Robotics Festival and Competitions Designed for STEM+C Education

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Abstract

In order to promote and support STEM+C (Science, Technology, Engineering, and Mathematics plus Computing, Coding, or Computer Science) education, a student-centered robotics festival and competition called Robofest (www.robofest.net) was launched in 1999. Robofest's primary focus is the learning of STEM subjects together with computer science through autonomous robotics. When we make robots think, we will learn more because we have to think more. We believe programming team-built-robots provides an effective environment to learn and exercise STEM disciplines in a truly integrated fashion. Furthermore, Robofest challenges are designed in such a way that dead-reckoning is discouraged, which means students must program their robots with sensors to accomplish tasks in a dynamic and partially unknown environment. Through the challenges with unknown factors that require programming without adults' direct help, students learn, reinforce, and master STEM+C knowledge for 21st-century jobs. Robofest meets the needs of students based on their respective age, interest, learning style, and prior experience by offering diverse competitions such as Game, Exhibition, Vision Centric Challenge (VCC), Global Robotics Art Festival (GRAF), and Unknown Mission Challenge (UMC). As entry level challenges for beginners, Robofest offers BottleSumo, RoboParade, and Carnival. After 17 years, there are currently over 2,500 students participating in our programs annually in fifteen US States and fourteen other countries. Assessment and survey results have shown that the Robofest robotics experience has provided on opportunity for thousands of participants to learn more about STEM. Importantly, more students in the post survey have indicated that they would consider a career involving STEM after Robofest exposure.

Keywords: robotics, coding, computing, problem-based-learning (PBL), STEM+C

Robotics Festival and Competitions Designed for STEM+C Education

Introduction

In 1967, Seymour Papert, Cynthia Solomon, Daniel Bobrow, and Wally Feurzeig crafted Logo, a revolutionary programming language, the first designed for use by children (Wikipedia, 2016), at a time when mammoth computers occupied entire rooms. Papert's vision was that children should be programming the computer. At last, a half century later, programming languages are becoming non-foreign languages. Worldwide trends show that coding will become increasingly more important in early K-12 education. For example, in September 2014, the UK initiated the most ambitious attempt yet to get kids coding, with changes to their national curriculum that includes coding lessons for children as young as five (Dredge, 2014). On December 10th, 2014, U. S. President Obama became the first president to write a line of code as part of the "Hour of Code" -- an online event to promote Computer Science Education Week. The line of code in JavaScript he wrote was (Mechaber, 2014):

```
moveForward(100);
```

Later, in January 2016 in his 2016 State of the Union Address, President Obama announced a "Computer Science (CS) for All" initiative to empower all American students from kindergarten through high school to learn computer science as a "new basic skill" and be equipped with the computational thinking skills they need to be creators not just consumers, in the digital economy, and to be active citizens in our technology-driven world (Smith, 2016).

Robofest (www.robofest.net), launched in 1999, is an annual robotics festival with competitions designed to promote and support STEM+C (Science, Technology, Engineering, and Mathematics + Computing, Coding, Computer Science) education (Chung & Sverdlik, 2001; Chung & Anneberg, 2003; Chung, 2005, 2006, 2007, 2008, 2009, 2011, 2014 January a, 2014 August, 2015, 2016; Chung & Cartwright, 2010, 2011, 2012, 2013; MacLennan, 2010; Chung, Marzougui & Lahdhiri, 2012; Coscarelli, 2015 March, 2015 September) with the following key strategies: (1) Autonomous robotics were chosen as a tool for STEM+C education because it provides a true hands-on learning environment and integrates all the components of STEM+C. (2) Robots were chosen, instead of simulation on a screen, as the target platforms to execute programs because Papert's research showed that children learned more efficiently if they could see a physical/tangible result for their computing efforts (Papert, 1980). (3) Competition provides an active, collaborative, student-centered, and problem-based learning (PBL) environment. (4) Competition stimulates student motivation and performance. (5) Computer Science was the focus because the concept of "STEM" overlooked the importance of computer science, computing, programming, and coding at the K-12 level.

Robofest's mission is to inspire K-12+ students in STEM+C, develop teamwork, enhance creativity and problem solving skills, and prepare them to excel in higher education and technological careers. Robofest challenges teams of students to design, build, and program autonomous robots to compete in various categories. Robofest has witnessed significant growth over the past 17 years. In the 2015-2016 season, 2,575 students participated in Robofest. Cumulatively over 20,000 students have been a part of this program since its inception in the 1999-2000 school year at Lawrence Technological University (LTU) in Michigan. Robofest has drawn students from 15 States (Michigan, Ohio, New Hampshire, Texas, Florida, California, Washington, Missouri, Hawaii, Colorado, Indiana, Minnesota, Louisiana, Massachusetts, and New York) and 14 other countries (Canada, China, Colombia, Egypt, England, France, Ghana, Hong Kong, Hungary, India, Korea, Mexico, Singapore, and South Africa) and continues to expand at a rapid rate. What makes Robofest events unique? The following paragraphs summarize the unique characteristics of Robofest.

STEM+C Learning through autonomous robotics: When we make robots think, we learn more because we have to think more. Autonomous robotics is one of the best ways to learn all the STEM disciplines in a truly integrated fashion by focusing on computer science, computer programming, and computational thinking. Furthermore, Robofest challenges are designed in such a way that dead-reckoning is discouraged. Students must program their robots with sensors to accomplish tasks in dynamic and partially unknown environments. Through specified challenges, students must apply the math and science skills learned in their classes to re-enforce the learning.

Affordable: Our emphasis is on making Robofest affordable to all students, parents, and schools, and we accomplish this by charging a minimal team entry fee ($0 ~ $50). Robofest does not require teams to hold major fundraisers to underwrite the cost of participation. Robofest encourages recycling of all the logistic materials, such as robotic kits, parts, sensors, actuators, and playing field materials, which helps to control costs. It is easy and simple for organizations to host their own qualifier since the Robofest headquarters provides basic competition materials including trophies, medals, name badges, and certificates to them free of charge.

Flexible: Robofest allows students to use robotics kits and programming language of their choice. Any material can be used. The playing field materials are affordable, modular, and easy to transport and store, allowing student teams to practice anywhere at their convenience. Teams can be formed by any organization, school, home school, club, neighborhood, or civic group.

Students rule: While adult mentorship is encouraged, students are requested to design, construct, and program the robots themselves, and adult coaches/mentors are not allowed to assist during the actual competitions.

Everyone is recognized: All registered participants receive personalized medals and certificates if they do not drop out. Winners of the qualifying and championship rounds receive trophies. Top teams in the World Championship Sr. division (grades 9-12) receive $2,000 LTU renewable scholarships.

Free technical workshops are offered to teams on campus and/or online. All the workshop materials such as PowerPoint slides, example videos, sample programs, and recorded webinars are available online for all teams. Some workshops are taught by high school seniors who have had extensive experience with Robofest.

Various opportunities for every student: Robofest meets the needs of a variety of students based on their age, gender, learning style, and experience/ability levels. The following *Figure 1* shows all eight Robofest program categories offered throughout the year and the different skill levels and interests.

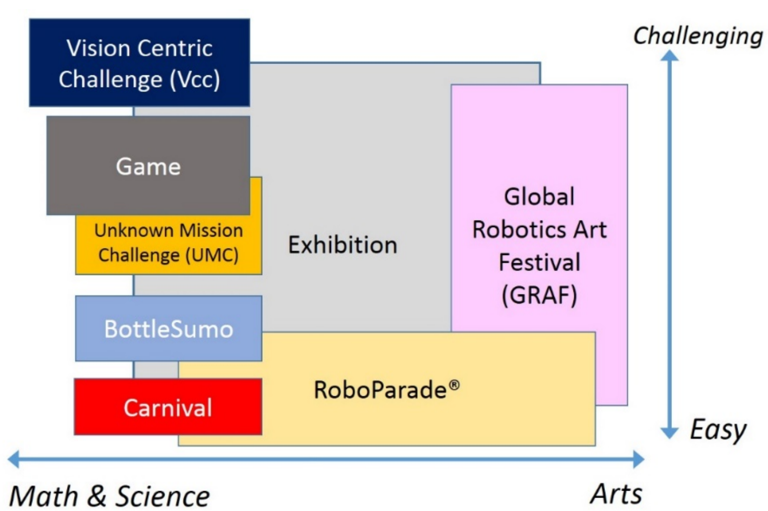

Figure 1. Diverse categories of Robofest programs.

Each category of Robofest is introduced in the following sections. Then outcome and evaluation results will be summarized. A summary and conclusion will follow at the end of this Chapter.

Game

Robofest Game, which is the most popular category in Robofest, is a timed mission defined with unknown factors and small unknown surprise challenges. Game is designed to adopt the Problem Based Learning (PBL) paradigm (Hmelo-Silver, 2004). Learning is driven by challenging problems with no one “right” answer. Team members work as self-directed, active investigators, and problem-solvers in small collaborative groups. Teachers/Coaches adopt the role as facilitators of learning, guiding the learning process. Robofest Game especially puts math skills to the test. Teams need to apply math concepts with computational thinking skills to solve the missions. A new Game is introduced each year. The following sub-sections describe the recent year missions from 2012 until 2016.

2012 Game – R2R (Robots to the Rescue)

Game synopsis: *due to an earthquake, high-rise buildings (tissue boxes) in a city are on fire. An autonomous robot is being sent to rescue people (tennis balls covered with aluminum foil tape) on the top of the two buildings*. R2R playing field is shown in *Figure 2*.

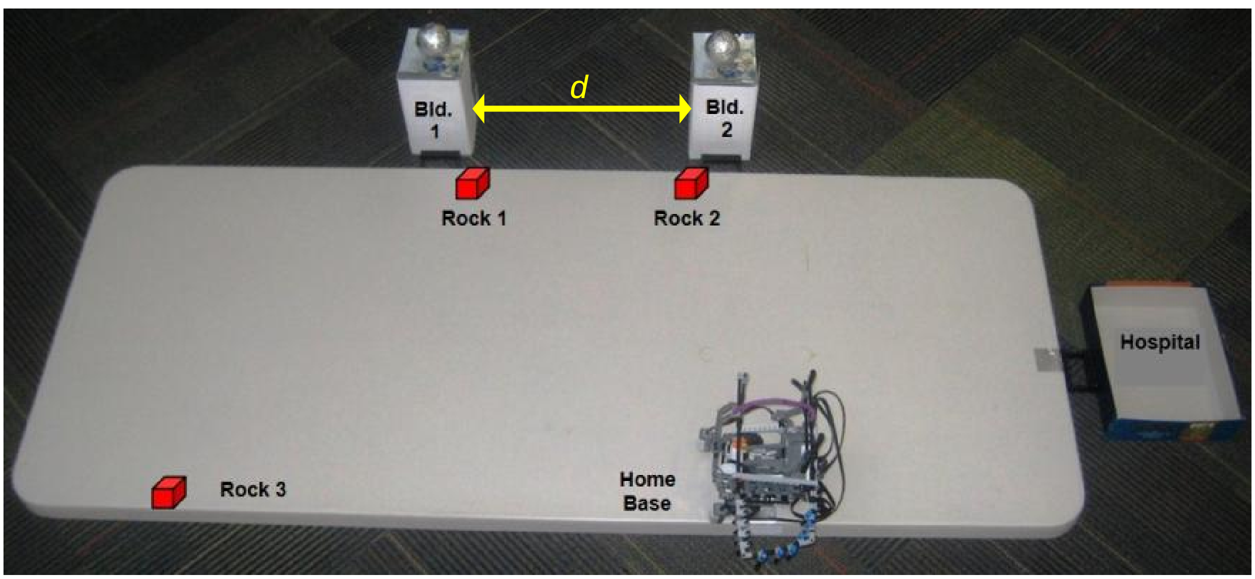

Figure 2. 2012 Game R2R (Robots to the Rescue) Jr. (Grades 5-8) Playing field.

Missions of R2R Game are (1) Remove Rock 3 off the table to clear the south edge road. (2) Move the rock in front of each building. (3) Rescue each individual (tennis ball) on each building. (4) Bring them into the hospital box. (5) Measure the distance between two buildings and report (display) the length in millimeters *at the Home Base*. Learning objectives of this Game are motion, manipulation, object detection, localization, logic, ratio, proportion, algebra, measuring, geometry, and navigation. High school teams were needed to use trigonometry especially, since the table was setup on an angle as shown in *Figure 3*.

