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Survey of K-12 Engineering-oriented Student Competitions*

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Fifty three primary and secondary level competitions were identified through an extensive web search. They range from local to national in scope and the most popular topic is robotics. A single team may do well in a competition for several years. When the competition requires building something, winning teams typically have an enthusiastic advisor and access to money, space, tools and experts. Although many students who participate in competitions study STEM disciplines at the tertiary level, it is not clear if competitions encourage students with no initial interest to study engineering or if students interested in engineering join these competitions.

Keywords: competitions; design; K-12, engineering outreach; robotics

INTRODUCTION

ALTHOUGH THE SITUATION is starting to change with laws in several states requiring students to study engineering and technology in the primary and secondary levels, most students in the USA do not study engineering before going to college. In addition, engineering may be the only major profession that is not directly familiar to most students. Because this situation negatively impacts the flow of qualified students into engineering, a number of different outreach activities have been developed. The goals of these activities include:

1. Encourage students to consider an engineering career
2. Motivate students to continue to take mathematics and science courses
3. Increase students' and hence the general public's technological literacy [1]
4. Help students and the general public understand engineering.

Student competitions that are engineering and technology oriented are common outreach activities that are expected to help meet these goals. In primary education, and to a lesser extent secondary education, science, mathematics, technology and engineering overlap considerably in competitions. For goals (2) and (3) this overlap causes few problems and it doesn't really matter if a student in primary school enters an engineering project in the local science fair and thinks of it as a science project. However, for goals (1) and (4), we need to try and obtain truth in advertising so that the public and students will understand the importance of engineering and students will understand the differences between careers in science, engineering, and technology.

There is significant confusion in the public's mind over what engineering is. A useful definition can be obtained by combining definitions from several sources. Engineering is the ingenious [2] "creation of devices, systems, processes and structures for human use" [1] under constraints such as money and the environment [3, 4] using heuristics to obtain solutions [4]. Furthermore, "math is the intellectual toolkit that separates the engineer from the technician" [2]. Hopefully, engineering competitions, particularly at the secondary school level would require students to meet most of the requirements of this or similar definitions.

BACKGROUND

A number of pre-college competitions have been discussed in the literature. The West Point Bridge Design Contest (No. 10 in Table 1) is one of the largest and most complex such competitions [5,6]. Contestants download the West Point Bridge Designer software and learn how to use this software during a collaborative (teams can work with teachers, parents, experts and other teams) two-month qualifying round. Forty teams are selected for the semi-final round in which they have three hours to solve a new problem in a non-collaborative mode. The top five semi-final teams are awarded trips to West Point, New York, for the two hour final round. The winners received $10,000 scholarships. At the contest peak in 2003 over 13,800 teams submitted over 77,600 unique bridge designs [6]. Because of reduced funding, there was no advertising in 2004, which probably caused the observed reduction in number of teams (10,700) and number of unique bridge designs

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submitted (49,200). To handle such an enormous number of entries, all judging was done by a computer program. Extensive assessment of the contest was conducted [6]. Students believed that they learned a significant amount about structures and the engineering design process. At the four schools studied the percentages of student who agreed or strongly agreed with the statement, "Contest increased my interest in engineering," ranged from 42.0% to 69.2%. In 2004 [6] 66.6% of the West Point Bridge contestants were male, 21.2% were female and the remainder did not provide this information. The distribution by race was: white, 59.9%; black or African American, 6.0%; Native American or Alaskan Native, 0.8%; Asian, 7.4%; Pacific Islander, 0.7%; other, 5.7%; and 19.5% did not provide this information. A Hispanic origin was claimed by 13.4% of the contestants, 61.8% were not Hispanic, and 24.8% did not provide this information. The authors were disappointed by the low percentages of women and minorities, which mirror the population of engineering students.

Another major competition is the FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition (No. 1 in Table 1) [7–11]. Currently, FIRST involves approximately 25,000 high school students in close to 1000 teams from Brazil, Canada, Ecuador, Israel, Mexico, the UK, and most states of the USA [7]. In addition to the FIRST Robotics competition, FIRST is introducing a less expensive VEX Robotics competition at the secondary school level, and has developed the FIRST LEGO League (FLL) competition for students ages 9 to 14. Most of the team mentors have backgrounds in engineering or technology. The FIRST Robotics competition is basically a robotics competition involving solving a particular problem better than competing robots both alone and in cooperation with other teams. It also involves a number of sub-competitions such as a web site competition, an animation competition, and a control systems competition. FIRST has sponsorship from a large number of companies [8, 9, 11], collaborates with ASME (American Society of Mechanical Engineers) [9], and works with a number of universities [9]. The impact of FIRST on students has been extensively studied [10]. Although a very high percentage of graduates (>40%) major in engineering in college, it is unclear if they joined FIRST because of this interest or became interested because of participation in the FIRST competition. First LEGO League participants are heavily male (70%) and white (78%) [10].

