, the type of catapult was decided upon by middle school students in South Africa during a visit by CPUT faculty, staff, and students. The complete Phase I design process employed by the UAH and CPUT design team has been previously reported and, for the purposes of the present paper, will not be restated[11, 12]. However, the STEM tool development steps used during the Phase II and Phase III STEM tool design processes will be elaborated upon in subsequent sections. The final Phase I catapult STEM tool is shown in Fig. 2.

Figure 2. South African middle school students are pictured with the ALLIES catapult and teacher, L. Olyn (second row, far left), as well as two CPUT faculty members, R. Setshedi (second from right) and A. Abrahams (far right) (*photo credit: A. Abrahams*)

A major lesson learned at the completion of Phase I regarded the high cost of shipping STEM tools from the US to South Africa, or vice-versa. As a result, it was decided that future ALLIES STEM tool collaborative efforts would focus upon UAH and CPUT communication throughout the two-semester STEM tool development, UAH student teams would fabricate the STEM tool and donate it to a regional school in the US and, finally, CPUT would replicate the product for donation to K-12 schools in South Africa. This rationale formed the basis of the Phase II and Phase III STEM tool design efforts-the focus of the present paper.

Phase II STEM Tool

Due to the success of Phase I, the UAH and CPUT CDC instructors decided to increase the complexity of the Phase II STEM tool design, as well as focus on one that would be related to aerospace education. It was decided that the Phase II ALLIES STEM tool would be a table-top wind tunnel. Because of the increased complexity of the new STEM tool design, and the fact that a clear set of manufacturing and assembly plans had to be created for ease of replication, it was uncertain if these additional requirements would result in a successful outcome.

The two-semester Phase II design effort began in May 2013 and concluded in December 2013. The STEM tool development steps with ALLIES modifications, as stipulated in the Appendix, were followed as closely as possible. Eight UAH CDC students selected the ALLIES Phase II table-top wind tunnel project among 3 options. Typically, UAH STEM tool teams meet with the teacher(s) that will receive the product, at the onset of the project. However, since the goal of Phase II was to design a wind tunnel that could be easily replicated in South Africa, the UAH students initially communicated only with CPUT in order to develop the wind tunnel design requirements. A few of the top level Phase II wind tunnel requirements were as follows (each prefaced with "the wind tunnel shall"):

- rest upon a table, counter, cart, or other stable surface similar in height
- measure no more than 1.5 meters (m) long, 0.5 m wide, and 0.6 m high
- weigh no more than 23 kilograms (kg)
- be fabricated using materials, manufacturing tools, and equipment available in the US and South Africa
- allow the user to measure aerodynamic forces such as lift, drag, and/or angle of attack
- be easily assembled and disassembled by 1-2 people
- produce a wind velocity of approximately 35 kilometers per hour (kmph)-40 kmph
- operate continuously throughout an entire class period (60-80 minutes)
- incorporate warning labels with "stay out" regions, a protective cage around the fan, rubber feet for stability, and an emergency disconnect switch
- have all sharp corners covered, tightly secured parts, and a frame onto which the wind tunnel rests in order to mitigate tipping or sliding of the wind tunnel
- include an Operations Manual as well as detail design drawings and manufacturing/assembly instructions for ease of replication
- include a teacher lesson plan and student worksheet that will allow measurements to be recorded and aerodynamic properties observed and calculated

After the requirements were documented and determined to be achievable, the UAH student team identified Huntsville High School (HHS) in Huntsville, AL as the Phase II wind tunnel recipient school. Recall that at the end of Phase I it was determined that the cost to ship a STEM tool overseas was exorbitant and the ALLIES design collaboration would focus upon STEM tool designs that could be replicated in the US and South Africa. Therefore, any product built by a student team would be donated to a school within their locale. As UAH and CPUT remained in communication throughout the development of the wind tunnel, the UAH student team visited HHS and met with a 12^{th} grade physics class to inform them about the wind tunnel that would be donated to their school. CPUT did not identify a South African K-12 STEM tool recipient school as CPUT students would first build the wind tunnel after receipt of the final design drawings and manufacturing/assembly instructions.

During the two-semester design process, the UAH CDC student team interacted with CPUT regarding design progress and provided CPUT with video recordings of 3 formal design reviews during the first semester and 2 design reviews during the second semester. Additionally, CPUT received all design presentation documentation produced during the two semesters and a Final Design Report at the end of the second semester. The UAH CDC student team conducted a Product Readiness Review (PRR) toward the end of the second semester whereby the completed table-top wind tunnel was demonstrated. Approval to deliver the STEM tool to HHS was granted by the UAH CDC instructor. CPUT faculty also approved of the wind tunnel.