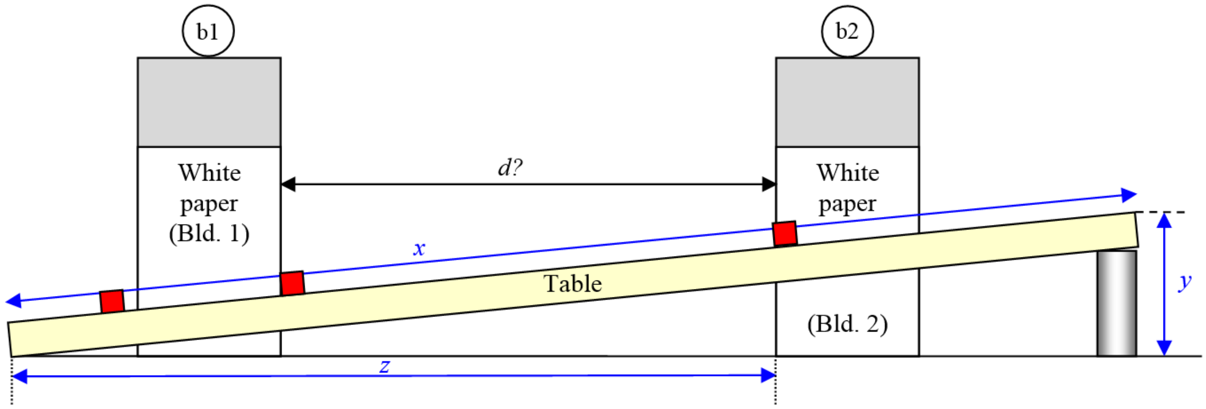

Figure 3. 2012 Game R2R (Robots to the Rescue) Sr. Playing field.

2013 Game – SRCC (Search, Rescue, Cleanup, and Collect data)

An autonomous robot must search for and rescue people trapped in the black box in the tower of boxes, collect data, and clean up a contaminated area around the tower. Detailed missions are to (1) Remove (clean up) the white toxic boxes from the table (2) Bring the black box out of the contaminated area to Home (3) Measure the size of the contaminated area in square millimeters and report/display the number (4) Return to the Home Base.

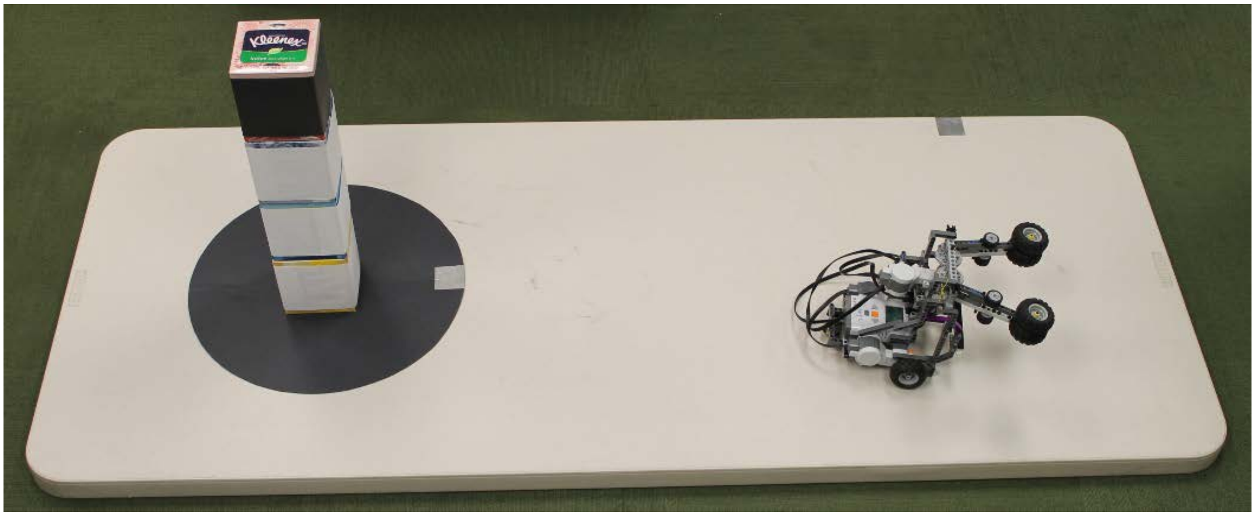

Figure 4. 2013 Game - SRCC (Search, Rescue, Cleanup, and Collect data) Jr. Playing field.

For the Jr. Division, a black circle is used to represent the contaminated area as shown in *Figure 4*. Two or three white boxes are used for the tower. The location of the black box is always on the top of the tower. The number of white boxes is unveiled 30 minutes before impounding robots to begin the competition.

For the Sr. Division, a right triangle shape is used instead of a circle. Two to four white boxes are used for the tower. The number of white boxes and the location of the black box in the tower is unveiled 30 minutes before impounding robots. It is known that the black box will not be at the bottom to make the challenge not to be too complicated. Teams are required to use geometry and/or trigonometry to measure the black shape. Sr. SRCC playing field is shown in *Figure 5*.

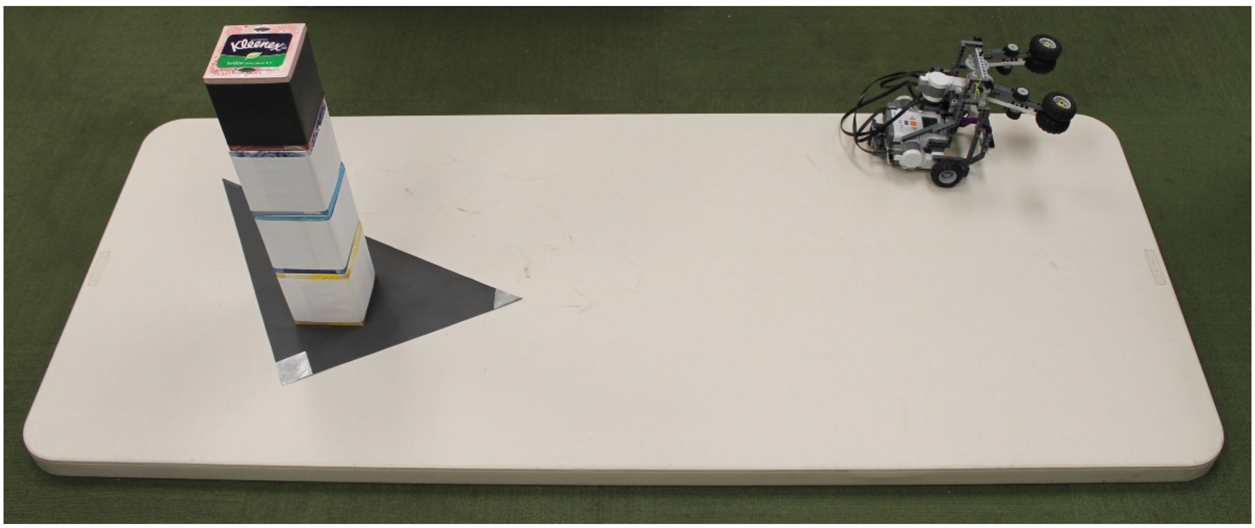

Figure 5. 2013 Game - SRCC (Search, Rescue, Cleanup, and Collect data) Sr. Playing field.

2014 Game – Avoid Meltdown

A nuclear power plant is in trouble. An autonomous nuclear responder robot has detected the problem and has two minutes to deliver up to 3 water balls (tennis balls) and a special ball (hardboiled egg) into the plant (box). The robot can carry only one ball at a time. Two concrete blocks (AA size batteries) near the plant need to be removed off the table. Also, the volume of the box (outer dimension) must be reported/displayed in cubic millimeters at the Home Base.

For the Jr. Division the height and depth of the box is given. The box is aligned in parallel with the table. For the Sr. Division, only the depth of box is given and the box is not aligned in parallel with the table. Jr. Division playing field is shown in *Figure 6*.

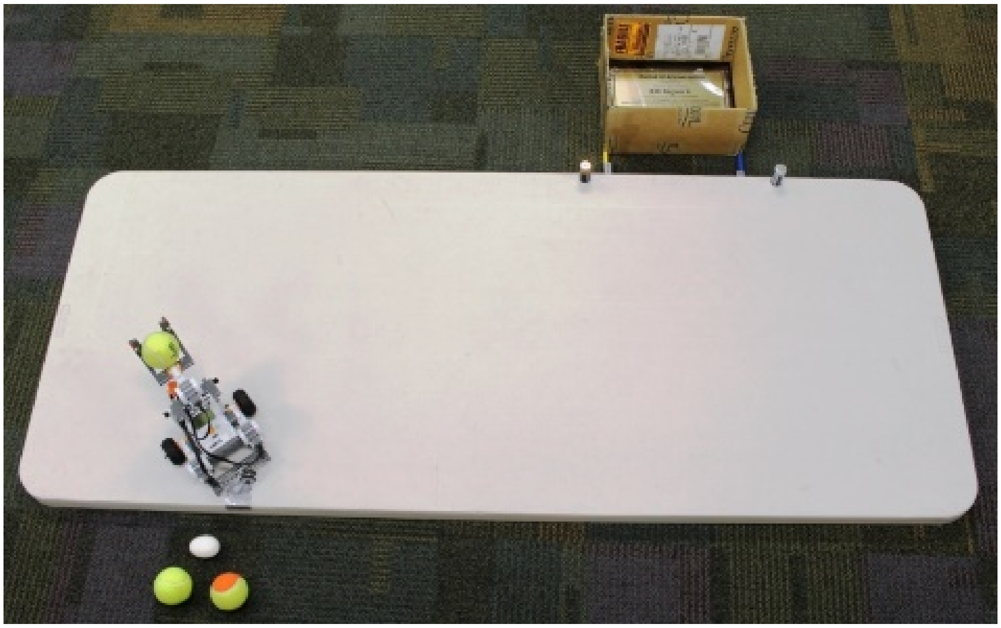

Figure 6. 2014 Game – Avoid Meltdown, Jr. Playing field.

2015 Game – RoboBowl

The robot is to bowl, throw, shoot, or kick a tennis ball to knock down four pins (500 ml water bottles). If pins are knocked down, the highest point value will be awarded. If the ball just moves pins (but does not knock them down), partial points will be awarded. If the ball ends up in the Pin Side Area, points are also given. In addition, the robot is required to report the height of the black rectangle shape on a letter size paper in millimeters. The location of Pins 1 and 2 is unveiled. The robot must calculate the location of Pins 3 and 4 based on the rectangle height measurement. *Figure 7* shows an example of RoboBowl, Jr. Playing field.

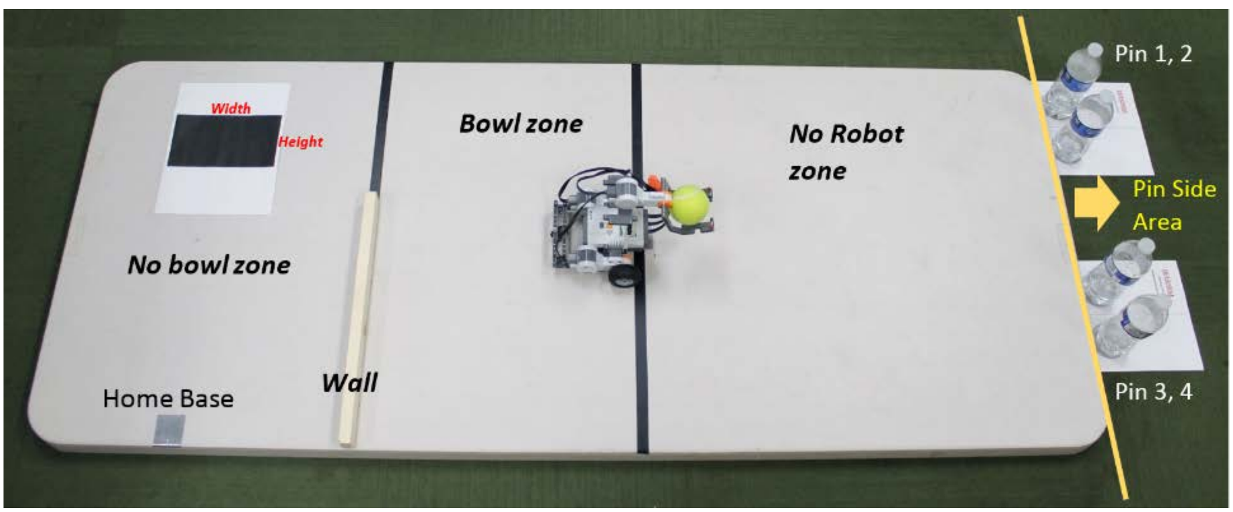

Figure 7. 2015 Game – RoboBowl, Jr. Playing field.