Robotics has been used as a recruitment tool for increasing the number of minorities in engineering. LEGO robots were used to include high school students from a minority high school in university-level competition [12]. The competitions were very attractive to students, but it is too early to tell if the high school students will matriculate in engineering. Smith College developed a competition to design toys as a method to encourage young women to consider engineering careers [13]. This competition has become the Toy Challenge sponsored by Hasbro (see item 29 in Table 1). Other engineering disciplines also use competitions for recruiting. The AIChE (American Institute of Chemical Engineers) Chem-E-Car competition developed for college students was adopted for high school competitions in a career day (No. 24 in Table 1) [14]. This competition appears to have a positive effect in influencing students to study chemical engineering.

There is some concern that competitions could result in negative learning experiences for some students. The Center for Youth and Communities at Brandeis University analyzed the impact of FIRST Robotics and FIRST LEGO League (FLL) [10, 15, 16]. FIRST Robotics participants and mentors reported [15] that students improved their communication skills (90%) and increased their understanding of teamwork (90%) and of the role of science and technology in society (89%). Eighty nine percent of participants reported having "real responsibilities" in FIRST, 76% reported involvement in leadership, and 74% thought the students made important decisions. Participants reported an increased interest in science and technology (86%), and 69% reported more interest in science and technology careers. Participants also reported an increase in their ability to solve unexpected problems (93%) and better time management under pressure (90%). Alumni reported that they had graduated from high school (99%), went to college (89%), and 41% of the alumni who reported a major were in engineering. In addition, 78% of the FIRST alumni anticipated earning a degree higher than a bachelor's degree. These percentages are all higher than national averages; however, the report notes that it is impossible to determine if participation in FIRST improves the quality of students or if strong students choose to participate in FIRST [15].

Participants in FIRST LEGO League were very positive about their experiences and only 1.5% did not like the program [16]. (Of course, students who didn't like the program are likely to drop out and not be in the group that was surveyed.) Ninety percent of the FLL participants reported that FLL increased their knowledge of engineering and science careers and 95% reported an increase in knowledge of the everyday importance of science and technology. The FLL coaches reported greater than 90% of the students increased their teamwork, leadership, basic science, problem solving and basic programming skills.

With US National Science Foundation support, Science Olympiad (No. 51 in Table 1) conducted a three year study of the impact on students of participation in the Georgia Science Olympiad [17]. Science Olympiad is an extracurricular activity that uses an inquiry-based format where teams of students compete with other student teams. The inter team competition encouraged extensive within team collaboration. Learning communities that included students at several grade levels naturally result as part of the structure. Students were enthusiastic and actively engaged during weekly preparation meetings and during competitions. The study showed that participants gained in collaboration, problem-solving and creativity skills. Science Olympiad appears to be more attractive to males than females.

The incentive to do this research came from an earlier research project on college-level engineering competitions [18]. College-level engineering competitions appear to have a significant positive impact on students including an increase in motivation and helping them learn about real-world design [18]. Although no college dominates all competitions, some competitions are dominated by one or two colleges. "Institutions that consistently win a competition usually have a dedicated faculty advisor/teacher and/or the close alignment of the competition with their curriculum. Also important are a tradition of winning, the quality of the students, and (for hands-on competitions) the availability of resources." [18]. The previous study of college competitions guided the development of the current study of primary and secondary level engineering-related competitions. This paper samples engineering-related competitions in primary and secondary education, mainly in the USA, and discusses the benefits of these competitions. The goal is to answer the key educational research question, "What is happening?" [19].

