CHALLENGES FOR A NEW GENERATION OF STEM STUDENTS

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ABSTRACT

STEM competitions are fairly widespread in middle schools and high schools, but do not commonly occur at the university level. We have developed a repeatable model for a one-day competition in which high school, community college and university students can build confidence in their own critical thinking abilities and develop enthusiasm for careers in science, technology, engineering and mathematics. The competitions are used to build confidence and excitement in students and to encourage them to consider choosing a STEM degree.

KEYWORDS

Competition, Challenge, Confidence, STEM

1. INTRODUCTION

The United States is not producing enough STEM (science, technology, engineering and mathematics) graduates to fill available jobs. According to the Office of the Chief Economist of the United States, STEM occupations have grown at a rate of 24.4% in the last ten years while non-STEM occupations have grown 4.0% [Noonan 2017]. STEM occupations are projected to continue growing in the future. Brian Kelly, editor of U.S. News & World Report states that "we need to focus our efforts on getting more kids, particularly women and African-Americans interested in pursuing STEM at a young age" [Laros 2016].

Fostering positive learning environments can increase student concentration and focus and contribute to student success in STEM. Self-efficacy ultimately determines if students overcome challenges that arise to persist in STEM, or resign [Hackett 1989]. Generally, if individuals participate in "manipulating, assembling, disassembling, constructing, modifying, and breaking and repairing components and devices," their confidence increases [Baker 2007]. Providing hands-on interactive experiences for students in STEM can potentially increase self-efficacy.

We have developed a STEM Challenge for high school, community college and university students in which students are given the opportunity to follow instructions, make decisions, and work with a team. The Challenge is an extra-curricular activity in which students are given several opportunities to find solutions to various problems without the pressure of being graded on their performance. In a fun and non-threatening atmosphere, students participate in problem-solving activities that help to develop critical thinking and technical skills.

The format of the STEM Challenge has changed significantly since its inception with input from student participants, student mentors, industry advisors, and faculty advisors. In this paper, we will discuss each challenge, then we will lay out the logistics for setting up a STEM Challenge. Finally, we will discuss the outcomes that we have met to date.

2. PROGRESSION OF THE CHALLENGE

As part of a computer science recruiting and retention grant from the state of Texas, our university, in partnership with a community college and representatives from local industries, instituted a Programming Challenge in 2008 as a pilot recruitment tool. Eleven teams with 34 contestants participated in the competition at two levels. Winners and participants won decent prizes including scholarships, internships and various gifts. Follow-up feedback indicated that 92% of the participants evaluated the Challenge as very good or excellent. This Challenge was successful in the intended mission: from the students who participated, 7 enrolled in STEM programs within the first year [Davari 2007].

This idea was further developed and became part of a major STEM grant proposal submitted to NSF which was funded in 2013. The 5-year NSF STEP grant was for a project with several STEM related activities that included a yearly STEM Challenge as one of the activities, with the main goal of recruiting and retaining students in STEM fields [Davari 2016].

Winners of the challenge receive scholarships to the university ranging from $250 to $500 funded by the grant. In addition to scholarships, winners receive internships and prizes. A raffle draw provides other participants with prizes ranging from restaurant gift cards to solid-state drives. Each participant also receives a t-shirt.

2.1 Robotics Challenge 2014

The topic for the very first STEM Challenge was robotics. Faculty in the computing and mathematics divisions decided on this topic as an interesting and stimulating way to introduce computing to students.

The challenge consisted of two levels of competition - beginner and advanced robotics programmers. Due to the cost of equipment, the challenge was limited to 15 teams, with a maximum of four members per team. Students who did not have any robotics experience were added to the beginner category. If any team member was a junior or above in college or they had any robotics experience, they were designated to the advanced category.

Since this was a robotics challenge, students without any robotics experience needed assistance to understand how Arduinos and robotics operated. Two weeks before the competition a three hour, hands-on ‘Tech Friday’ was presented to anyone who wanted to attend. This presentation was also videotaped and posted on the project website with access to all.

During the challenge, each team spent 50 minutes at one robotics station, trying to complete up to 4 different tasks, before rotating to the second and third station. Each task was assigned a point value, and tasks had to be completed in a particular order and demonstrated before receiving instructions for the next task. Each subsequent task became more challenging.