2016 Game – RoboGolf

There are four green areas with a golf ball. The robot must autonomously find each green area, locate a golf ball, stop, and putt the ball into a hole by using a specific piece of wood (wooden putter). The center hole, “a” in *Figure 8*, has the highest point value. For the Jr. teams, the location of the four green areas will be unveiled at the competition site. However, for the Sr. teams the exact location of the green area No. 4 will be completely unknown. The exact location of the golf ball on the green paper is unveiled to teams at the start of the competition.

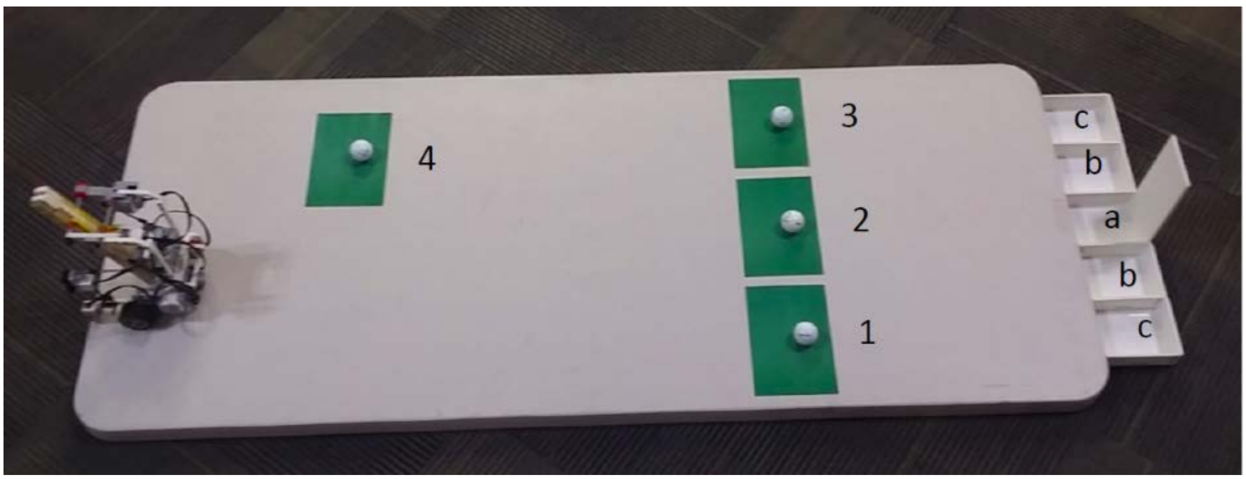

Figure 8. 2016 Game – RoboGolf, Jr. Playing field.

During onsite workshops or webinars, three methods to aim for the hole suggested were (Method 1) Search for the flag pole by scanning using a sonar sensor, (Method 2) Compute the location of the hole mathematically, (Method 3) Determine the location using trial and error - we can find the hole by rotating the robot different amounts in an attempt to find the correct orientation.

In the workshops and webinars, the instructors reviewed the basic geometry needed to implement the (Method 2) mathematical approach. In order to aim the robot towards the center golf hole, the angle θ can be calculated using geometry as shown in *Figure 9*. Then actually the robot needs to spin, 90 – θ degrees. When the robot spins, the wheel path is a red circle centered between the wheels as shown in *Figure 9*.

We explained an example to spin 90 degrees when the robot’s track width is 16.2cm and the diameter of the robot’s wheel is 5.5cm. Students are instructed to calculate the circumference of the robot’s path for a complete spin (the circumference of the red circle): Cp = PI * D =

3.14*16.2cm = 50.87cm. Then students are asked to calculate the circumference of the robot's wheel: Cw = PI * D = 3.14 * 5.5cm = 17.27cm. Since 90 degrees is ¼ of a circle, the robot travels 50.87cm/4 = 12.72cm in order to spin 90 degrees. The final calculation is, "How many wheel rotations are needed to travel 12.72cm?" The number of rotations can be found by dividing the distance by the wheel circumference. Therefore the answer is 12.72 cm / 17.27cm = 0.74 rotations.

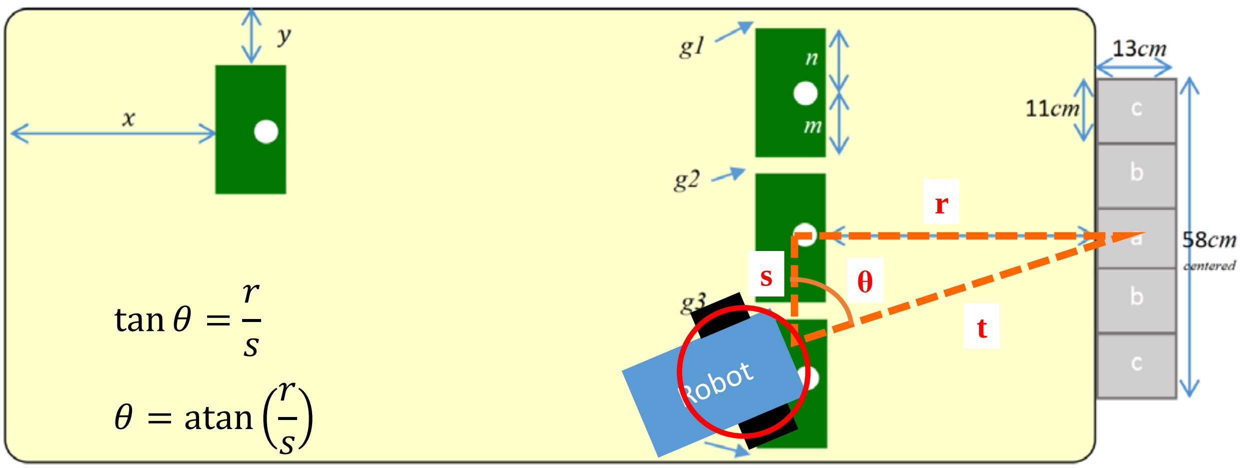

Figure 9. 2016 Game – RoboGolf, Jr.; to aim the robot towards the center golf hole

Exhibition

Since the Game competition with fixed rules may limit students' creativity, Robofest offers a science-fair like stage for exhibitions to demonstrate creative robotics projects. The robotics exhibition is a great way for students to show off their imagination and creativity. Each team has complete freedom to create any autonomous robotics projects such as robot pets, robots for scientific experiments, and practical robotics applications for any field. Computer controlled robots with sensors may be of any size and can use any material as long as it is safe for team members as well as spectators. Hard-wired remote control is not allowed, but wireless host computer/robot control via software messages is allowed. Robot to robot communication is encouraged as well as human interaction with the robots. Suggested human interaction with robots include: claps/knocks, flash light, color cards, and hand gestures. The application of math and science theories that are appropriate to the team members' age level is a strong plus for judging. Table 1 shows the summary of Exhibition Judging rubric.

Table 1. *Exhibition Judging Rubric*

Judging Category	Weight
Math & science concepts applied?	8%
Students understand the math & science concepts applied?	8%
Project Idea	6%
Originality	6%
Robot demo performance	10%
Project presentation	8%
Project info (poster, brochure, website, video, etc.)	4%
Teamwork	8%
Robot mechanical design	7%
New technologies, tools, parts, and materials	3%
Project size	7%
Practicality	7%
Programming	8%
Team Independence	10%

The following *Figures 10 ~ 17* show some notable exhibition projects from recent years. Automated chocolate factory was created using LEGO robots as shown in *Figure 10*. *Figure 11* shows Z-bots with an Arduino micro controller and 4 Omni wheels solving maze problems and demonstrating swarm behaviors. All the plastic body parts were made from scratch using a 3-D printer.

Figure 10. Automated Chocolate Factory

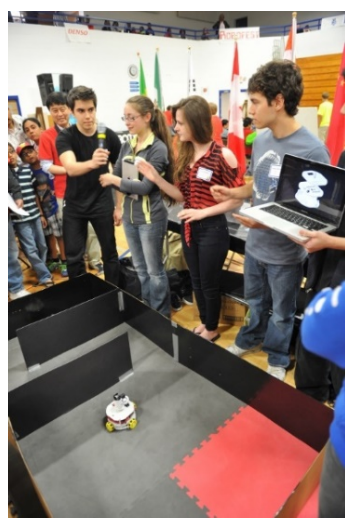

Figure 11. Arduio swarm robots

Figure 12 shows an autonomous land mine seeker and destroyer robot. Students presented a GPS guided robotic boat monitoring and measuring ecological data (See *Figure 13*). A student is playing a robotic violin (see *Figure 14*) created with LEGO NXT controller and NXT sensors. *Figure 15* shows intelligent 4-way stop traffic control with self-driving cars built using Arduino controllers and ZigBee communication. *Figure 16* shows a sensor-heavy smart robot arm built using Arduinos. A student is demonstrating a smart stick for the blind. It vibrates on the yellow line and it beeps when it detects obstacles (see *Figure 17*).

Figure 12. Landmine seeker

Figure 13. GPS guided boat

Figure 14. LEGO NXT violin

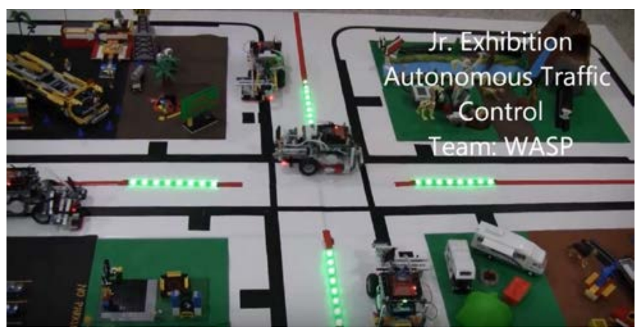

Figure 15. Self-driving Arduino cars at 4-way stop

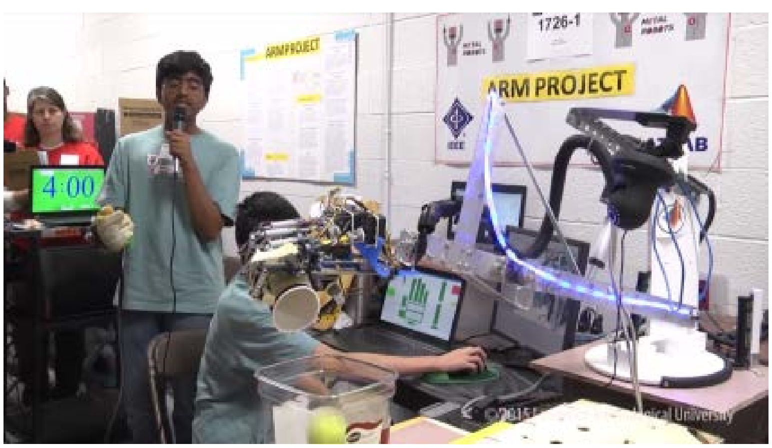

Figure 16. Sensor heavy robot arm controlled by Arduino

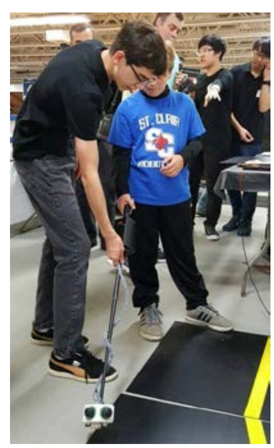

Figure 17. Stick for the blind

GRAF (Global Robotics Art Festival)

Robotics is all about STEM, and art is tightly coupled with all the S. T. E. M. components. The idea of GRAF is to integrate the arts with robotics to provide effective and interdisciplinary STEM learning environments where students will have an unforgettable "show and tell like" experience by creating robotics art projects using a universal language: art (Hamner & Cross, 2013). GRAF implements the idea of "STEAM = STEM + A (Arts)" with two main categories: Performing Arts Division and Visual Arts Division. The Performing Arts Division includes Dance / Synchronized Group Dance, Fashion Show, Music Band, Robot and Human Playing music together, Robotic musical instruments played by humans (Chung, Cartwright Chung, 2014 March), and Robot Skit. Examples of Visual Arts Division are Kinetic Sculptures, Kinetic Canvas, and Robotic Painting. The following paragraphs introduce some GRAF projects.

