AC 2008-2221: MAKING MATH AND SCIENCE EXCITING THROUGH ENGINEERING SPORT: THE WRIGHT STATE UNIVERSITY TREBUCHET COMPETITION

Joseph Slater, Wright State University

Dr. Joseph C. Slater received his B.S. and M.S. degrees in Aerospace Engineering, and Ph.D. in Mechanical Engineering from the department of Mechanical and Aerospace Engineering at the State University of New York at Buffalo under the guidance of Dr. Daniel J. Inman. Dr. Slater joined the Department of Mechanical and Materials Engineering at Wright State University in the Fall of 1993. His research interests are mode localization (pertaining to high cycle fatigue), nonlinear dynamics, nonlinear system ID, turbomachinery dynamics, smart structures, viscoelastic damping, and gossamer structures. He is a member of AIAA, ASME, SEM, the American Academy of Mechanics, Tau Beta Pi, Sigma Gamma Tau, and Phi Eta Sigma, is an Associate Editor of Shock and Vibration and the International Journal of Modeling and Simulation, and is an officer of the AIAA Gossamer Spacecraft Program Committee and is a member of the AIAA Structural Dynamics Technical Committee.

Making Math and Science Exciting Through Engineering Sport: the Wright State University Trebuchet Competition

Joseph C. Slater

February 29, 2008

1 Abstract

The Wright State University Trebuchet Competition distinguishes itself from other STEM outreach events in that it combines teamwork and a sporting event at the culmination of in-school educational activities. A moving average of approximately 20 local high schools participate in this event each year, with a total of 450 active participants in 2007 (year over year increase of approximately 20% for the seven year life of the event) with a drop to 277 in 2008 explained later. The competition held each Winter in a sports arena pits teams of four trebuchets against each other (four trebuchets on each side) in a battle-like match. The event has the atmosphere of a sporting event, and students are demonstrably emotionally involved with the event. Students who return after observing or participating in a previous year gain a strong understanding of the importance of preparation and teamwork. Teachers report significant increased engagement in the classroom due to the eventual payoff. Surveys illustrate a 49% increase in interest in STEM area and a 36% greater interest in attending Wright State University, even though they do not visit the campus proper during the event. With an operational budget under $2000/year, this event provides an extremely economical outreach opportunity that provides a benefit/cost ratio far beyond typical activities.

2 Introduction

Numerous outreach activities are performed by universities and professional societies and other organizations each year with goals of improving understanding by K-12 students of STEMM (Science, Technology, Engineering, Math, and Medicine) and positively impacting performance and recruitment of students into these fields through more informed educational choices. Examples of these are the NSF STEP programs[1], Science Fairs, the First Lego League[2] the TEAMS competition[3], the West Point Bridge Design Competition[4] and others.[5] Assessment of the impact of these events is challenging as the independent impact of a single event amongst many others is difficult to assess, it takes a very long time for gestation to be assessable, and keeping track of participants or finding them many years later is challenging.[6–8] These events usually entail significant cost for either personnel or equipment requiring very significant resources from foundations, government grants, participants, or individual donors.[1;2;5;8;9]

The Wright State University Trebuchet Competition distinguishes itself from every other STEMM outreach events in at least one of the following ways. First, it combines teamwork and a sporting event at the culmination of the outreach activity performed within students' home institutions. This has two positive effects: cost of sponsorship is minimized and the duration of the actual outreach activity is longer lasting. Second, the hardware and personnel costs are minimal due to the short obligation of the effort for the organization allowing for use of volunteers, and the minimal cost of materials. Third, though the fundamental operation of a trebuchet is easy to understand, the implementation and optimization that provide the bulk of the STEM educational experience are sufficiently difficult that computer modeling, experimental design, and significant redesign must take place. The effort level spanning multiple months typically precludes domination of the event by over-eager parents and teachers. Fourth, participants retain, at their pleasure, the working devices that so much effort was put into creating. Fifth, the wide variety of high school course curricula that have been impacted by the project.