The Morse Code station had students representing Morse code using the LEDs on the Arduino boards. The first challenge was to create a sequence of characters in Morse code using a LED. Each team was assigned to code the letters A, B, C, D, and E. For example, A is dot followed by dash, where the dot is represented by a ¼ second (or 250 millisecond) light and the dash is represented by a ¾ second (or 750 millisecond) light. The two are separated by a ¼ second interval of no light. There should be a ¾ second delay until the next letter. The next challenge in that station required the team to create the string “UHCL SJCD NSF” using Morse code and the LED. The final challenge in the station was to create a script that would turn a Bluetooth command into Morse code. The phrase was given at the time of judging.

The Sensor station required students to work with different sensors and complete tasks. For example, one task was to set up a LED to begin blinking if a fire was detected, with the fire sensor calibrated to work for a bright light. Another challenge required the teams to read the temperature using the DHT11 temperature sensor and display it in Celsius on the LCD screen.

The Tank station required the teams to move a tank, starting with just left, right, forward and backwards, and the final task having to get the tank to move through an obstacle course.

Participants ranged from 7^{th} graders to college seniors. The registration closed very quickly, and many students and teams were turned away. Fifteen teams with 51 contestants participated in the competition with 8 beginner teams and 7 advanced teams.

2.2 STEM Challenge in 2015

At the external advisory board meeting for the NSF grant, several board members expressed concern that robotics only encompassed a very small portion of computing. They recommended that the challenge be more generic. Therefore, the theme of the next challenge was STEM as a whole.

Over 8 different high schools and 6 different community colleges and universities were represented in the challenge. The challenge consisted of two levels of competition. The event was limited to 18 teams. Twelve beginner teams and 6 advanced teams participated in the event.

Each team rotated through three stations: Game of Clues to challenge their math knowledge, Creative Inventors to showcase their imaginative skills and Robot Adventure to test their problem-solving and programming skills.

The Game of Clues station showcased different ciphers with increasing degrees of difficulty. The first cipher was very simple, with A=1, B=2, … , Y=25, Z=26. A phrase was given to the teams where the words in the phrase were in order, but, the letters were jumbled. The teams had to translate, unscramble and produce the phrase. The second cipher was more complex, where a coded message had to be translated using a formula incorporating modulus functionality. Another challenge used the Playfair Cipher. Yet another challenge was a Numbrix puzzle.

The Creative Inventors station required the teams to create things. The first challenge required the team to build a free standing structure 3 levels tall, using only the notecards that were provided, while not talking to each other, using only one hand and not folding, bending, or tearing the cards. The second challenge built on top of the first one, where the structure now needed to be 4 stories tall, and also needed to hold the weight of a dinosaur that was given to them. Another puzzle was to figure out how four people crossed a bridge within an allocated time, with different constraints given. Another puzzle was, if 8 balls were given, with 7 of them the same weight, while one was slightly heavier, how to figure out the ball that is heavier by using a balance only two times.

The Robot Adventure station required students to use the programming language Python to program a Turtlebot. The first challenge was to modify the code to create a turtle. The second challenge required the teams to move the turtle manually using the arrow keys. The next challenge was to teach the turtle to play golf. The turtle needed to move behind a ball in such a way that it was in-line with the ball and the hole and facing the ball. For the next challenge, the turtle needed to push the ball into the hole. For the final challenge the turtle graduated to a professional player and needed to play 9 holes of golf.

2.3 STEM Challenge in 2016

The previous year’s idea of making the challenge more generic was received well. We continued on this theme but expanded the challenge to accommodate more participants. Twenty-one teams (13 beginner teams and 8 advanced teams) registered for the event.

In 2016, instead of a station comprising several small challenges, the Creative Inventors challenge comprised of one challenge. Teams had 35 minutes to use the provided materials to construct the tallest free standing structure within the allocated time.

The Software Design challenge had different challenges for the two levels of competition. The beginner levels played an open-source game, where they had to make their way through the levels of the game by coding and gathering gems. The goal was to get through as many levels as possible in the allotted time. The advanced levels, on the other hand, had to play a text-based game named Python Warrior. They played as a warrior that is trying to find his way out of a tower. Each floor has a map. On each floor, the warrior’s objective was to find the staircase leading to the next floor. The game automatically awarded points depending on the actions.