Team Courageous 1 introduced a piano playing robot and a robotic guitar instrument (see *Figure 17*). The piano robot had a creative mechanism with three motors to control six fingers. The guitar robot made different tones while sensing the finger locations with an infrared distance sensor.

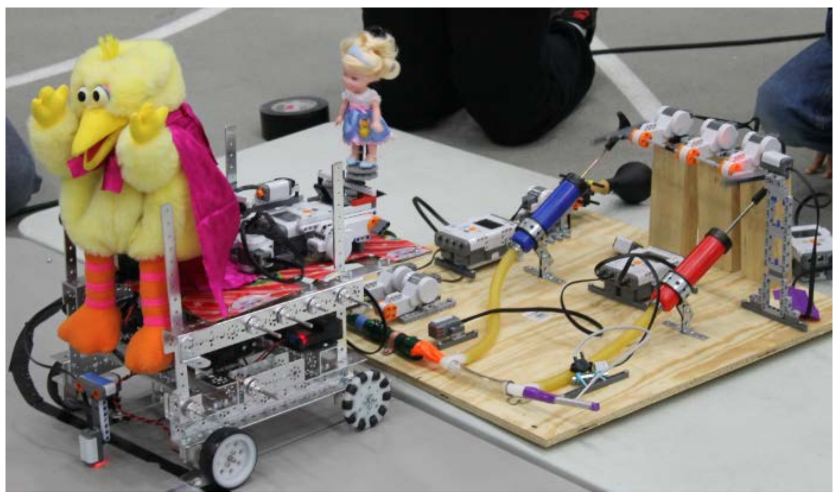

Figure 17. Piano Robot and Robotic Guitar. *Figure 18*. A recorder playing robot

Team RoboCruisers introduced a believed-to-be the world's first robot playing a recorder (See *Figure 18*). Three motors were synchronized to control two pumps to provide air powerful enough into the recorder windway to produce sound. When the robot plays "Mary had a Little Lamb" on a recorder, the other robot Big Bird dances to the music synchronized by Bluetooth signals.

Team Moodpainter from Mexico developed a robot system with a database that draws a shape by spraying different color paint according to a person's mood determined by the music played on a foot keyboard (See *Figure 19*).

As shown in *Figure 20*, team ALL2JESUS created a robot that displays kinetic art patterns by using 16 servo motors and distance sensors. The robot changes the pattern whenever it detects a new spectator or by using a built-in timer.

Figure 19. Painting by mood

Figure 20. Kinetic art patterns

Team The Supernovas created a robot, Franc (See *Figure 21*), which is designed to paint letters based on pre-entered coordinates. Franc painted the official logo for the Global Robotics Art Festival (GRAF) as shown in the figure.

Team Spruce Goose created an Arduino-based mechanical kinetic sculpture that abstractly depicts a cam shaft, in an artistic way, playing a LED light show activated by IR distance sensors (See *Figure 22*).

Based on the assessment results published (Chung, 2015), the GRAF has accomplished its goal to get students to pursue their interest in science, technology, engineering and math subjects, by using the power of universal human interest in arts. Student projects show hands-on application of STEM and computing science skills to create robotics art projects that also require problem-solving skills. We also learned, as Gullatt argues, that arts are not only for (self) expression, but also for discovery (Gullatt, 2008). Arts promote creativity while making everyone feel beauty and joy. Participation data show that the inaugural GRAF resulted in bringing more female and young students into STEM learning compared to Robofest competition populations (Chung, 2014 Jan a). The acronym for STEM + Arts is STE**A**M. Since robotics art is a typical example of STE**A**M, similarly, GRAF can be represented by ST**R**EAM, adding an R (Robotics) to STEAM.

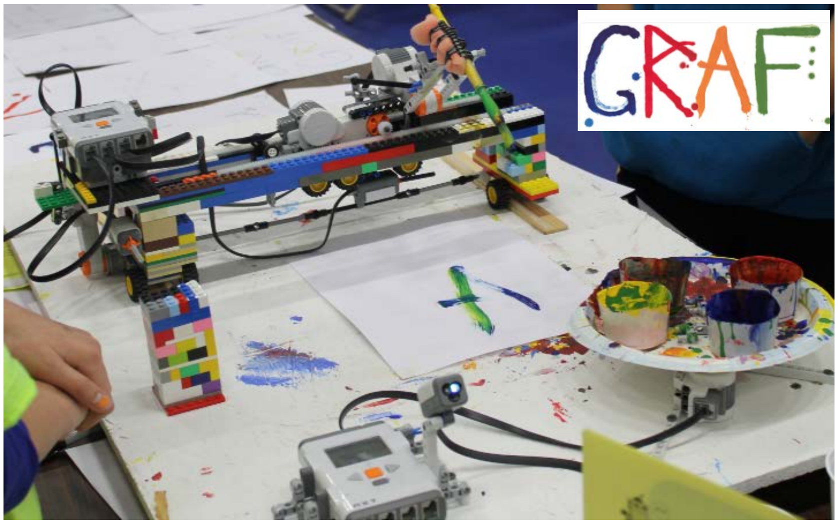

Figure 21. Letter drawing robot and GRAF logo drawn by the robot

Figure 22. Kinetic sculpture, Spruce Goose

Vison Centric Challenge (VCC)

Why is vision important to robots? Clearly, vision will enable a robot to become intelligent and autonomous in undertaking manipulation, navigation, and even social interactions. In this VCC launched in 2007, teams are required to build and program a robot with camera(s) to solve challenges that needs "seeing". This VCC is for advanced high school students as well as college students. Earlier challenges involved recognizing red /green light signals and green arrows, and following a lane while avoiding obstacles between 2 dashed lines (Crocker, 2011) as shown in *Figures 23 ~ 25*.

Figure 23. Red/green light detection

Figure 24. Green arrow detection

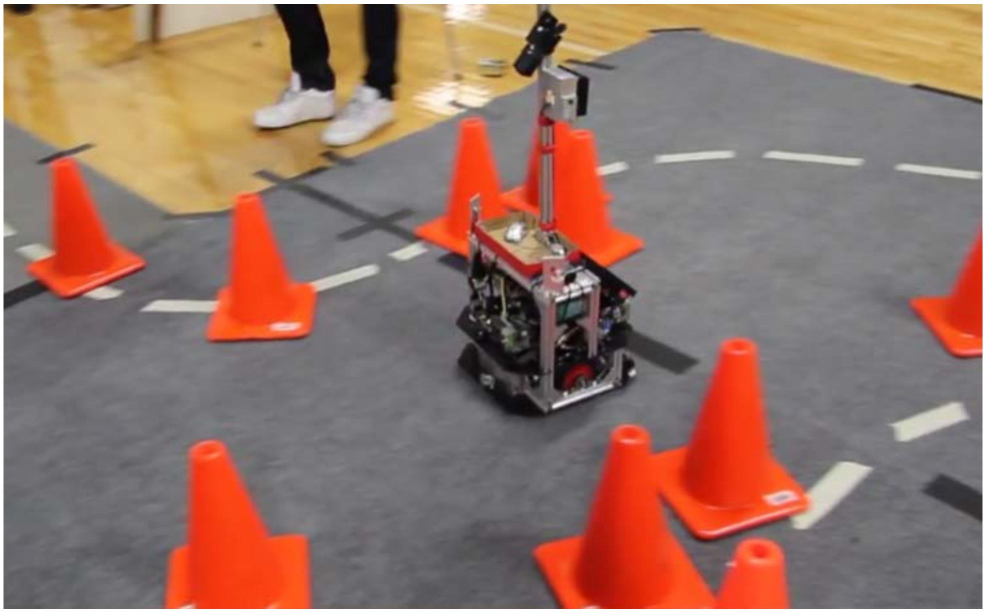

Figure 25. Lane following while avoiding orange cones

VCC 2014 – Color Cup Navigation

To start the competition, a judge will show either *Figure 26* or *27* to the robot camera. Then the robot will be shown a digit on a letter sized paper. After recognizing the digit, the robot should navigate through the path in such a way that the blue cups are always on the left side if *Figure 26* is shown to the robot, for example. If the number given was 2 for example as shown in *Figure 29*, the robot needs to return back home at the 3rd yellow cross-line while maintaining the left blue color rule.

Figure 26. Blue cup left

Figure 27. Red cup left

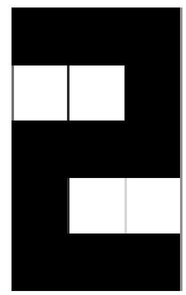

Figure 28. Pattern for number 2

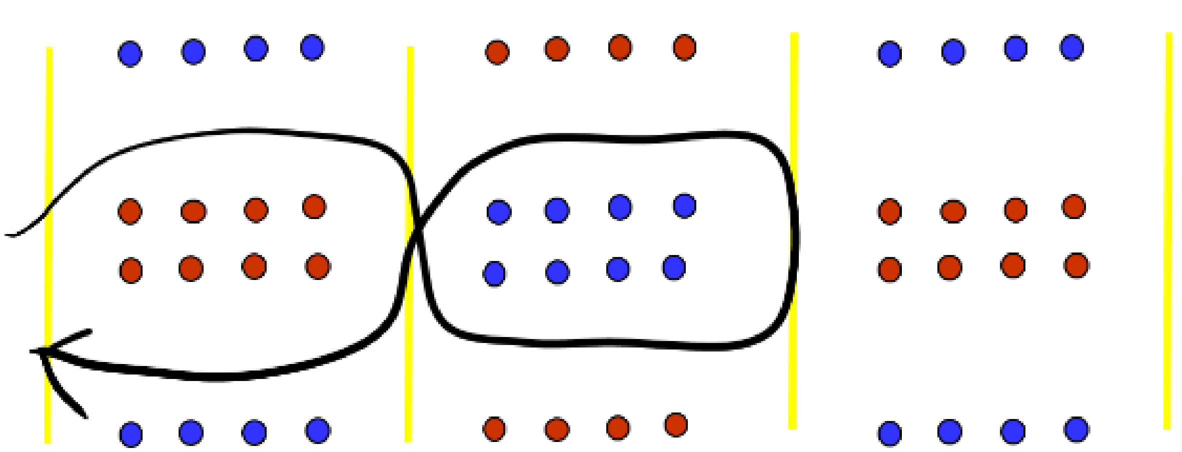

Figure 29. Color Cup Navigation course example

VCC 2015 – MaxMin

The robot must follow a solid or dashed line to a series of waypoints (See *Figure 30*). Each waypoint will be associated with a numeric digit. Robots must locate and traverse all waypoints recording their associated values during the challenge. Once all waypoints have been evaluated the robot must return to the waypoint with the largest numerical value and spin 720°. The robot must then return to the waypoint with the smallest numerical value and stop. Waypoints for High School teams are represented by 9 x 12 inch sheets of colored construction paper. A table of the waypoint color to numeric value information is provided in *Figure 31*. College waypoints are represented by white 8.5 x 11 inch sheets of printer paper. Each waypoint will have a printed orange shape. Paper and shape orientation will vary but remain consistent for all teams. All shapes with their associated numeric values is provided in *Figure 32*.