3 Event Description

An average of approximately 18 local high schools participate in this event each year for the past 3 years, with a peak of 450 active participants in 2007 and 1,968 participants since 2001. There has been a year over year increase of approximately 20% for the seven year life of the event (see Figure 4). Snow cancellation and rescheduling resulted in a reduction in the number of participants in 2007. The competition held each winter in the Nutter Center in Dayton, OH pits teams of four trebuchets against each other (four trebuchets on each side) in a single elimination tournament.

Schools design trebuchets and assemble teams based on the "rules of the year", creating difficult challenges in design and significant opportunities for application of math, physics, experimental design, and computer simulation to the task. Typically, this is incorporated into the classroom lessons in schools and provides and exciting framework to engage students in these topics with construction performed after school. Limits are prescribed (weights, lengths, etc.) and changed each year for the trebuchets allowing a significant, but not unmanageable, design space within which the designers must work. Performance minimums, typically a minimum throw of 30 feet, are prescribed as a requirement for competing. This ensures that participants have a minimum level of competency which can cause significant embarrassment.

At one point in time the field design was random and unknown to competitors, but practical constraints for us have resulted in the length of the field being the width of a basketball court with the width of the field adjusted as needed (see Figure 1). As the event has grown, we now operate 6-8 fields (depending on attendance) in an area the size of a standard professional hockey rink. Each team is provided a "bucket" target representing their flag that they may place anywhere on their side of the field and must provide 10 squash balls (often reused from one year to the next,

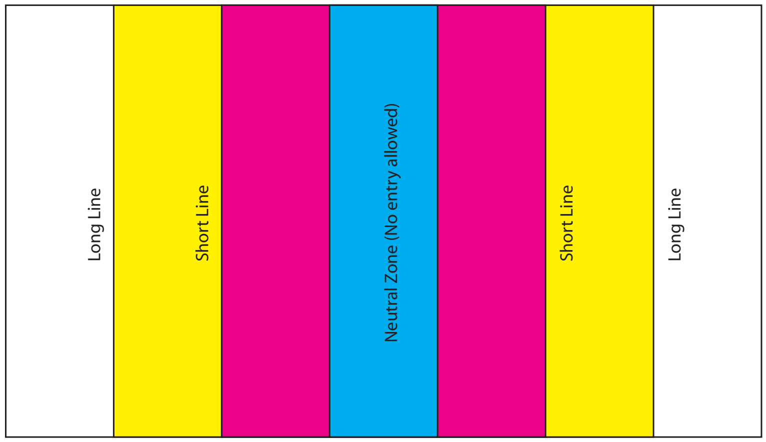

Figure 1: Trebuchet Field Design

representing an approximately $25 cost to the team) while each trebuchet comes with its own target. If their opponents strike their flag with a squash ball, they have lost the match and are out of the tournament. Thus it behooves them to attempt to place the "flag" target in as challenging a location as possible. Knowledge of ones opponent can play an important role in this decision as some teams have great difficulty firing short distances. Initially, teams must place 1 trebuchet in the yellow zone, touching the short line, and the remainder in the white zone, touching the long line. This initially provides even weak teams with one target that is in range, but some protection is afforded to the remainder of the team. Those trebuchets whose targets are hit are removed from the match. Loss of all 4 trebuchets also results in loss of the match by knockout. Every 5 minutes teams are provided a 10 second opportunity to move forward or backwards one line, and as far left or right as the field permits. This provides significant strategic options to teams that recognize them. It further provides an opportunity to move trebuchets that are being close in on by opponent projectile fire. Trebuchets with poor range are typically forced to move forward, closer to opponent fire, while trebuchets with better range will typically retreat for protection. However, the opportunity to advance to within range of the opponent's flag is certainly a tempting, if sometime catastrophic, decision.