The UAH CDC student team met with a 12th grade physics class at HHS in order to administer a pre-demonstration survey, discuss the design process utilized to create the wind tunnel, discuss the basic theory of wind tunnel aerodynamics, demonstrate the wind tunnel, and administer a post-demonstration survey. The wind tunnel and all corresponding documentation were donated to HHS. The UAH team is shown in Fig. 3 conducting a Power Point® presentation whereby the ALLIES table-top wind tunnel and basic aerodynamics were described. A demonstration of the wind tunnel followed, as shown in Fig. 4. The results of the pre-demonstration survey and post-demonstration survey administered to the HHS students will be provided in a subsequent section of the present paper. A detailed description of the wind tunnel engineering design process employed by the UAH CDC student team has been previously reported[14, 15]. At the completion of the second semester, CPUT received a Final Report that provided a complete engineering description of the Phase II wind tunnel as well as detail drawings, manufacturing plans, assembly instructions, and a thorough Operations Manual.

Figure 3. Six of the eight UAH CDC student team members discuss the ALLIES Phase II wind tunnel STEM tool, as well as wind tunnel and aerodynamic theory, with HHS students (*photo credit: C. Carmen*)

Figure 4. Five members of the UAH CDC student team demonstrate the table-top wind tunnel to the HHS students (*photo credit: C. Carmen*)

Phase III STEM Tool

Due to the successful design, development, and delivery of the Phase II table-top wind tunnel and donation to HHS, as well as the provision of detailed replication plans to CPUT, another ALLIES table-top wind tunnel project began in May 2014. Similar to the Phase II effort, the 8 process steps outlined in the Appendix were followed during Phase III. However, CPUT determined that the manufacturing and assembly complexity associated with the Phase II wind tunnel was still too great to allow for ease of replication by CPUT students. Additionally, both CDC instructors agreed to require that the Phase III wind tunnel allow for visual observation of the flow streamlines over the wind tunnel test articles. Some of the top level Phase III wind tunnel requirements were defined as follows (each prefaced with “the wind tunnel shall”):

- not exceed 1.25 meters in length, 0.6 meters in width and 0.6 meters in height
- have a mass/weight less than or equal to 23 kilograms
- demonstrate visual flow across a test article
- have an adjustable angle of attack during demonstration
- be able to operate continuously throughout an entire class period (60-80 minutes)
- have all materials and parts available in Cape Town, South Africa
- have sharp corners covered
- be disassembled into four pieces (bell mouth/nozzle, test section, fan, humidifier)

As occurred during Phase II, the UAH and CPUT partners maintained close communication during the two semester design effort to ensure that the STEM tool design could be replicated in South Africa. The partners frequently utilized Skype® to conduct online video meetings, as shown in Fig. 5. Since the final Phase III wind tunnel would be donated to a K-12 school in the US, the UAH team identified St. John’s Middle School (SJMS) in Madison, AL as the recipient in order to also keep them apprised of the design and ensure the product would meet curriculum requirements. CPUT did not identify a recipient school as CPUT students would first build the wind tunnel when the final design drawings and manufacturing/assembly instructions would be received from UAH. The 2-semester Phase III design process proceeded in a similar manner as Phase II, whereby the UAH CDC student team provided CPUT with video recordings of 3 design reviews during the first semester and 2 design reviews during the second semester, and CPUT received all design presentation documentation, as well as a Final Design Report at the end of the second semester.

Figure 5. A Skype® screenshot showing the CPUT representative (far left) and the UAH CDC Phase III STEM tool design team during an online meeting (*photo credit: A. Bryant*)

The completed Phase III wind tunnel is shown in Fig. 6. On the far left is a black container that houses the misting devices which, in turn, produce visible streamlines within the test section. As shown in Fig. 6 and Fig. 7, the test article is a round sphere and the air flows from left to right over the test article. Upstream of the test article, the streamlines are laminar and continue to be as they initially progress over the test article. However, at some point the flow separates, becomes turbulent, and the streamlines no longer maintain a laminar state over the test article.

Toward the end of the design effort, in November 2014, the UAH Phase III design team visited an 8th grade science class at SJMS in order to administer a pre-demonstration survey, provide a Power Point® presentation detailing the design process and basic aerodynamic theory, demonstrate the wind tunnel, and administer a post-demonstration survey. The University team is shown demonstrating the wind tunnel to the middle school students in Fig. 8.