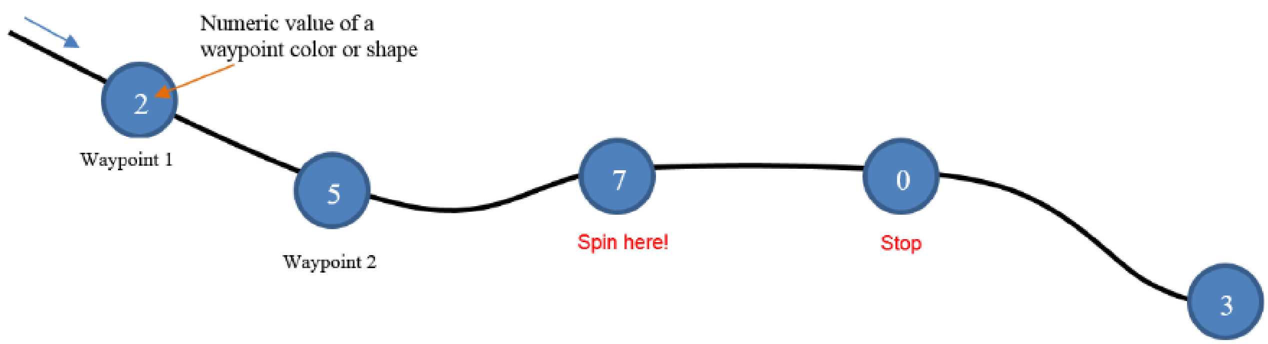

Figure 30. Course with waypoints

Shape		***Numeric Value***
Circle		0
Square		1
Triangle		2
Pentagon		3
Hexagon		4
Cross		5
Arrow		6
Moon		7
Heart		8
Star		9

Figure 32. Waypoint numeric value chart for College

Paper Color	***Numeric Value***
Black	0
Blue	1
Brown	2
Green	3
Orange	4
Pink	5
Scarlet	6
Violet	7
White	8
Yellow	9

Figure 31. Waypoint numeric value chart for Sr. Division

VCC 2016 – Mosaic

Due to the camera's limited field of vision, the robot can see only a portion of an alphanumeric pattern on a mosaic comprised of fifteen pieces of colored paper on the floor. The mosaic will be arranged in five rows and three columns. The robot must move to read all paper colors necessary to identify the digit or letter represented. For example, *Figures 33* and *34* represent the number '2' and the letter 'A', respectively. Note that *Figure 35* is a varied pattern for A. The robot must report (display) the recognized digit or letter after spinning twice (~720 degrees) on the field.

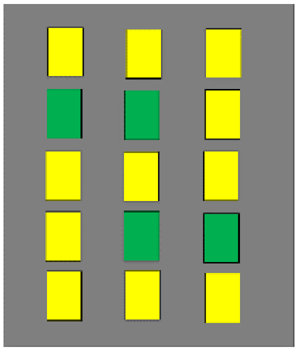

Figure 33. Pattern for "2"

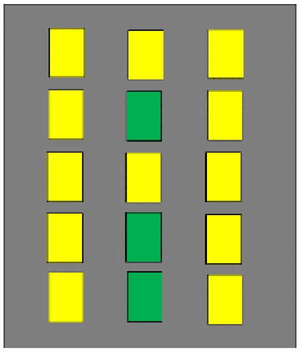

Figure 34. Pattern for "A"

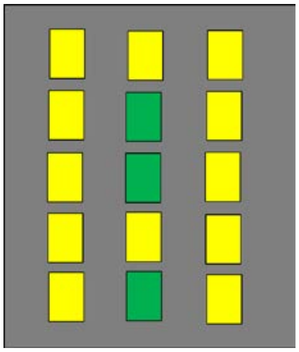

Figure 35. Varied pattern for "A"

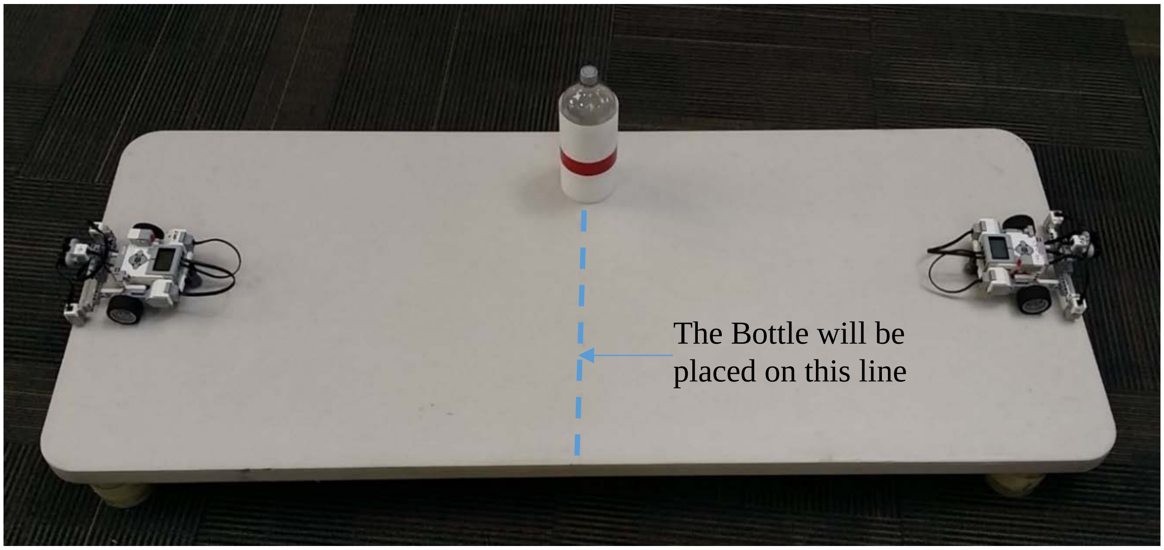

Figure 36. An example of BottleSumo Initial Configuration, Jr. Division

BottleSumo

The objective of the game is to either be the first robot to find and intentionally push a 2 liter bottle (filled with 1 liter of water) off the table OR be the last robot remaining on the table.

In either case, after the event (either the bottle was pushed off or the opponent are off the table), the robot must survive (remain) on the table for at least three (3) seconds. A robot is considered off the table when any of its parts are touching the floor, whether it was pushed off the table by the other robot or it fell off the table on its own. Each robot must be fully autonomous. No human control, signal, or remote computer control (tele-operation) is allowed. Through this entry level BottleSumo, students can learn multiple STEM subjects such as physics, math, gears, logic, mechanical engineering, computer programming, and engineering design process by doing. The introduction of an additional target object, a two liter bottle filled with a liter of water, makes the game even more challenging and minimizes the random chance of winning. *Figure 36* shows Jr. BottleSumo starting configuration using a 6ft table. The Senior Division field is made up of two tables.

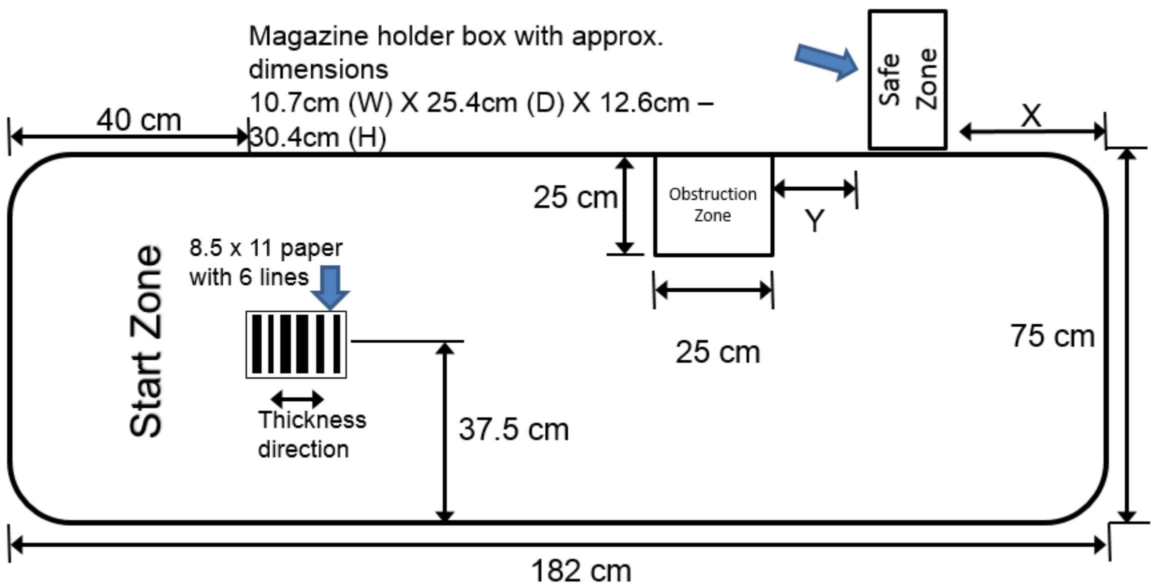

Figure 37. UMC 2016 Problem – Read a barcode and Deliver

Unknown Mission Challenge (UMC)

Mission tasks will be totally unknown until the day of competition. Contestants solve simple missions in a very short timeframe (less than 3 hours). The goal of this challenge is to provide an opportunity to develop problem solving skills on the fly without any help from adult coaches. Teams may use only approved robot kits. Pre-assembled robots cannot be used. Sensor or motor multiplexors are not allowed. The UMC 2016 Challenge problem was “read the barcode and deliver” (See *Figure 37*). Your robot begin in the start zone loaded with a tennis ball and complete two tasks: (1) Report the total line thickness (sum of the individual six line thicknesses displayed on the robot screen) (2) Deliver and tennis ball to the safe zone. The X value in *Figure 37* is 4 * (total barcode line thickness). We have witnessed and were truly amazed by the teamwork and solutions generated by the teams. The "parent-free" environment is enjoyable.

RoboParade

RoboParade, a parade of self-driving cars, is an entry level program to engage, inspire, challenge, and prepare 4th-12th grade students for STEM+C learning and careers (Chung, 2010; Chung & Cartwright 2014 Jan b). RoboParade students design, build, program, and *decorate* autonomous robotic floats that follow a parade route, a black line. This fun event has featured miniature robotic floats with moving parts, sparkling lights, and all sorts of bells, drums, and musical instruments rolling down a parade route without remote controls. The students must program their robots to obey speed limits (minimum 7 cm / second and maximum 17 cm / second), display the current average speed, follow a black line, and avoid other robots using sensors. Through these tasks, students are learning, experiencing, and reinforcing STEM subjects such as proportion, arithmetic operation, arithmetic mean, linear function, unit conversion, ratio, circles, logic, data analysis, speed calculation, sensors, gears, motors, force, friction, center of gravity, and many others. To join the official parade, teams must pass a qualifying test that includes a written qualifying exam. The annual non-competitive RoboParade has been designed to complement the competition-oriented robotics events, targeting younger students and less experienced teams by providing an entry level robotics program into STEM, and freeing them of the stress of competition. RoboParade provides an interdisciplinary hands-on experiential approach where students may improve learning STEM subjects.

Robofest conducted a controlled experiment showing that students who participated in RoboParade 2012 and 2013 showed improvement on a pre-post STEM multiple choice test compared to students who did not participate in RoboParade (Chung & Cartwright, 2014). We believe the speed display requirement and the written qualifying test asking about speed calculation embedded into the RoboParade program contributed to the improvement of the RoboParade group. In addition, the artistic and non-competitive nature of the event seems to attract more female participants, with an over 28% female participation rate, well above the other STEM programs. RoboParade is expanding to other cities. Two cities in Michigan, one city in

Florida, one city in Texas, and one city in Virginia have offered this fun and effective informal STEM and STEAM learning opportunities. *Figure 38* shows the Halloween RoboParade 2015 at Macomb Community College in Warren, Michigan.

Figure 38. RoboParade 2015 at Macomb Community College, Michigan

Carnival

Individual students will first learn how to program robots to follow a black line and to send Bluetooth messages to robots, then visit Multiple Stations (Programming/Construction, Beginner/Advanced) to program the controller and play the games explained in the following paragraphs. Note that Carnival is not a team-based program.

Scorpion Balloon Blaster: If the controller is programed correctly, students are asked to select a math or science trivia quiz card. If the answer is correct, then they will have the chance to control a LEGO scorpion robot via Bluetooth to pop a balloon. If the answer is not correct, the student may go back to the end of the line to try the trivia quiz again. Winners will be determined based on the completion time. See *Figure 39*.