The Engineering Design challenge required participants to use the provided materials to construct the most effective parachute. The parachute needed to carry all of the provided marbles when dropped from the third floor. The parachute designed was required to slow the descent of the marbles as much as possible. Points were assigned according to the time the parachute took to land, with the longest time to descend earning the maximum amount of 40 points, and the next slowest receiving 3 points less, and so on.

Between each of these challenges, a 5-minute fun math challenge was added to break up the stress of the competition. One such challenge was to complete the Towers of Hanoi from the leftmost peg to the rightmost peg, where the team members stood behind a mark, and one team member moved ONE disk and returned to the back of the line, before the next team member got his/her turn. Another math challenge was a logic and deductive reasoning grid puzzle. The third math challenge was to decode an encoded message.

2.4 STEM Challenge in 2017

In 2017, we had the biggest turn out yet, with 29 teams (19 beginner teams and 10 advanced teams) and 111 students.

The stations comprised of a Math station, Engineering Design station and a Software Design station. This was the first challenge where all the challenges in a station were given to the teams, and the teams got to choose which challenges to attempt, and in which order. The challenges had different scoring values. At the end of the allocated time, the teams returned their packets.

In the Math station, teams were given a packet with 11 challenges. One of the challenges was to solve a given puzzle to find which letter corresponded to which number. The puzzle was G T O M + P N A G = E G O A T, where G=5, A represents an odd digit and 6 and 4 are not used. Another puzzle was to figure out how many squares were there on a checkerboard, based on a picture of it. Another challenge was to figure out how many ways to make change for 50 cents, using nickels, dimes and quarters. Some of these were very easy, while some needed a lot of reasoning. This was done purposely to make sure that the teams felt a sense of accomplishment.

In the Software Design station, the teams were provided with a Challenge List. It listed all the challenges, their IDs, and their score value. The teams chose which challenges to attempt and the order in which they attempted them. They were allowed to program in either C++, JAVA or Python. The challenges were auto-tested and their scores were updated with the points. All the team scores were displayed live on a large screen, so that they were aware of their status. On the screen, each team was represented by its own avatar. Some of the easy challenges were to find the average and the median. Some more complex challenges were to find the least common denominator, to find if a number is a prime number and to find the convert second to time.

In the Engineering Design station, each team was provided with $500 worth of paper money and an egg. Their goal was to design a system that will carry an egg from the third floor to the ground floor without breaking it, while spending the least amount of money for materials. The team that designed a system that carried an egg from the third floor to the ground floor without breaking it in the allotted time, while spending the least amount of money for materials received full points with each consecutive team with the least amount of spending receiving 2 points less.

3. EVALUATION

A mixed methods approach was used by an external evaluator to collect both quantitative and qualitative data through the distribution of both pre- and post-surveys, and open-ended questions. Using a Likert scale, surveys gauged student interest in STEM (and more specifically technology) prior to and following immersion in each Challenge. As well, student participants of the STEM Challenges were requested to provide candid feedback in response to open-ended survey questions. The data collected by the external evaluator was analyzed and disseminated to UHCL administrators to improve future student STEM Challenges. The narrative that follows provides a brief synopsis of the most compelling data collected during these Challenges.

Participants of the Robotics Challenge were queried about their natural inclination to learn technology. Fifteen students submitted both pre- and post-surveys. No qualitative data was collected. The pre-survey indicated that only 40% of students felt they possessed an “extremely high ability.” However, data yielded from the post-survey, immediately following the intervention, indicated that 67% felt their technological aptitude was “extremely high.” In addition, students were prompted to provide feedback relating to their interest in robotics both before and after the intervention. The pre-survey indicated 40% of students were “extremely interested” in robotics, while post-survey data revealed that 50% felt their participation in Tech

Friday increased their interest in robotics. While 10% is somewhat incremental, it does suggest an impactful intervention.

Analogous to the Robotics Challenge, the STEM Challenges facilitated between 2015 and 2017 allowed for data collection from students before and immediately following participation. Exactly 74 students participated in the pre-survey, while 95 students submitted responses to the post-survey. A limitation to this data collection was the ability to distribute pre-surveys prior to the event (hence the variation in responses), due to participant arrival times and other logistics. Nonetheless, the data captured suggested a successful intervention. Prior to the STEM Challenges, nearly 35% of students suggested their technological ability was "extremely high." Subsequent to the STEM Challenges, 44% of students responded that their technological capabilities were "extremely high," a notable increase. In addition, the pre-survey requested that students gauge their knowledge relating to careers in STEM fields. A mere 14% responded that they were "extremely knowledgeable." However, 25% more students suggested they were "extremely knowledgeable" about careers in STEM fields in response to the post-survey. As well, students confirmed their interest in STEM was strengthened as a result of their participation in this event. Approximately 43% of students inferred their interest in STEM was moderate, prior to the intervention. More than 55% of students responding to the post-survey "strongly agreed" that their interest was strengthened because of their participation in the STEM Challenge.