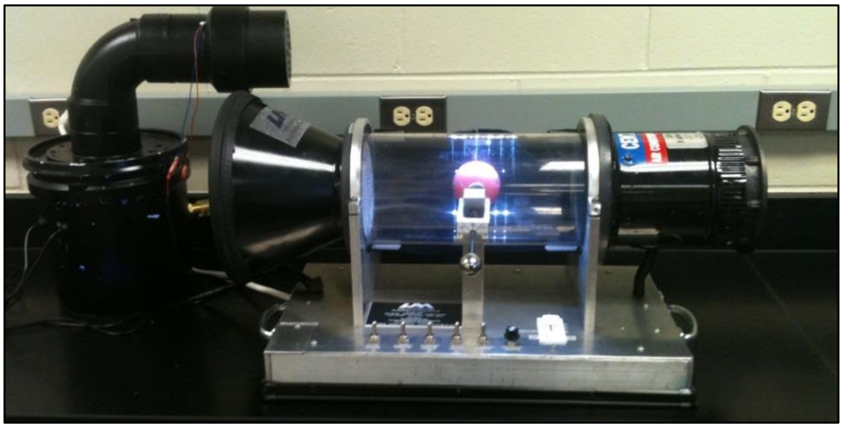

Figure 6. The Phase III ALLIES table-top wind tunnel displaying visible streamlines over a spherical test article (*photo credit: C. Carmen*)

Figure 7. Test section of the Phase III wind tunnel showing visible laminar streamlines upstream (left) of the spherical test article and turbulent flow downstream (right) of the test article (*photo credit: C. Carmen*)

Figure 8. UAH student team demonstrating the Phase III wind tunnel (*photo credit: C. Carmen*)

An important aspect of the Phase III STEM tool effort was the creation of a teacher lesson plan for the 8th grade science teacher. The lesson plan included basic fluid flow information appropriate for middle school students in both the US and South Africa. An example of a graphic within the lesson plan is shown in Fig. 9, and demonstrates the difference between laminar flow and turbulent flow. The two different types of flows can be viewed within the wind tunnel by varying the speed of the wind tunnel fan over the test article or changing the test article. Additionally, the 8th grade teacher was provided with student worksheets such that students could record observations of various test articles within the wind tunnel.

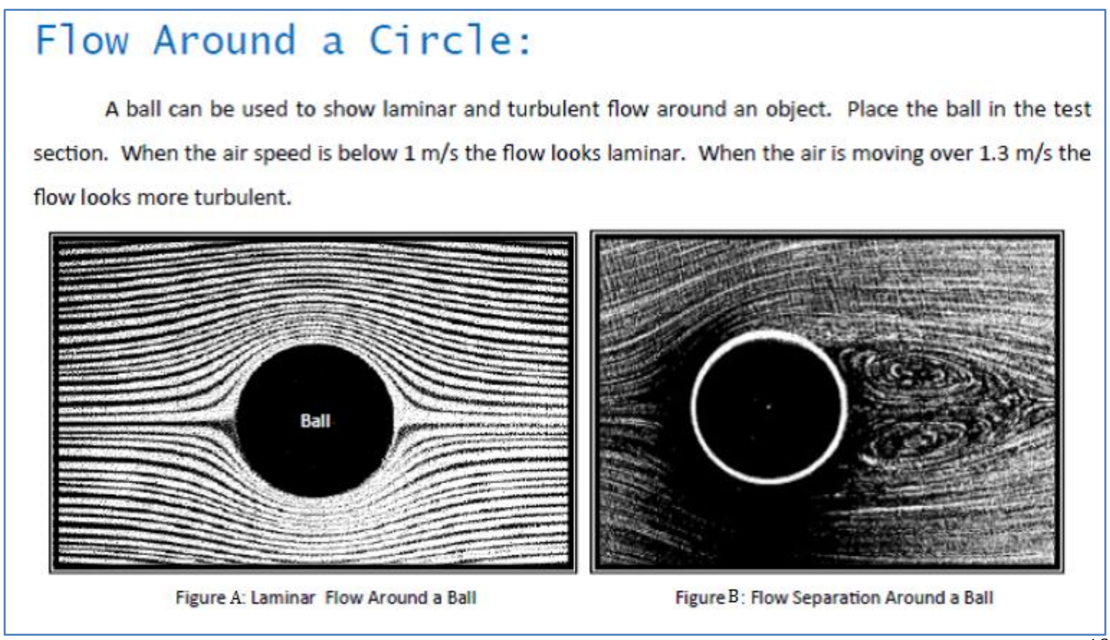

Figure 9. Sample graphic within the Phase III wind tunnel K-12 teacher lesson plan[16]

Survey Results

In order to assess the learning outcome of the Phase II and Phase III wind tunnels on the US K-12 students, pre-demonstration surveys and post-demonstration surveys were administered by the UAH student teams upon delivery of each wind tunnel. Note that similar surveys will be administered to South African K-12 students upon completion of the wind tunnels by CPUT CDC students and staff.