Matches are 15 minutes long with a 5 minute setup period provided, with the exception of semi-final and final matches as necessary. Historically we have found that this is more than sufficient for better teams to complete a match by defeating an opponent. Record completion of a match was under 2 seconds – the duration of the first volley. Weaker teams typically finish matches without a knockout. A performance based decision, similar to a boxing match, is made. There hasn't been dispute of the decisions made as teams that cannot perform a knockout in 15 minutes do not typically make the round of 8 and thus are well understood by participants to be irrelevant with respect to tournament outcome. Typically at this level one team will win in about 7 minutes as the teams at this level are the most highly skilled. Further details are available on the site's website.

4 Educational Impact

While it would be desirable to have a quantitative measure of event educational impact, the current level of resources dedicated to the event precludes such a study. Evidence collected is qualitative, localized and anecdotal. because education takes place in the high schools, and there is no current direct interaction with students or engineering education of the teachers, the degree and areas of learning vary widely from school to school and teacher to teacher. This is good on the on hand because it provides maximum flexibility to the teachers for incorporation of concepts into their classes as time permits and other teaching requirements allow. On the other hand, the under-education of teachers in engineering concepts leads to mixed results, especially when the least engineering inclined teachers over-advise. This was illustrated very recently in the 2008 event where multiple teams did not participate (note declined participation) because the lack of a formal engineering approach to problem solving left many schools with unworkable designs until it was too late to schedule busing. Numerous teachers refused advice from the author to use computational design tools (for example, WinTreb), to initiate the design process instead of repeatedly building and testing.

Phone interviews with these teachers indicated the following: it is common for high school "engineering" projects to be to build something of a device, evaluate how it works, and move on. Many of these articles are either pieced together from standard building blocks, and thus easily built, and rebuilt, until success is achieved, or in many cases directly from plans. Plans for trebuchets abound on the Internet, and the impression becomes one of engineering as following plans for construction.

Unfortunately for them, the design requirements for the competition preclude using a "canned" design, and the problem is one of multi-dimensional constrained optimization. Of course there is no expectation that the phrase "multi-dimensional constrained optimization" would mean anything, but it was surprising how much resistance existed to using computational tools in the way engineers do. One of the requirements was that the arm length be below what turned out to be a rather ridiculously long length after analysis (exceedingly far from optimal). Unfortunately, many teachers took the maximums allowed by the rules as the starting point for their design, and small incremental changes were insufficient to drive them to a workable device. We will be seeking funding to generate continuing education courses for teachers to address this. The constrained trebuchet design problem, with relatively few variables, demonstrated clearly that implementation of engineering design practices is necessary to generate a successful design given the time available.

Some direct evidence of the application of engineering principles in design is illustrated through the report competition, which not all teams participate in. The winners of the 2007 report competition have a table illustrating their study of the impact of string length on throwing distance and chose a length of 12 inches based on their experiments. Teams participating in the report competition are required to provide descriptions of their design methodology and demonstrate experimental results. Within the submitted reports, sections on experimental design and analysis illustrate variation of design parameters, the resulting performance of the trebuchet, and optimization of the design based on parameters studies by the team. Parameters studies include length of the arm, location of the pivot on the arm, height of the pivot, brands of soda used at the counterweight, length of the string (see Figure 2), different material choices, choice of bearing, lubricants, etc. No single team has reported studying all of these variables, but study of these variables has been reported to me through the reports or through discussions with the teachers.

Figure 2: Holes in the arm near the pivot illustrate use of experimental design to determine optimal pivot location.

One variable, choice of brand of soda, is confusing to many participants and observers. The rules state a number, variable from year to year, of cans as the counterweight, but not the actual mass. This is an intentional design variable left open to participants to discover. Some teams do discover the variable, but most do not. Measurement of brands in the area illustrate an 11% variation in mass, and thus can contribute significantly to a teams success. Discovery of this and other design opportunities is illustrated in the creativity of the designs.