WEB SEARCH OF COMPETITIONS

A web search identified 53 regional and national engineering-related competitions for primary and/or secondary students, mainly in the USA (Table 1). Table 1 is an extensive sample of the types of engineering-related competitions available at primary and secondary levels. A sampling of large science fairs (items 32–38) is included since many student projects for these fairs are engineering or technology. The largest fair officially recognizes this in its name—Intel International Science and Engineering Fair (item 34) and Science Service also recognizes that fairs are science/engineering (item 37). Obviously, a much larger number of local and regional science/engineering fairs that feed into the national fairs could have been included. A few college engineering open houses that hold competitions are included as a sampler of the many similar programs (items 18–23). Also included are related competitions in biology (item 52), chemistry (item 53), mathematics (items 49–50), science (item 51), and technology (item 46).

Popular competitions include various robotic competitions such as the FIRST Robotics Competition (item 1) [7,10] and Best Robotics (item 9); bridge design as exemplified by the West Point Bridge Design Contest (item 10) [5, 6]; space exploration (items 42–44); Future City Competition (item 41); original research (items 32–39); and tests such as Mathcounts (item 49), ACSL computer science contest (item 12) and TEAMS sponsored by JETS (item 31). Robotics is the most popular subject for primary/secondary competitions—more than 25% of the competitions listed in Table 1 have at least one sub-contest involving robots. This popularity is not surprising since robotics is a very popular topic for contests at all levels [20]. Contests involving programming, web page development or use of simulators are included in about 15% of the competitions in Table 1. Programming is also a popular topic for contests at all levels [21]. Original research is also featured in 15% of the competitions—mainly at science/engineering fairs. Bridge design and/or construction are included in about 11% of the competitions in Table 1, although it is the major focus of only the West Point Bridge Design Contest. Many competitions have bridge building as one of a series of contests [e.g., building a bridge of balsa wood (items 19 and 22 in Table 1), of spaghetti (item 24 in Table 1) or of toothpicks (item 23 in Table 1)].

Competition prizes range from a certificate or plaque to $100,000 scholarships. Generally, prizes are larger for competitions supported by companies and/or the US government than for competitions supported by colleges and/or professional societies. Approximately one-third of the competitions were for individuals, one-third for either teams or individuals, and one-third for teams. Entry fees range from no charge for the West Point Bridge Design contest [5, 6] to $5000 per team for FIRST [7]. Judging may require evaluation of a handful of entries to the over 77,000 unique bridge designs submitted to the West Point Bridge Design Contest in 2003 [5]. Roughly half of the competitions involve paper/computer designs or tests while roughly half involve building something (e.g. a robot or a bridge) to complete a task.

The web search also looked for winning schools (first, second or third place) from 2001 to 2004. Schools that won the same contest more than once are listed in Table 2. Because many of the contests are new or do not archive their winners in an easy to access manner, this listing is incomplete. It is clear that a school or consortium of schools can do quite well in a competition several years in a row, but unlike the college competitions [18], there are relatively few primary and secondary competitions that are clearly dominated by a given school. The reasons for this difference between the college and primary/secondary levels are unclear.

STUDY OF FIRST ROBOTICS

A more detailed study of FIRST Robotics (No. 1 in Table 1) was conducted to look at appropriate definitions for success, the reasons why teams are successful, the benefits of being involved in competitions, and whether FIRST is successful at recruiting new engineering students. FIRST was selected for a variety of reasons. It is a large-scale, international competition that is heavily supported by companies [7, 8] and universities [9]. In addition to the marquee robotics competition, FIRST has competitions in a number of other areas including web site design, animations, and community service. A very large number of documents are stored within the FIRST web site [7] including several studies on the impact of FIRST Robotics and FIRST LEGO League on students [10, 15, 16]. I was also familiar with FIRST because both my children belonged to FIRST at the West Lafayette High School and because Purdue University supports FIRST. There also was easy access to FIRST mentors and advisors for interviews. Finally, the experience of FIRST might be directly useful to engineering colleges for volunteer community service or service learning opportunities [9], as a recruitment tool, or for project ideas in robotics courses used for retention of first year engineering students [22].

Structured interviews were conducted with six people who have extensive experience with FIRST in one or more aspects such as advisors, mentors, alumni, engineering and technology professors, parents, and involvement in running regional competitions. The following questions were used as a basic structure for the interviews although all six interviewees were encouraged to add additional comments at any time. Although answers did not always follow the order of the questions, they will be grouped in this way for clarity.

Questions at interviews

Q1. Do competitions involve students more than activities that do not include a competition?

Most of the interviewees thought the answer was yes. With all the activities available to students, the competition does attract students who would not keep coming otherwise. The competition provides a context to work on a complicated technical project with realistic objectives and deadlines.