Figure 39. Scorpion Balloon Blaster

Goal Challenge (See *Figure 40*): If the controller is programed correctly, students are asked to select a math or science trivia quiz card. If the answer is correct, then they will have the chance to play with a LEGO soccer robot to kick tennis balls. If not correct, the child may go back to the end of the line to try the trivia quiz again. There will be 4+ tennis balls with numbers on the field and some obstacles. The goal is to maximize the sum of balls successfully kicked into the goal. Some balls are easy to kick in, but the values are low. Only 2 minutes will be given for each player. Winners will be announced based on the scores earned.

Lifter Design and Race (See *Figure 41*): If the controller is programed correctly, Students are asked to design a robot arm to lift a LEGO barbell. If a student brings back the barbell using the robot with the arm, the mission is accomplished. Winners will be determined based on the programming completion time and the game completion time.

Figure 40. Goal Challenge

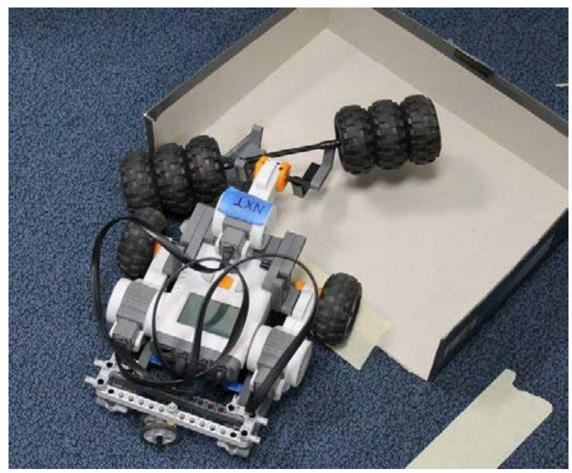

Figure 41. Lifter Design and Race

Speed Calculation Challenge: After introducing the concept of speed/velocity calculation, a robot car will be started to follow a straight black line. When it stops at the red color tape at the end of the black line, the robot will display the time taken from the beginning. Students are asked to calculate the speed of the robot car in cm/sec as well as inches/sec. Students will be given a tape measure. Winners will be determined based on the accuracy and use of correct mathematical formulas in the calculation. Additional recognition will be given if the student implements more complex line following algorithm with 3 states.

Block Math: Students are asked to calculate the number of LEGO blocks used to construct shapes/structures. A bonus problem involves calculating a gear ratio. Three minutes are given to complete the task. Winners will be determined based on (1) accuracy (2) use of math formulas / calculations, and (3) time to calculate.

Slope Calculation: Each student is given a distance sensor connected to a LEGO computer. They must watch a presentation to understand how the sensor works. The goal is to calculate the slope of a secret board inside a black-box using the distance sensor. Winners will be determined based on accuracy and the mathematical description used to solve the problem.

Outcomes of 2015-2016 Academic year

In the 2015~2016 academic year, a total of 2,575 students on 834 teams participated Robofest from eight countries (Canada, China, Colombia, Egypt, Ghana, Hong Kong, India, and South Korea) in addition to 13 States from the U. S. (California, Florida, Hawaii, Illinois, Massachusetts, Michigan, Minnesota, Missouri, New Jersey, North Carolina, Ohio, Texas, and Washington) (Chung, 2016). *Figure 42* shows the number of student participants since 2000. There was a surge in numbers this year due to the growth in the international sites especially in India. The cumulative number of registered students and teams in our web database since 2000 has reached 20,569. Note that some of these students are duplicated from year to year.

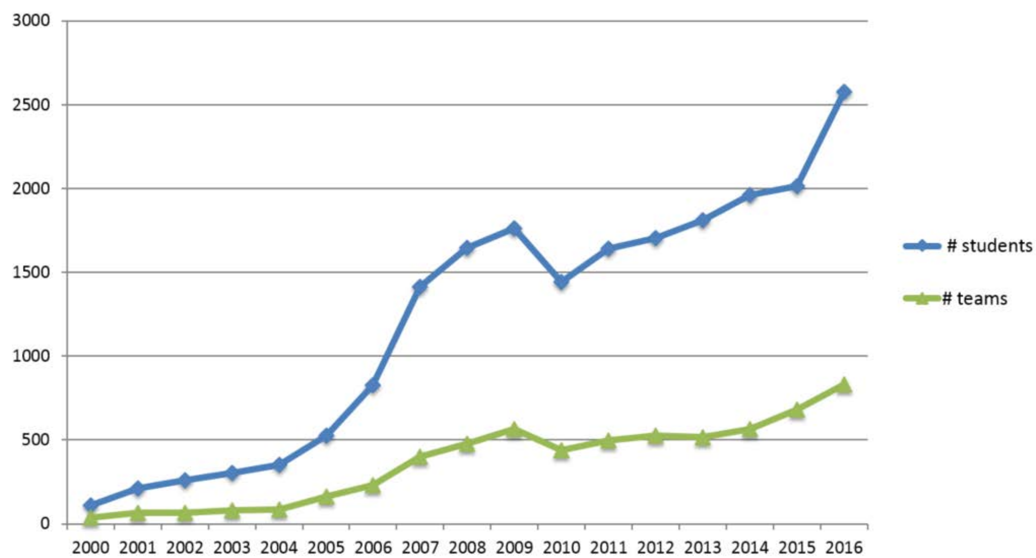

Figure 42. Number of Robofest student participants and teams since 2000

The average Robofest team size in 2016 was 3.0 which is same as that of last year. We believe this small team size is good for effective learning, since each student has more opportunity to contribute to the team’s objectives.

Robofest offers a variety of categories in which to compete. 36% of teams participated in the RoboGolf Game in 2015-2016 year. The second most popular category was BottleSumo with 34%, then Exhibition with 15% of teams. *Figure 43* below shows percentages of teams by competition category. This does not include Robofest Camp (workshop plus mini competition) data.

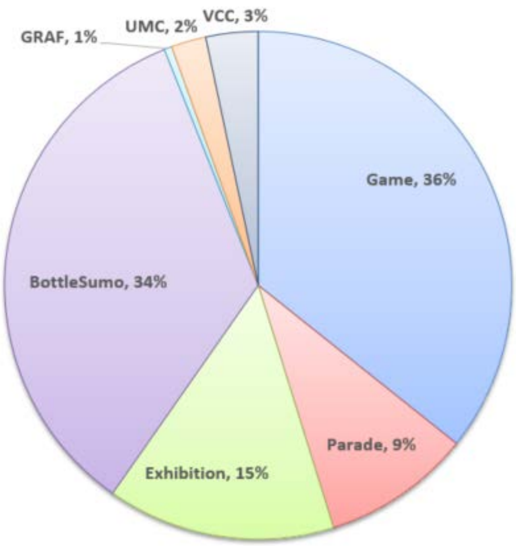

Figure 43. Percentages of Teams per Competition Category in 2016

Robofest competitions can be generalized into two categories: Games that use fixed rules including BottleSumo, VCC (Vision Centric Challenge), and UMC (Unknown Mission Challenge) and open-ended style with no fixed rules including Exhibition, RoboParade, and GRAF (Global Robotics Art Festival). *Figure 44* shows the trend of number of teams between Games and Exhibition since 2005. We can see that the participation in the open-ended exhibition categories has been decreasing since 2013. We think students are more interested in fun game style challenges than creative science-fair like categories.

Robofest checks and records students' school grades, not ages. 40% of the students were from middle school, 6th through 8th grade. 27% were from high school, 17% were 5th graders, 15% were below 5th grade, and 1% were college students. *Figure 45* shows the trend of each school grade (age) group since 2005. From 2015 to 2016, the percentage of 5th grade or younger increased from 22% to 32%. We believe this trend is positive since hands-on STEM+C learning opportunities should be offered earlier to talented young students.

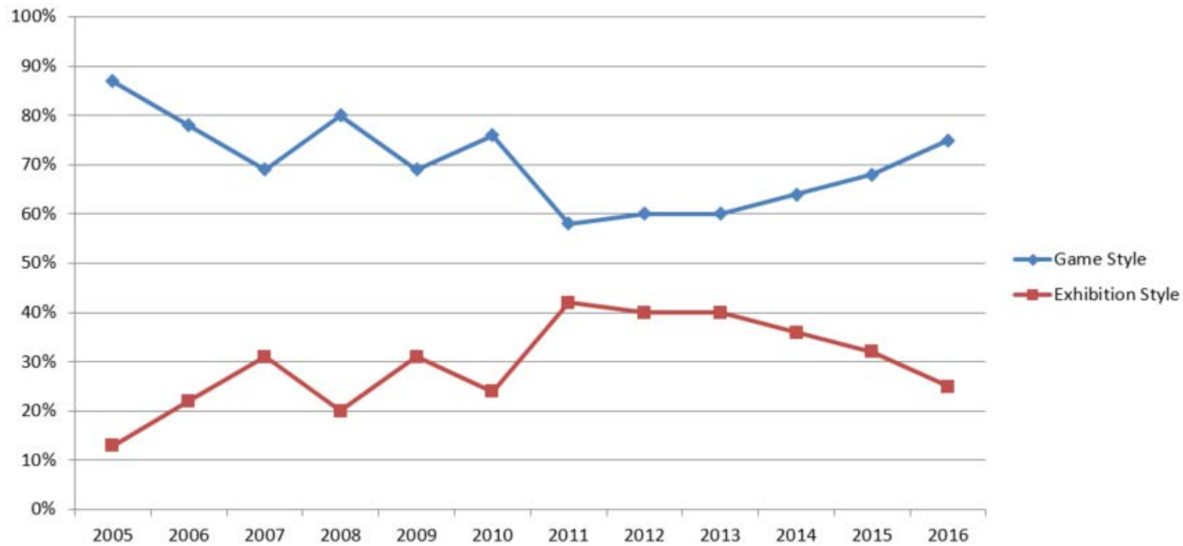

Figure 44. Percentages of Game and Exhibition teams

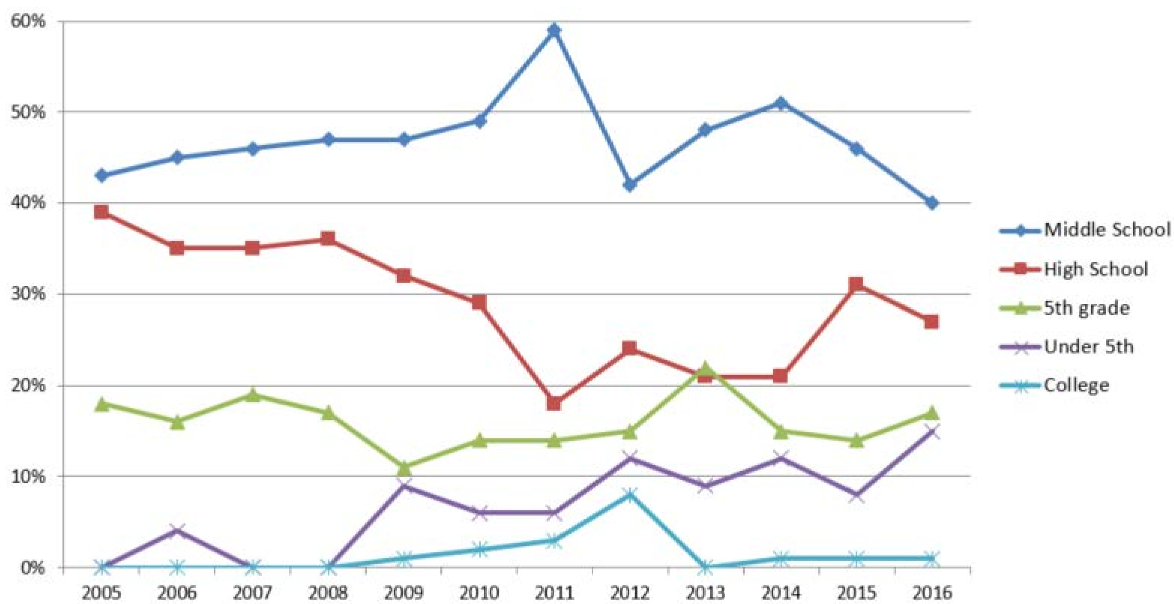

Figure 45. Percent of age group since 2005

Regarding gender, we experienced an increase of female student population in 2016; 71% were male and 29% were female students. *Figure 46* shows the gender ratios of Robofest students. The average since 2005 is 75% male and 25% female. Clearly, young female participation in Robofest is far higher than female college student participation in college engineering programs, which is ~15% (Godfrey et al., 2010). We believe this is due to female friendly categories such as Exhibition, RoboParade, and GRAF. Note that again, the data is taken directly from our registration database which means it does not include the students participating in Korea, Ghana, China, or Hong Kong as they were using their own registration system and did not provide us with their data.