5 Event Impact

One of the strongest endorsements of the event is the growth of participation experienced during the past five years as show in Figure 4. The only advertising that is performed is a mailing to regional teachers in math, science, and technology, in addition to their supervisors. A two year lull occurred in the 2003 and 2004 time frame due primarily to a lack of sufficient and timely promotion. The 2004 event was the first time that investment in dollars and assigned personnel costs for the event exceeded the cost of busing of any individual school (approximately $500). At this time a one course release was given to the event director to further the outreach effort and $500 was provided by each of the two STEM colleges. Prior to that small donations from local companies provided money for 40 or so volunteer t-shirts and pizza for the volunteers. Donations exceeding $1000 were first received in 2005 and have since been leveraged to provide a more professional level of support for the event. Nevertheless, the event still typically operates for approximately $2000 per year plus the cost of replacing the lost teaching assignment with an adjunct. Gifts from

Figure 3: Hole in the arm of the trebuchet illustrate an understanding of parasitic mass, but not necessarily experimental design.

the university for the purposes of promotion of the university are given and typically cost about twice as much as running the event itself. The real cost of the event is born by the additional hours worked by staff members, students, and faculty who volunteer time to the event.

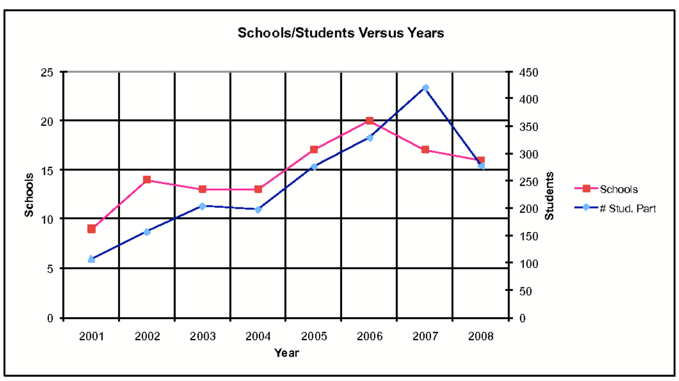

Figure 4: Participation over a five year period. 2007 attendance was hurt by a snow cancellation and rescheduling. Attendance in 2008 was hampered by a lack of application of engineering design processes.

The most obvious impact of the event to participants and observers is that it is a thrilling event. With 60 teams competing in the single elimination tournament in 2007, the event has the atmosphere of a sporting event and students are demonstrably emotionally involved with the event. The tournament is scheduled in-situ, but every effort is made to assure that teams from the same school play each other as much as possible before exposure to other schools. While not providing a true champion for each school, it does prevent an entire school from from loosing all teams in the first round. Further, by assuring that schools don’t span the four major brackets, we assure that the same school cannot win more than one of the top four places (There have been exceptions made for unusual cases). This is important because it keeps schools emotionally vested and interested in the event. Further, the schools will rally around their remaining teams with an unusually strong emotional response not typical of technical competitions due to the direct competition with rival schools. Significant rivalries have been formed between the competing schools and this motivates a very proactive response post tournament of planning for the next year's event. Screaming, cheering, crying, anguish, and relief illustrated by competitors attest to the emotional impact of the event and the investment the students have put into preparation for the event. Students often wear a uniform of some sort, depending upon the personality of the team, including fatigues, sports wear, matching shirts with team names, an and annual favorite the "Flying Pigs", an all girl team dresses head to toe in pink with matching trebuchets.

Trebuchet Competition Survey
February 8, 2008

Please take this completed survey to the tables located on the concourse in between sections 219-224 between 10am – 2pm to receive a FREE t-shirt

Name: ____________________

Address: ____________________

City: ____________________ State: _______ Zip: _________

Birth Date: ____________________ (mm/dd/yyyy) Gender: ______________

High School: ____________________ Graduation Year: _________

The Trebuchet Competition increased my interest in engineering, science, math, technology, etc.
___ Strongly agree
___ Agree
___ Disagree
___ Strongly disagree
___ Does not apply

I would recommend that my friends participate in the Trebuchet Competition next year.
___ Strongly agree
___ Agree
___ Disagree
___ Strongly disagree
___ Does not apply

I am considering secondary education in a technical field.
___ Strongly agree
___ Agree
___ Disagree
___ Strongly disagree
___ Does not apply