The UAH student team demonstrated and donated the Phase II wind tunnel to a 12th grade physics class at HHS. The HHS class included twenty 12th grade students and one 11th grade student. Seventeen of the HHS students were male and 4 were female. Two of the HHS students were 18 years of age and the rest were 17 years old. A "Pre-Demonstration" survey was administered to the high school students at the start of the classroom visit. The UAH students then discussed basic aerodynamics, wind tunnel specifics, the design process, and subsequently demonstrated the wind tunnel. Finally, a "Post-Demonstration" survey (identical to the Pre-Demonstration survey) was administered. Each survey question required a response based upon a 1 to 5 scale (1=No/Not at all, 2=Very little, 3=Somewhat, 4=Fairly well, 5=Yes/Very much.)

One survey question inquired whether the HHS students had basic knowledge regarding wind tunnels. As shown in the pre-demonstration results in Figure 10, only 2 of the 21 high school students responded that they knew what a wind tunnel was and how it operates. After the presentation and wind tunnel demonstration, 14 students responded "Yes/Very much" in regard to their knowledge of a wind tunnel. The average score increased from a pre-demonstration average of 3.19 to 4.62, post-demonstration. This represents a 44.78% increase in knowledge regarding the purpose of wind tunnels.

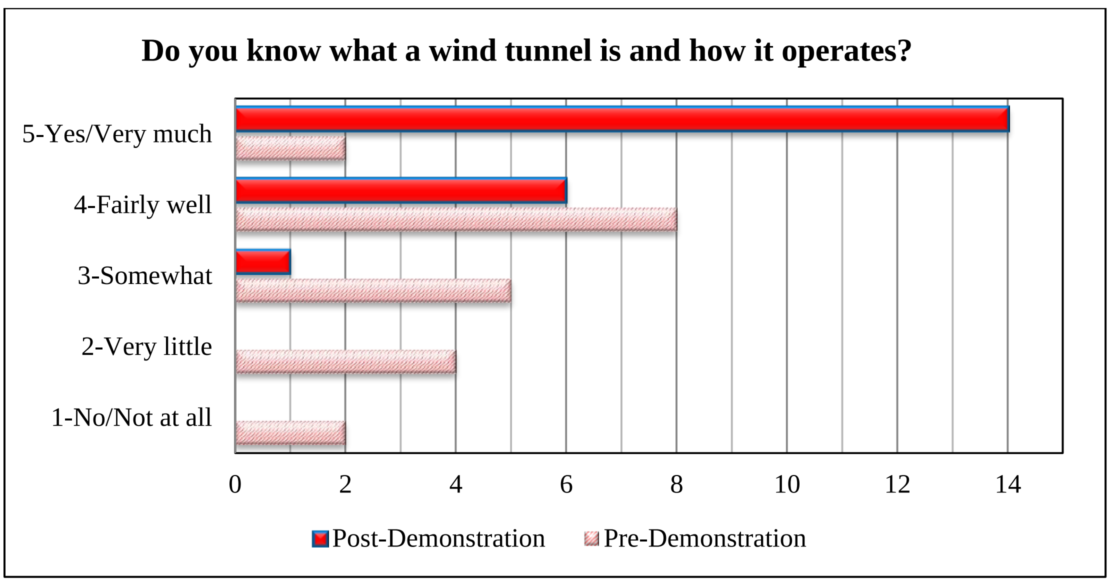

Figure 10: Phase II wind tunnel HHS survey results regarding students' knowledge of wind tunnels

Another survey question inquired whether the HHS students knew what types of items can be tested in a wind tunnel. As shown in Figure 11, the pre-demonstration results show that only 1

HHS student stated "Yes/Very much." After the presentation and wind tunnel demonstration, 13 students responded "Yes/Very much." The average pre-demonstration score of 2.67 increased to a post-demonstration average of 4.48, representing an increase of 67.86% in knowledge regarding wind tunnel test articles.