Qualitative data was also collected from student participants at the conclusion of each STEM Challenge. Open-ended questions prompted students to offer feedback, and suggestions for future improvements. Initially, students were asked, "What did you like most about the STEM Challenge?" A sample of these responses is detailed below.

- "I like the cooperation the Challenge requires to solve problems."
- "I learned about the skills I have, and what I need to improve."
- "Fun, challenging, helps you in a fun way to see what your strengths and weaknesses are."

Student participants were also requested to provide feedback on what they would change about the STEM Challenge. A sample of their responses are outlined below.

- "Actual live science problems and questions, some anatomy, chemistry, physics."
- "I think it was great. With the programming, I think it would be helpful to see some feedback while programming."
- "Include more physics."

The final question of the post-survey urged students to offer any additional information or recommendations for program administrators. A sample of their responses are provided below.

- "Please keep doing the STEM Challenge every year."
- "I had great fun today!"
- "Good event, overall really fun."

Conclusively, the data collected between 2014-2017 infers that student self-efficacy was strengthened as a result of participation in these experiential events conducted by UHCL. Students with minimal exposure to technology received hands-on experience, networking opportunities, and support from their peers and faculty. As a result, STEM Challenges have become wildly popular not only at UHCL, but throughout the larger Houston academic community.

4. OUTCOMES

The event has progressively grown over the years. Through the four challenges, we had a total of 293 students participate in the event. Twenty-three student mentors and research assistants participated in the organization and facilitation of the event over the years. Sixty-eight faculty, alumni, industry advisors participated in various capacities, such as judging and advising.

Overall, student participants have been very happy to attend the challenge. Pre- and post-surveys are given and Table 1 shows some of the student comments on the open-ended survey questions on the post-survey.

Table 1. Open-ended Student Survey Answers

It made me realize that I am good with technology (2014)
I loved solving the logic and math based problems. The cryptologic questions were well made and challenging (2015)
I would've liked to have a different language than Python to code (2015)
I loved and really enjoyed the Python game from code combat, it was utterly the fastest way I have been introduced to a program language (2016)
I liked everything. The activity was fun and I learned a lot about robots (2014)
The event was amazing and I really cannot name anything that was worth changing. (2016)
I learned about the skills I have to work to improve (2017)
The challenge taught me to think outside of the box and learn to communicate my opinion without worry (2016)
Fun, challenging, helps you in a fun way to see what some strengths and weaknesses are (2017)
It was a lot of fun and the challenges had a great mix of problem solving and technical ability (2015)
I thought I wouldn't be able to understand robotics, because I don't have experience. The staff was really nice though and helped me and my team (2014)
Very fun! Will come back again and win (2015)
I think it was great. With the programming, I think it would be helpful to see some feedback while programming (2017)

Throughout the four years, 24 internships were offered to participants of the STEM challenge. Nineteen students utilized this opportunity. When asked for feedback, one employer said "…extremely impressive in the way they understood, analyzed, designed and implemented a solution to the problem presented by the project. They were self-motivated and was creative in the way they found solutions. I would rate them as the best internship group we have ever worked with. If the STEM program can provide this type of quality interns to the industry, the program would have an excellent future."

Since 2016, the judges were also asked to provide their feedback about the event. Table 2 contains some of the comments from judges when asked what they thought about the STEM challenge.

Table 2. Open-ended Judge Survey Results

My students had nothing but praises for the event. They liked the idea of thinking outside the box (2016)
My only concern is the programming as you used Python. For my students, it was not a problem. However, if some students had not been exposed to C++, Java and/or Python, they would be lost (2016)
Make sure that students participate for the challenge, not the incentives (2016)
I think that most contestants had fun with the engineering challenge. I liked it because you were able to see how each team came up with different concepts (2017)
All of my students left wanting to know how to program (2017)
I had three students participate last year, I had 20 interested this year. They are excited about it (2017)

5. CONCLUSION

Figure 1 shows the growth of the number of student participants in the challenges from 51 in 2014 to 111 in 2017. The number of students in our computer science, computer information systems and information technology degrees has grown in the same time frame. While the growth of these 3 programs cannot be fully attributed to the success of the STEM challenges, we feel that the excitement of the events has impacted not only prospective students, but also current students, and even faculty.