The Trebuchet Competition has increased my interest in attending college.
___ Strongly agree
___ Agree
___ Disagree
___ Strongly disagree
___ Does not apply

Attending this program provided me with Wright State information I wanted/needed.
___ Strongly agree
___ Agree
___ Disagree
___ Strongly disagree
___ Does not apply

I am more interested in attending Wright State after my visit.
___ Strongly agree
___ Agree
___ Disagree
___ Strongly disagree
___ Does not apply

I would like to see more of campus or receive more WSU information during the event.
___ Strongly agree
___ Agree
___ Disagree
___ Strongly disagree
___ Does not apply

I would like to receive more information about WSU from (check all majors you are interested in):
The College of Engineering and Computer Science
__ Biomedical Engineering
__ Computer Engineering
__ Computer Science
__ Electrical Engineering
__ Engineering Physics
__ Industrial and Systems Engineering
__ Materials Science Engineering
__ Mechanical Engineering
__ Undecided Engineering
The College of Science and Math
__ Biological Sciences (Environmental Health Sciences, Exercise Biology and Clinical Laboratory Sciences)
__ Chemistry
__ Earth and Environmental Sciences
__ Integrated Science for Educators
__ Mathematics & Statistics
__ Physics
__ Psychology
The College of Nursing and Health
__ Nursing

Suggestions for improving next year's Trebuchet Competition:

Figure 5: Survey required by attendees, participant or not, at the 2008 Trebuchet Competition.

The challenge with quantifying this impact is that it is very distributed (multiple schools, multiple courses), and design of a controlled experiment within the region is no longer realistic due to its wide-reaching effect. It is necessary to have a school commit to the event more than a year in advance, but not attend in the intermediate year, in order to isolate the impact of the event from other factors. An attempt will be made this year to do this with one large local school district that historically has not attended but is considering future participation. Regardless, reports and discussions with teachers attest to the improved focus and excitement that this brings to the classroom, as any topic that may provide a team an edge in competition becomes one of vital interest to the engaged students.

Surveys were conducted of all attendees who were students (see Figure 5). A summary of the results (more detail in Table 1) are:

1. 84% of students became more interested in STEM areas as a result of participation in this

program (up from 49% in 2007).

2. 88% would recommend their friends participate in the event.

3. Subsequent to the event, 61% are now considering an education in STEM areas (up from 45% in 2007).

4. 67% of students had an increased interest in attending college after this event (up from 40% in 2007).

5. 52% of students are more interested in attending Wright State University after the event (up from 34% in 2007).

6. 51% of students want to see more information about Wright State University at the event (up from 46% in 2007). This is after setting up 12 tables with demonstrations from across two colleges, as well as admissions support and scholarship support.

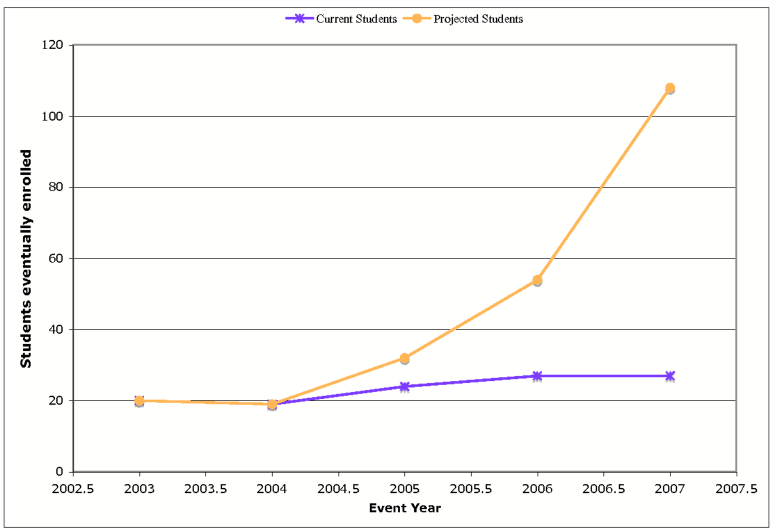

Figure 6: Enrollment numbers from each year's participants. Note that it takes four years for all participants in a given year to be eligible to enroll in college.