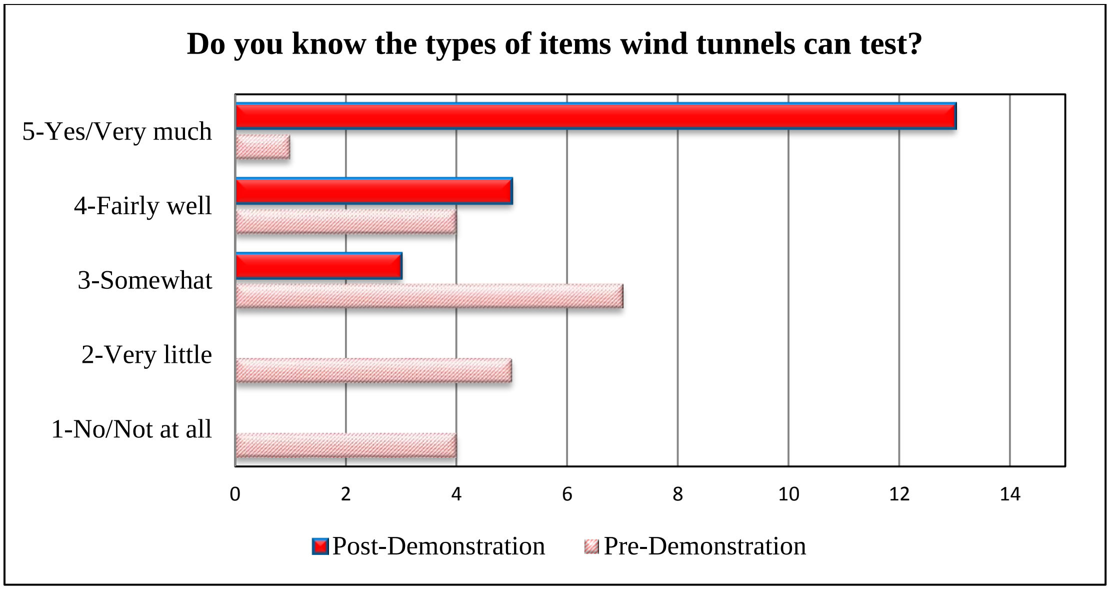

Figure 11: Phase II wind tunnel HHS survey results regarding students' knowledge of wind tunnel test articles

In November 2014, the UAH CDC student team demonstrated and delivered the Phase III wind tunnel to an 8th grade science class at SJMS. Prior to any discussion of the wind tunnel, the team administered a pre-demonstration survey that inquired about the student's knowledge of wind tunnels and other basic technical questions. The survey was completed by 19 students within the science class and the results of two survey questions are provided. The first survey result regards the middle school students' knowledge of the purpose of a wind tunnel. As shown in Fig. 12, only 2 of the 19 students knew the purpose of a wind tunnel. However, after the discussion and demonstration of the wind tunnel, 15 of the 19 students responded that they knew the purpose of a wind tunnel. The average pre-demonstration score was 2.68, with a jump to 4.68, post-demonstration. The wind tunnel presentation and demonstration accounted for an increase of 74.51% regarding the middle school students' knowledge of the purpose of wind tunnels.

A second survey question inquired whether the middle school students understood the difference between laminar flow and turbulent flow. As shown in Fig. 13, thirteen of the students indicated that they had no knowledge, or very little knowledge, regarding the difference between laminar and turbulent flow. However, after the UAH student team discussion and demonstration of the wind tunnel, 16 of the 19 middle school students stated that they understood the difference. This represents an increase in the average pre-demonstration score of 1.95 to a post-demonstration average of 3.95-a significant increase of 102.7%. The laminar/turbulent flow discussion included content from the teacher lesson plan created by the UAH student team as well as a wind tunnel demonstration showing laminar flow transitioning to turbulent flow via an increase in the wind tunnel airflow velocity.