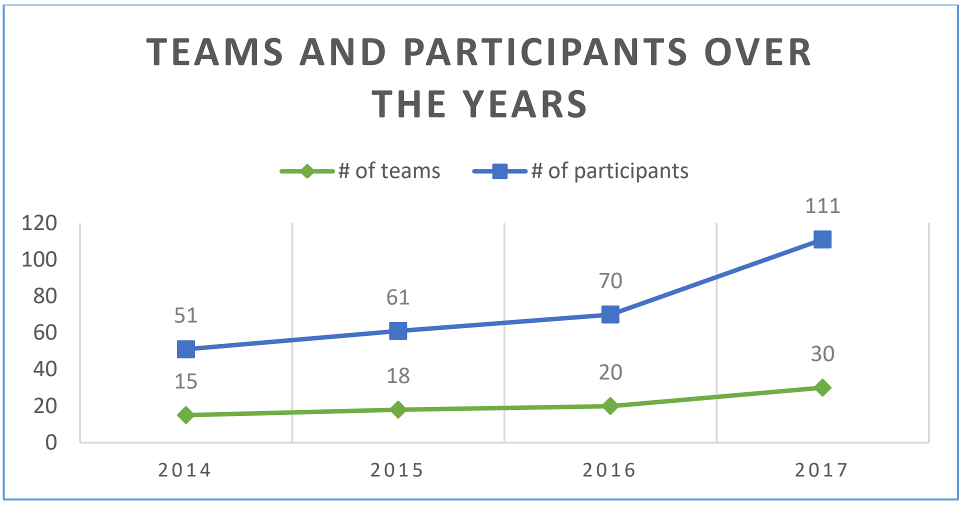

Figure 1. Team and Participant Numbers at the Various Challenges

The project team is very interested in increasing the number of women participants in the challenges and in our STEM degrees. Figure 2 shows that women participation grew to 22.5% in 2017. This is very exciting and encouraging to the project team.

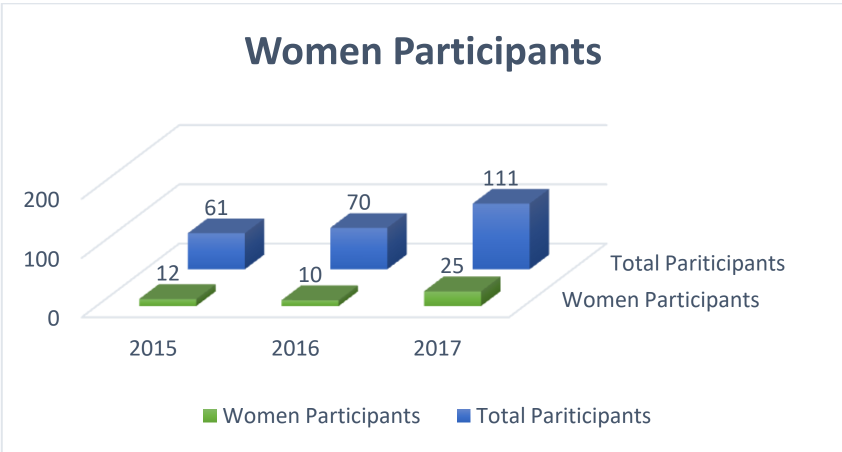

Figure 2. Women Participant Numbers at the Various Challenges

The Challenges introduced students to both basic and advanced STEM concepts. Generated data conclusively infers that only moderate alterations should be considered for this program. As a result of engagement in this event, student participants acknowledged an increase in STEM interest. Additionally, despite possessing minimal experience in both programming and robotics, most student participants were successful in the completion of these events, and subsequently implied increases in confidence.

However, the data derived also illuminates the need for precise and less complex instructions. Uncertainty relating to instructions could be explained by variations in age groups among student participants. Some participants also recommended, “pairing” middle school and high school students in groups with university students to make the challenge more equitable.

Highly engaging activities like the Programming Challenge can be used and replicated as a model by institutions to ensure that self-efficacy among students, specifically in STEM fields, is achieved.

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