Within the understanding that surveys are not outcomes, they do strongly indicate a very strong positive impact beyond impacting STEM education in high schools. The event clearly:

1. Changes perception and improves interest in STEM careers.

2. Creates a significant recruitment opportunity for the hosting institution. This in spite of very minimal demonstration or recruiting during the event and the fact that students didn't see the campus or other university facilities during the event.

3. Improves interest in post-secondary education broadly. This is vital to the region as Ohio is falling far short in providing trained professionals with STEM backgrounds.

Due to ad-hoc nature of the event in its early years, records of participant names are poor, even through 2007, so direct enrollment impact of the event is challenging to assess. Also, since participants range from middle school in some cases to seniors, and students often participate multiple times, the impact of a single event takes a long time to assess in terms of university enrollment (3 years for a freshman participant). Further, since there is no assurance of correct names, and there are certainly spelling errors, false names, and nicknames used in place of real participant names, tracking is further damaged. However, and automated tracking system, which compares names of registrants to names in the university database was created to simplify this process. Results from those searches are presented in Figure 6. As it takes 3 years for freshman in the competition to be eligible to enroll, only the outcome from 2004 could be assessed in fall of 2007. Projected numbers for years after that were generated by presuming that the true enrollment numbers are prorated by the portion of students eligible for enrollment in Wright State University and adjusted accordingly. For instance, only one quarter of 2007 participants could enroll in college in 2007, but one half of 2006 participants could be enrolled in college by 2007. Thus it is expected that enrollment of participants from 2007 would be approximately 2/3 of the enrollment from 2006 participants given the greater participation in 2007. In fact, this number is better than expected, and is likely the result of the two simple recruiting and advertising efforts that were put forth in 2007. Further supporting these projections is that in the two years of the event for which all students have been eligible for enrollment, 10% have enrolled at Wright State. Given a 10% recruitment success rate, 27 participants from the 2005 event would be expected to enroll. The projection using proportioned numbers only slightly exceeds this (by 10%). Keep in mind that no efforts at recruiting or follow up were made until 2007. Recruitment numbers for 2007 *without* active recruitment and followup would be predicted at 42 using the 10% number. However, at the 2007 event 3 recruiting professionals representing the College of Engineering and Computer Science were on hand to speak about programs and other opportunities. The 34% of students whose interest in WSU increased as a result of this event amount to 140 students. If less than half of them are recruited our projection will be matched. A much more extensive recruiting effort was implemented in 2008, but results of surveys, etc. have not yet been compiled. However a quick review of the results indicates that the improved recruiting effort increased this number from 34% to over 50%. Nevertheless, it will take at least 3 more years to completely evaluate the success of the event for the purposes of recruitment.

An optional report competition with monetary prizes provides additional learning opportunities and motivation for students. These reports are usually team written and used as course assignments. The enthusiasm for the event helps motivate technical writing, noted as one of the most critical shortcomings of engineering graduates today.[10] The quality of these reports is encouraging as an educator and also provides additional direct interaction opportunities with some of the brightest participants. We are hoping to transition to scholarships in the near future.

6 Conclusion

With an operational budget under $2000/year, this event provides an extremely economical outreach opportunity that provides a benefit/cost ratio far beyond typical activities. Year over year growth and feedback from students and teachers alike validate the claims of significant im-