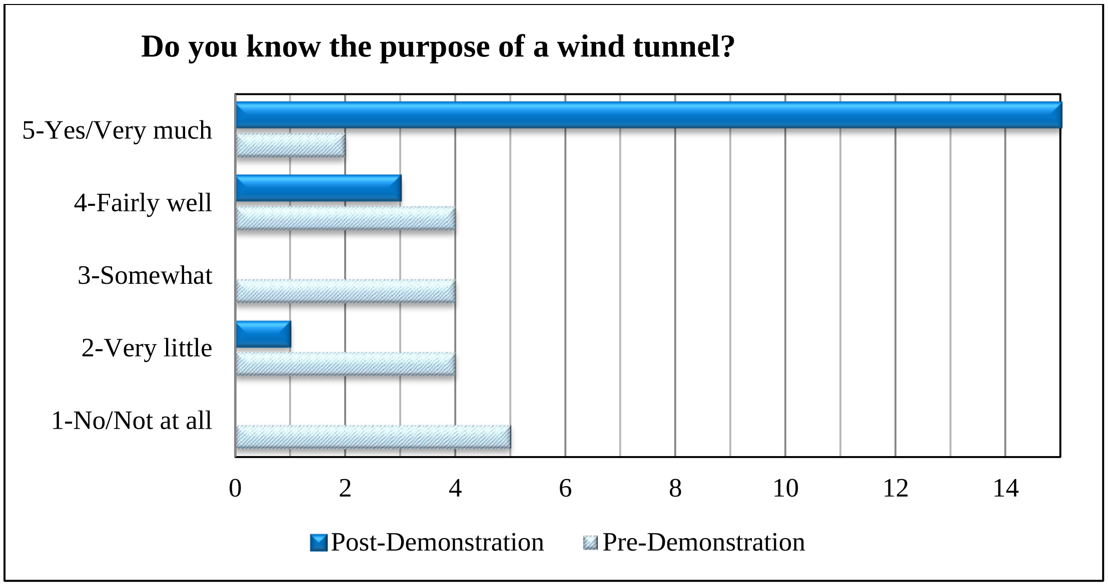

Figure 12. Phase III wind tunnel SJMS survey results regarding students' knowledge of wind tunnels

The educational impact of the wind tunnels upon US middle school and high school students was clear and significant. With respect to the impact upon South African K-12 students, the results are pending the completion of a wind tunnel and subsequent delivery to a regional school.

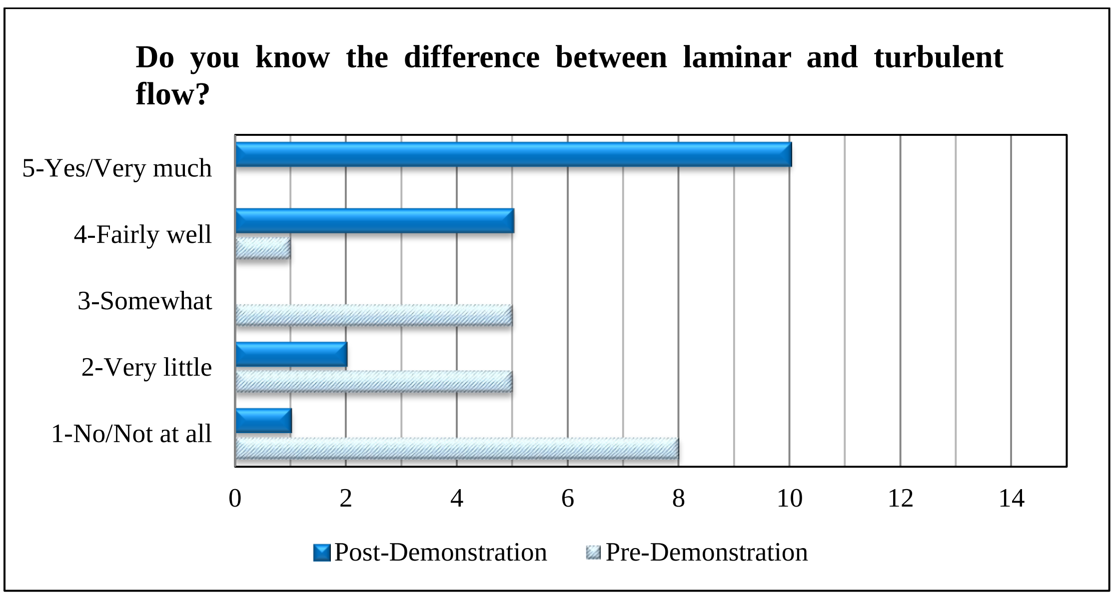

Figure 13. Phase III wind tunnel SJMS survey results regarding students' knowledge of laminar and turbulent flow

Engineering Student Team Assessment

At the conclusion of the Phase II and Phase III design efforts, UAH student team members were each administered a confidential survey regarding their ALLIES project experiences. The results of 6 survey questions are provided in Table 1. Note that the Phase II team consisted of 6 UAH

MAE students and the Phase III team consisted of 5 MAE students. Each student team had one female member.