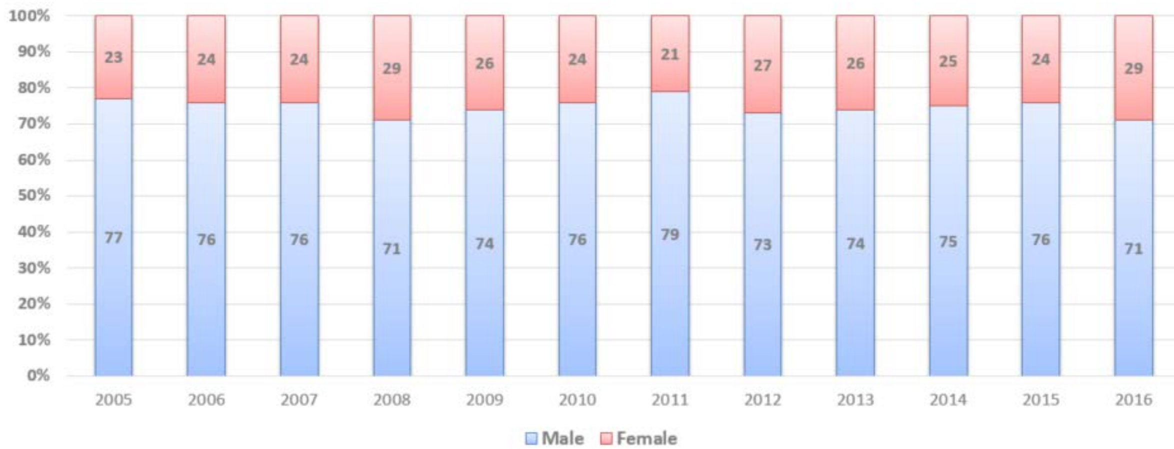

Figure 46. Gender Ratios of Robofest Students

Robofest is completely open and allows the use of any robotics platform, which is one of Robofest's unique features to promote creativity. *Figure 47* shows the data on robotics kits used by the teams. Still the majority of the teams (79%) were using LEGO® products. The use of Arduino increased notably from 3% in 2015 to 11% in 2016. Other kits include Raspberry PI (Pandey, 2013).

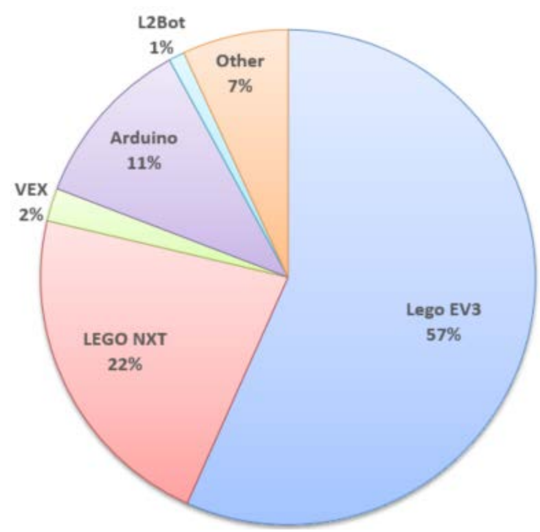

Figure 47. Percentage of Robotics Kits Used by teams in 2016

Robofest remains focused on the student participants learning STEM+C through computer programming and testing. The programming languages used in Robofest 2016 are graphed in *Figure 48*. Student teams continue to use advanced and varied forms of programming languages. Allowing students to use whatever programming language they prefer is one of the unique features of Robofest for STEM+C education. “Other C” in the figure includes Easy C, NXC, and Arduino C (Sketch). RobotC became popular when Carnegie Mellon Robotics Academy provided free licenses for Robofest teams beginning in 2009. All C-style languages together totaled 18%. Robofest provides opportunities to learn professional programming languages and helps to prepare our students for future professional career paths. Robofest students continue to show advanced technical skills and improvements in their problem-solving abilities. This is possible because of the many dedicated coaches and technical mentors associated with Robofest teams.

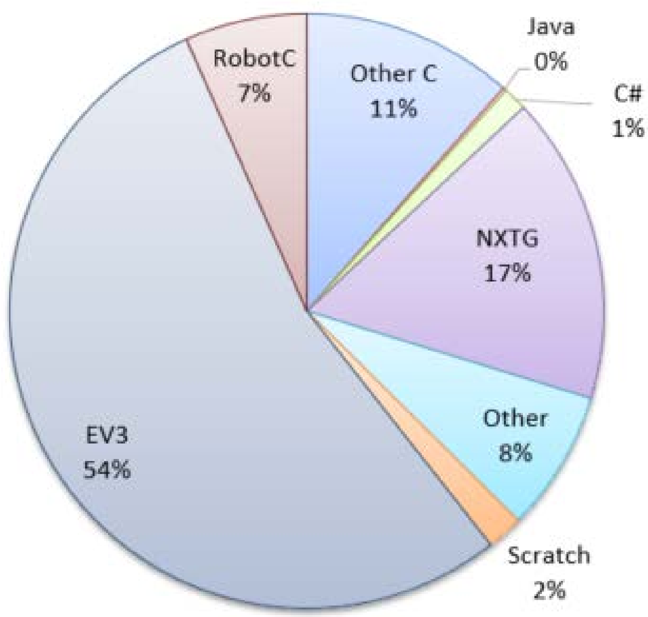

Figure 48. Percentage of Programming languages used

Evaluation

We have designed Robofest programs to collect data to evaluate the following 3 levels of impacts/outcomes (McLaughlin & Jordan, 1999):

Short-term Impact: Acquired robotics knowledge and skills can be viewed as a short-term outcome/impact. Robofest is a perfect setting for students who want to be in the STEM+C career pathway as Robofest utilizes skills from all the STEM+C subjects. During the four months of the program, many students will learn for the first time in their lives how to write computer programs for real-time embedded control systems, which are their robots! Programming itself is not easy, but when their robots function correctly, it motivates students to work harder. In addition, they will learn many aspects of real-world engineering projects, which require problem specification, system design, implementation, and testing skills.

Intermediate-term Impact: Changes in students' behavior can be viewed as an intermediate-term impact/outcome of Robofest. Based on the knowledge and skills they learned and the real-world-like competition experience, their view of STEM+C related classes will change. Students will have a reason to be more interested in learning about these subjects and they will have changed their learning behavior in relating class subjects to real-world problems. As a result, they will be more attentive in their classes and have more confidence in their skills in these subject areas.

Long-term Impact: While they are participating in Robofest competitions, students who may have not yet decided on their career path could experience a life-changing revelation, which may result in a decision to study in STEM+C related fields in college.

Short-term Impact

To assess the short-term impact of Robofest robotics competitions, students were asked to take online assessments before and after the competition based on methodologies discussed in a previous study (Trudell & Chung, 2009). In addition, the same assessment was taken with another group of students who did not participate in the competition as a control group. Each assessment consisted of 15 multiple-choice mathematics questions. Additionally, we collected information on the students' grade, gender, and whether or not they participated in Robofest, but no other identifying information. The pre- and post- assessments were implemented as a Google form.

Data (Chung & Cartwright, 2011) from Robofest 2011 involves a comparison of math scores among 4th to 12th grade students who did and did not participate in either Robofest or other robotics competitions. The pre-assessment comparison comprised 164 students who participated in Robofest and 47 students who did not participate (the control group). The post-assessment comparison involved a subset of the students who took the pre-assessment: 51 Robofest students and 40 Control students. The pre- and post-assessments were multiple-choice tests of 15 similar math questions. As shown in Figure 49, Robofest students' mean scores improved from 7.19 to 7.94 ($p < .10$), while the control group's scores actually decreased slightly.

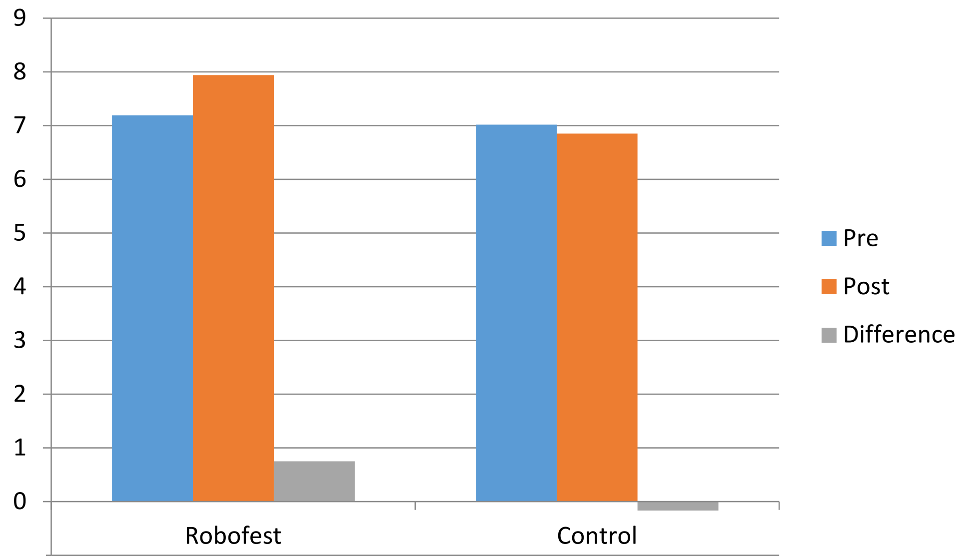

Figure 49. Robofest 2011 math assessment results

In 2013 (Chung & Cartwright, 2013), each assessment consisted of 8 multiple-choice STEM questions (6 math, 1 science, and 1 engineering). Additionally, we collected information on the students' grade, gender, and whether or not they participated in Robofest, but no other identifying information. The pre- and post- assessments were implemented as a Google document. Data from Robofest 2013 involves a comparison of math scores among 5th to 12th grade students who did and did not participate in either Robofest or other robotics competitions. The pre-assessment comparison comprised 167 students who participated in Robofest and 104 students who did not participate (the control group). The post-assessment comparison involved a subset of the students who took the pre-assessment: 75 Robofest students and 102 control students. As shown in Figure 50, Robofest students' mean STEM scores improved from 4.23 to 4.56 ($p = .19$) and STEM scores from students in the control group improved from 3.74 to 4.26 ($p < .10$) . The higher participation rate from the control group (98% of the control group students took both the pre- and post- tests while only 45% of the Robofest students that took the pre- test also took the post-test) was a result that the control group took these assessments as part of their regular classroom, while the Robofest students took these assessments outside of the classroom.