Table 1: 2008 Survey Results

Question number	Response Option	Number of Responses
The Trebuchet Competition increased my interest in engineering, science, math, technology, etc.	Strongly Agree	76
	Agree	158
	Disagree	24
	Strongly Disagree	6
	Does not appply	15
I would recommend that my friends participate in the Trebuchet Competition next year.	Strongly Agree	114
	Agree	131
	Disagree	17
	Strongly Disagree	9
	Does not appply	6
I am considering secondary education in a technical field.	Strongly Agree	80
	Agree	86
	Disagree	70
	Strongly Disagree	12
	Does not appply	25
The Trebuchet Competition has increased my interest in attending college.	Strongly Agree	75
	Agree	113
	Disagree	43
	Strongly Disagree	13
	Does not appply	35
Attending this program provided me with Wright State information I wanted/needed.	Strongly Agree	50
	Agree	124
	Disagree	46
	Strongly Disagree	14
	Does not apply	45
I am more interested in attending Wright State after my visit.	Strongly Agree	49
	Agree	94
	Disagree	60
	Strongly Disagree	15
	Does not appply	56
I would like to see more of campus or receive more WSU information during the event.	Strongly Agree	49
	Agree	88
	Disagree	72
	Strongly Disagree	18
	Does not appply	43

pact. Controlled studies via replication of the event elsewhere are necessary to better quantify the impact of the event. Replication of the event has already occurred elsewhere, but no significant collaboration has taken place as of yet. Thus the ability of the event to be replicated and successful in other environments has yet to be proven.

7 Acknowledgements

The author would like to acknowledge Cathy Davis and Ann Wright for compiling the survey results and data. The author would also like to thank leaders of the event Raymond Hill, Michael VanHorn, Michael Myers, Tim Leger, Renecia Joseph, David Kender, Greg Wilt, Ravi Penmetsa, and other valuable volunteers who assist with the event. Appreciation is also extended to Dean Wheatly of the College of Science and Math, Dean Jang of the College of Engineering and Computer Science, Provosts Hopkins and Angle, Vice President Abrahamowicz, EE Department Chair Fred Garber, ME chair George Huang for sponsorship and support. Special thanks is extended to Vickie Slone and the EE department for staff support for the event and John Cox and John Siehl of the Nutter Center for providing the facility and support at no cost. The majority of student volunteers came from the student SWE and Wright Engineering Council. Funding was provided by Honda, Goodrich, Delphi, the Ohio Space Grant Consortium, and Business Labs.

References

1. Hixson, S. H., "NSF STEP Program," Tech. rep., National Science Foundation, 2007.
2. [online]Jan 2008. Available from: `http://www.firstlegoleague.org`.
3. [online]Jan 2008. Available from: `http://www.jets.org/teams`.
4. Ressler, S. J. and Ressler, E. K., "Using a Nationwide Internet-Based Bridge Design Contest as a Vehicle for Engineering Outreach," *Journal of Engineering Education*, Vol. 93, No. 2, Apr 2004, pp. 117–128.
5. Jeffers, A. T., Safferman, A. G., and Safferman, T. I., "Understanding K-12 engineering outreach programs," *Journal of Professional Issues in Engineering Education and Practice*, Vol. 130, No. 2, Apr 2004, pp. 95–108.
6. Moreno, N., "Science Education Outreach: How K-12 School Partnerships Benefit Higher Education," *Faseb Journal*, Vol. 18, No. 8, May 2004, pp. C115–C115.
7. Moskal, B. M., Skokan, C., Kosbar, L., Dean, A., Westland, C., Barker, H., Nguyen, Q. N., and Tafoya, J., "K-12 Outreach: Identifying the Broader Impacts of Four Outreach Projects," *Journal of Engineering Education*, Vol. 96, No. 3, Jul 2007, pp. 173–189.
8. Wankat, P. C., "Survey of K-12 Engineering-Oriented Student Competitions," *International Journal of Engineering Education*, Vol. 23, No. 1, 2007, pp. 73–83.

9. Cejka, E., Rogers, C., and Portsmore, M., "Kindergarten Robotics: Using Robotics to Motivate Math, Science, and Engineering Literacy in Elementary School," *International Journal of Engineering Education*, Vol. 22, No. 4, 2006, pp. 711–722.

10. Sageev, P. and Romanowski, C. J., "A Message from Recent Engineering Graduates in the Workplace: Results of a Survey on Technical Communication Skills," *Journal of Engineering Education*, Oct 2001.