According to the survey results, 5 of the 11 student team members considered work on an international engineering design project to be very important, 5 considered it somewhat important, and 1 student was neutral about the importance. However, as indicated by the results of the second question, all 11 students felt that it was somewhat or very likely that they would be working with an engineer or engineering team from another nation when in the engineering workforce. It is interesting to note that only 1 of the 11 UAH students had ever worked on an international engineering project prior to working on an ALLIES STEM tool project. Additionally, each student team member selected the ALLIES project as their first choice among other project options – another indication of their interest in working with partners from another nation. When the students were asked if working on an ALLIES project prepared them to be a better engineer, 3 students replied “yes/very much” and 8 replied “somewhat.” All 11 students believed that the ALLIES STEM tool would motivate South African K-12 students to pursue a STEM education. Additionally, all students believed that the STEM tool could be replicated in South Africa. The final survey result indicated that all 11 student team members felt a personal satisfaction knowing that the STEM tool may inspire K-12 students in South Africa to pursue a STEM education-7 replied “yes/very much” while 4 replied “somewhat.”

Table 1. UAH Phase II and Phase III engineering student survey results

Question	1 No	2 Very Little	3 Neutral	4 Somewhat	5 Yes	Average Score	Standard Deviation
1. Do you think it is important for US engineering students to work on international engineering design projects?	0	0	1	5	5	4.36	2.59
2. Do you think that as a professional engineer you may have to work with engineering professionals and teams from other nations?	0	0	0	4	7	4.64	3.19
3. Have you ever worked on an international design project before?	10	0	0	0	1	1.36	4.38
4. Do you feel that working on the ALLIES project has prepared you to be better engineer?	0	0	0	8	3	4.27	3.49
5. Do you think the ALLIES STEM tool will help South African K-12 students become motivated to pursue a STEM education?	0	0	0	7	4	4.36	3.19
6. Do you think your ALLIES STEM tool can be replicated in South Africa and distributed to additional K-12 schools?	0	0	0	3	8	4.73	3.49
7. Do you have any personal satisfaction knowing that your STEM tool may inspire South African K-12 students to pursue a STEM education?	0	0	0	4	7	4.64	3.19

The UAH students provided written answers elaborating on their Question #4 survey response, and the comments are as follows:

- “Improved communication skills” (Phase II)
- “It exposes you to working on a tight schedule, using conversions, and requires strong written communications” (Phase II)
- “Because of the teamwork necessary” (Phase II)
- “Helped for real life experiences” (Phase II)
- “Yes, the process reinforced a rigid design schedule/process” (Phase III)
- “Teamwork” (Phase III)
- “Requires good communication, which leads to good team dynamics” (Phase III)
- “New experiences” (Phase III)
- “It has helped with understanding design” (Phase III)

An open-ended question posed to the UAH students queried them about the most difficult aspect of working on the ALLIES project. The replies are as follows:

- “Communication with South Africa was difficult” (Phase II)
- “Lack of email response from teachers” (Phase II)
- “Gaining customer input to complete project” (Phase II)
- “Time to get everything done” (Phase II)
- “No communication from South African team” (Phase II)
- “Feedback from customers” (Phase II)
- “The accelerated time frame for accomplishing the project goals” (Phase III)
- “Time management” (Phase III)
- “Redesigning” (Phase III)
- “Time and schedule difference between teams” (Phase III)

Conclusions

Thus far, the ALLIES partnership has resulted in 3 STEM tools and has provided engineering design students at UAH and CPUT the opportunity to collaborate on the development of products that are subsequently donated to K-12 classrooms in the US and South Africa. The partnership initially intended for the jointly designed STEM tools to be built by the UAH students within a CDC that focuses upon the design, fabrication, and delivery of a fully operational product that meets customer requirements. However, certain issues and successes associated with the Phase I catapult STEM tool project changed the scope of the Phase II and Phase III efforts. Specifically, Phase I confirmed that international shipping costs of the STEM tool were too high and, as a result, the ALLIES collaboration shifted focus to the collaborative design of STEM tools to be donated to K-12 schools in the US, but can be replicated in South Africa. The Phase I catapult was eventually donated to a school in South Africa and maintains a fully operational status. The inaugural ALLIES effort proved to generate excitement among the UAH and CPUT students as well as provided South African middle school students with a hands-on tool to reinforce classroom lectures.

Due to a significant amount of space related research efforts at UAH and CPUT, the Phase II and III STEM tools were intended to stimulate interest in aerospace related topics. Thus, the subsequent two STEM tools were both table-top wind tunnels. The UAH students continuously communicated with CPUT throughout both two-semester design efforts. The most frequent collaboration occurred during the requirements development phases. Due to the shift in focus after Phase I-from a STEM tool shipped to South Africa to one that can be replicated in South Africa-it was critical that both wind tunnels were designed using parts, materials, manufacturing and assembly methods, and tools that are readily available in South Africa. Upon completion of Phases II and III, the wind tunnels were delivered to HHS and SJMS, respectively. Surveys completed by the high school and middle school students indicated a positive learning impact. Initially, less than 10% of the high school students and 9% of the middle school students understood the intent and purpose of a wind tunnel. After the wind tunnel was discussed and demonstrated, 100% of the students indicated that they had, at a minimum, some understanding and knowledge of the purpose of a wind tunnel. The Phase III wind tunnel, which allowed for visible airflow streamlines to be observed, enabled the middle school students to understand the difference between laminar flow and turbulent flow. Eight of the 19 middle school students, or 42%, had no prior understanding of laminar versus turbulent flow. After the discussion and demonstration of the wind tunnel, only one student indicated that he/she still did not understand the difference between the two types of flow.