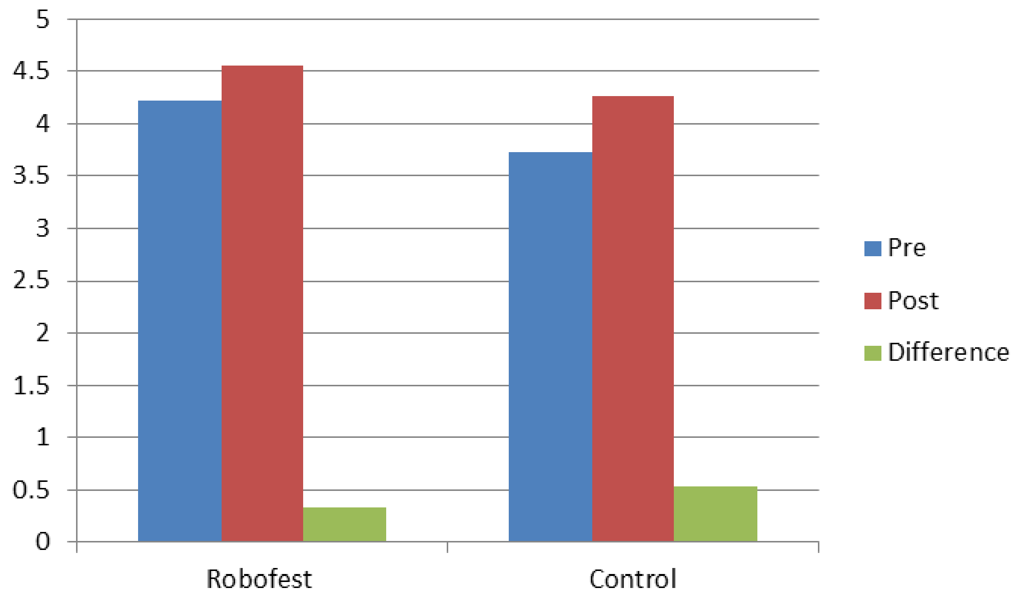

Figure 50. Robofest 2013 math assessment results

2014 assessment (Chung & Cartwright, 2014) consisted of 7 multiple-choice STEM questions (5 math, 1 science, and 1 engineering). Data from Robofest 2014 involves a comparison of math scores among 5th to 12th grade students who did and did not participate in either Robofest or other robotics competitions. The pre-assessment comparison comprised 195 students who participated in Robofest and 61 students who did not participate (the control group). The post-assessment comparison involved a subset of the students who took the pre-assessment: 21 Robofest students and 8 control students. Average school grade level of Robofest group was 7.52, while the control group average grade level was 10.8. Since the post assessment was more difficult, both groups did not improve their scores. However, the Robofest group had higher scores, even if the average grade level is much younger and the control group performed worse on the assessment than Robofest group, as shown in *Figure 51*.

These assessment studies in 2011, 2013, and 2014 suggest that participation in Robofest robotics competitions can help improve STEM scores (Chung, Cartwright, & Cole, 2014; Chung, 2015). We believe the use of explicit math components and unknown factors in Game designs as well as judging criteria requiring the use of mathematics and science components in Exhibition helped improve the STEM scores.

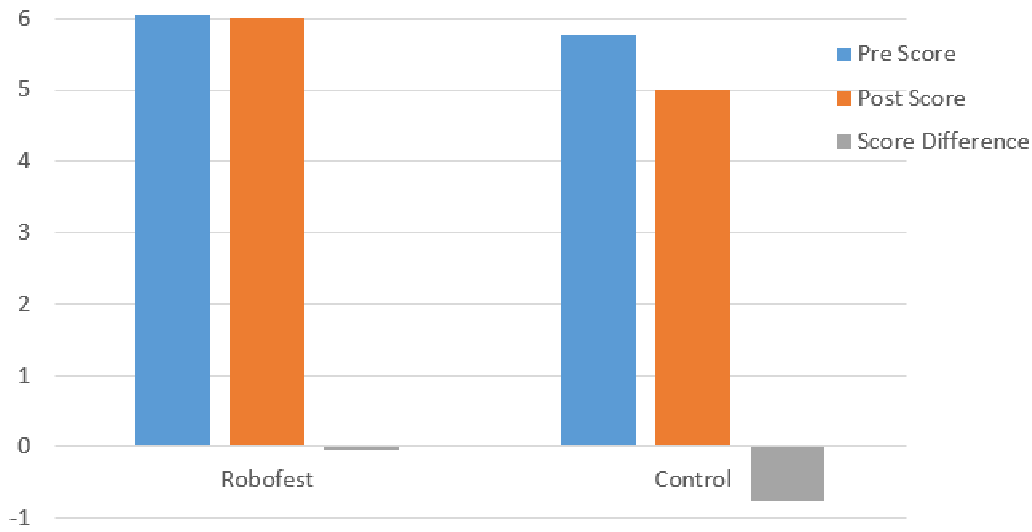

Figure 51. 2014 STEM score comparison between Robofest and Control group

Intermediate-term Impact

In 2014, we added a question to the pre and post assessments to check whether Robofest's experience would change students' interest in STEM subjects. *Figure 52* strongly shows that Robofest experience impacted their preference toward STEM subjects as compared to a result of a control group. Robofest group's STEM interest increased from 77% to 96%; whereas the control group's STEM interest decreased from 63% to 50% (Chung & Cartwright, 2014).

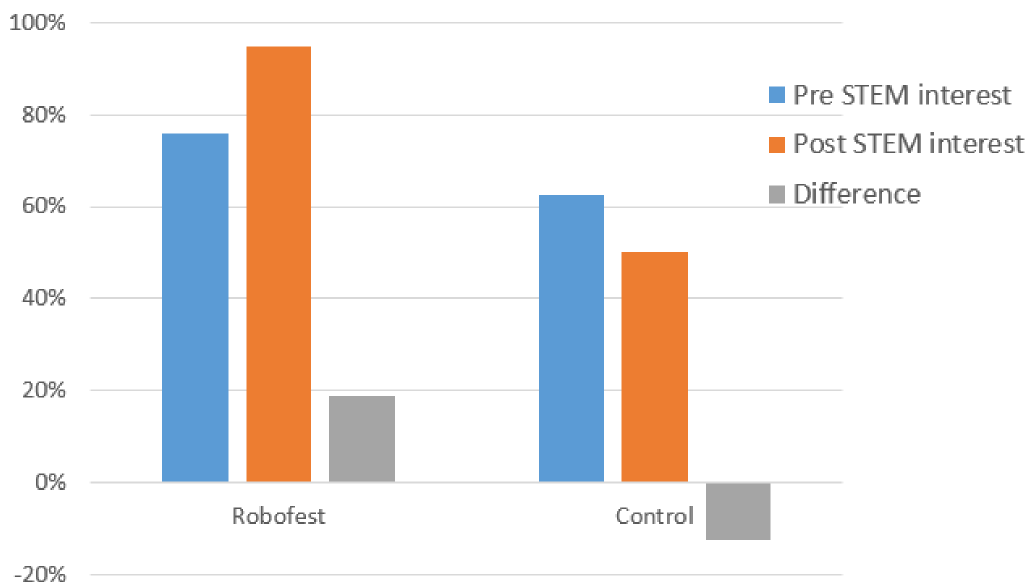

Figure 52. 2014 STEM interest comparison between Robofest and Control group

In 2015 and 2016 years, Students were asked if they would be interested in professional STEM and computer programing careers in the future. As shown in Figure 53, 82.8% of Robofest 2015 students expressed their interest in STEM+C careers before participating in Robofest. After completing their Robofest participation for around 4 months, 88.7% of the students expressed their interest in STEM+C careers in the future (Chung, 2015). 2016 results showed similar impact, from 81.8% to 63.3% (Chung, 2016).

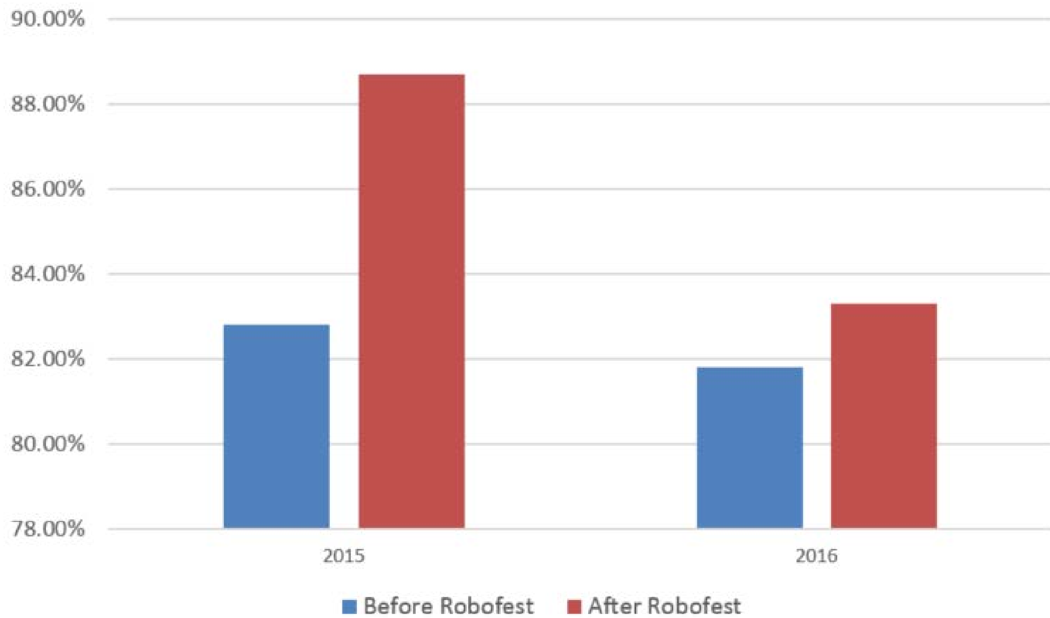

Figure 53. STEM career interest

Long-term Impact

To check how many students actually chose STEM career path, we contacted all the students who participated in the inaugural Robofest in 2000. 109 students participated in the first autonomous Robofest. Among them 12 Lawrence Tech college students entered the college level firefighting race, so they were omitted in our contact list. In 2011 after 12 years, using the phone number on the photo release form (at that time we asked only phone numbers, no mailing address) we tried to contact 97 K-12 students, after verifying the last name with Internet sites such as whitepages.com. However, after more than a decade, we were able to contact only 14 of them (either the student or parent) successfully. *Table 2* shows the summary result. 50% of them (7 students) majored in STEM areas, 43% did not major in STEM, and 7% did not go to College (Chung & Cartwright, 2011). Table 2 also lists their majors.

Table 2. *College majors of inaugural Robofest students*

Computer Science & Eng.	2
Mechanical Engineering	2
CAD (associate degree)	1
Biology	1
Civil Engineering	1
Business	2
Public policy	1
Film, broadcasting	1
English, Marketing	1
Political Science	1
Did not go to college	1

Summary and Conclusion

Autonomous robotics can play an important role in STEM+C education because it naturally promotes hands-on learning and the integration of STEM subjects with computer programming and coding. Robofest has provided something for everyone, from novice to advanced, whether they like math & science subjects or not. Since Robofest challenges are relatively simple and small, iterative & incremental learning is practically possible within one season. Robofest introduces some new ways to use robotics like VCC as an educational tool. Table 3 summarizes characteristics of the eight Robofest competition categories.

Table 3. *Characteristics of the eight Robofest competition categories*

Competition Category	***Rules***	***Unknown factors***	***Difficulty level***	***Art component***	***Age Divisions***
Game	Fixed	Some	Intermediate	No	Jr. & Sr.
Exhibition	Open-ended	N/A	All	Possibly yes	Jr. & Sr.
VCC	Fixed	Some	Advanced	No	Sr. & College
GRAF	Open-ended	N/A	All	Yes	Jr. & Sr.
RoboParade	Semi Open-ended	None	Beginner	Yes	4^{th} grade, Jr. & Sr.
BottleSumo	Fixed	Some	Beginner	No	Jr. & Sr.

UMC	Fixed but unknown	All	Intermediate	No	Jr. & Sr.
Carnival (Individual)	Fixed	None	Beginner	No	4th grade, Jr. & Sr.

Robofest is a student-centered program and has generated enthusiasm among students. Programs are designed to adopt the Problem Based Learning (PBL) paradigm. Team members work as self-directed, active investigators, and problem-solvers in small collaborative groups up to five members. Teachers/Coaches works as facilitators of learning to guide the learning process.

Robofest has been operating successfully for seventeen years and has made broad impacts locally, nationally, and internationally. Every year, over 2,500 students and over 800 teachers, coaches, parents, competition judges, and volunteers have been closely involved in Robofest programs. Robofest has been financially stable with support from team registration fees, sponsorships, and the donation of time by many volunteers. Robofest’s eight innovative programs advanced STEM+C education by providing stimulating and diverse learning environments and by integrating STEM and Arts components through the use of computer science oriented robotics. Robofest is an affordable and cost-effective program and the ROI (return on investment) is relatively high (Chung, 2015, p. 18).

The Robofest workshop curriculum focuses on mathematics and computational algorithms to solve the Robofest challenges. Assessment and survey results show that the Robofest robotics experience helps students learn more about Science, Technology, Engineering, or Math. Students expressed that they would consider a career involving Science, Technology, Engineering, or Math after participating in Robofest programs after participating in Robofest programs. Regarding long-term impact of Robofest programs, a preliminary survey shows that 50% of first year participants in 1999-2000 majored in STEM areas when they attended college years after.

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