International collaboration in the development of products has proven beneficial to UAH students as well as to the efforts of CPUT to promote STEM education in South Africa. CPUT students and faculty successfully involved a middle school in the requirements development of the table-top catapult, and conveyed those requirements to UAH such that the final product included the design elements specified by the middle school students and teacher. CPUT was also closely involved in the development of the Phase II and III wind tunnels. UAH students appreciated the opportunity to work on an international design project as well as a garnered a sense of satisfaction knowing that the wind tunnels could positively impact K-12 students in South Africa. Only one UAH student had ever been exposed to an international project prior to the ALLIES project, while 100% believed that it was important to do so and believed they would be required to work with engineers from another nation during their engineering careers. The primary issue encountered by the UAH students regarded difficulty communicating with the CPUT representatives. However, this was a minor matter compared to the positive benefits gained by the UAH students.

Future ALLIES work will entail the dissemination of results regarding ongoing efforts by CPUT to monitor the use of the catapult in the South African middle school, with an assessment of the educational impact of the catapult. Additionally, CPUT has attempted to replicate the Phase II and III wind tunnels, with limited success. To address this issue, Phase IV, which has recently been initiated, will focus upon the fabrication and assembly of a wind tunnel that can be completed in 20 minutes or less. The goal is to build a wind tunnel using parts and materials readily available in most parts of the world, and will require simple tools to assemble. Additionally, a future collaboration between UAH and CPUT students will focus upon the synchronous fabrication of a wind tunnel-as opposed to delayed fabrication of the Phase II and Phase III wind tunnels by CPUT. A synchronous effort will eliminate difficulties associated with the inability to communicate with UAH students, who typically graduate after the second semester of the CDC.

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Appendix

Table A. Typical UAH STEM tool development steps and modifications needed for an ALLIES international STEM tool project

UAH CDC STEM Tool Development Steps	ALLIES STEM Tool Development Step Modifications
1. CDC representative (i.e. instructor, CDC student, or STEM tool project stakeholder) identifies and contacts a K-12 school or science center interested in receiving a donated STEM tool for use within the school or center	*CPUT may identify a K-12 STEM tool recipient school*
2. CDC representative communicates with the school teacher(s) or science center representative(s)-also known as the project customer(s)-regarding the desired STEM tool requirements or provide customer(s) with options	*CDC representative also communicates with CPUT regarding desired STEM tools*
3. CDC student team selects the STEM tool project among other options (note: typically UAH CDC student teams are comprised of 4-7 students)	*CDC student team members understand additional ALLIES project requirements*
4. CDC student team commences communication with the project customer in order to clarify and refine requirements	*CDC student team also incorporates CPUT design requirements*
5. CDC student team meets with potential users of the product (K-12 students or science center visitors) in order to introduce the CDC student team and conduct a market survey (i.e. query potential users about the STEM tool in order to integrate specific product suggestions and requests)	*CPUT stakeholders (instructors, students, staff) visit South African K-12 STEM tool classroom in order engage teachers and students in the design of STEM tool*
6. CDC student teams proceed through the 2-semester CDC process whereby 5 design reviews are conducted-often with project sponsors and customers in attendance	*CDC student team communicates with CPUT during the 2-semester design process and records the 5 design reviews for viewing by CPUT in order to receive feedback*
7. Final design review-the Product Readiness Review (PRR)-is conducted during the last few weeks of the second semester in order for the customer to view, provide feedback, and approve the STEM tool prior to delivery and demonstration (if possible) of the STEM tool at the recipient K-12 school or science center	*CDC student team provides CPUT with documentation and a video recording of the PRR in order to receive feedback*
8. CDC student team delivers the STEM tool to the K-12 school or science center whereby the team administers a "pre-survey," discusses and demonstrates the STEM tool, and administers a "post-survey"	*UAH delivers STEM tool to South Africa or provides CPUT with detail drawings and instructions for STEM tool duplication*