Q2. What factors have you observed that lead to success of a student team? (a). High school student quality? (b). Leadership by one or two high school students? (c). Experienced students?

There was considerable discussion over what constituted success. Although winning was recognized as important and the desire to win is a strong motivator, there was general agreement that the competition should be much more than winning. FIRST emphasizes this by having the highest award, the Chairman's award, be based on community service and connections with younger students. FIRST also has a number of ways that students can participate in addition to technical contributions to the robot. For example, students can work on web pages, an animation, publicity, setting up the playing field and so forth. Several mentors thought that success should be measured in the students learning about themselves and about engineering as a potential career.

Quality was defined more in terms of motivation and work ethic than grades. Students need to be interested and committed, and have the ability to work as a team. It is helpful to have at least one student who is a whiz at programming, but that student also needs to be a team player. The best form of student leadership is to have a whole group of students who step in to lead at appropriate times. Perhaps surprisingly, the leaders do not have to be seniors and do not have to have significant experience with robotics—novice teams can do quite well in the competition. Students with too much experience may think they can build faster and better than other students and tend to prevent them from learning.

Q2 (d). How important are advisors and mentors (both from university or companies and from high school)? Q2 (e). How important is parental involvement?

Advisors and mentors are critically important. Mentors in particular serve as role models. If advising is dysfunctional, the team will be dysfunctional. It is necessary to have a "champion" who is typically an advisor or coach (connected to a school) or one of the engineering mentors. FIRST teams often disband when mentors become burned out. In addition to providing history and core memory of what is important the champion is a sparkplug to start and complete the task. When college students are involved as mentors, there is always a period where they are learning the process. It is not essential that the high school teacher have technical skills since the engineering mentors can provide that; however, the high school teacher needs to be able to work effectively within the school system. Parental involvement is useful to get students to meetings, to raise money, and to help students balance their time. If large numbers of students plan on going to regional and national competitions (strongly encouraged by FIRST) from $30,000 to $50,000 may need to be raised. At a minimum, parents should not be a barrier to the involvement of students. One difficulty that FIRST has is obtaining parental involvement of at-risk students (of course, the lack of two parents at home is often a major reason a student is at-risk).

Q2 (f). How important is a tradition of winning? Q3. Are competitions good learning experiences for students?

A tradition of winning is often moderately helpful since it energizes the students, but can also lead to an excessive focus on winning without considering the other aspects of successful teams. Too much focus on winning may limit learning of many students. It would be better to ensure that a larger number of students have to become involved with the game. Competitions are useful learning experiences since they motivate students—the energy at regional and championship competitions is incredibly high. [Author's

Table 1. Competitions included in the analysis

KEY

A	Age	W	Web Page	HS	High school
G	Grade	Q	Quiz Bowl	JHS	Junior high school
T	Team	R	Research Project	MS	Middle school
I	Individual	O	Oral Presentation	ES	Elementary school
B	Build	Pr	Program (computer)		
P	Paper	Int	Interview		
Tt	Test	V	Video		
Ph	Photo				

	Competition	Sponsors	B/P	URL	A/G	T/I
1	FIRST (For Inspiration and Recognition of Science & Technology)			http://www.usfirst.org/		
–	Robotics Competition	FIRST, United Technologies Corp., BAE Systems, NASA	B	http://www.usfirst.org/robotics/	HS	T/I
–	Lego League	FIRST, Lego Corp.	B	http://www.usfirst.org/jrobtcs/flg_abt.htm	A 9–14	
–	Vex Challenge	FIRST, Radio Shack, CMU Robotics Instit.	B	www.usfirst.org & www.vexrobotics.com	HS	T/I
2	Robotic Technology & Engineering Challenge	Robotics International, SME	B	http://www.sme.org/cgi-bin/eduhtml.pl?/educat/srcpg.html&&&SME&	MS/HS	
–	New name is, National Robotic Challenge	Ohio Technology Education Assoc., Bender, Whirlpool, Harbot	B	http://www.nationalroboticschallenge.org/		
3	RoboCupJunior (robotics): Soccer, Rescue, Dance	Zenrin, Sony, sgi, EK Japan Co. Ltd.	B	http://satchmo.cs.columbia.edu/rcj/	ES & MS ≤A14	T/I
4	Battlebots IQ (robotics)	Battlebots, NPC robotics, IFI robotics	B	http://www.battlebotsiq.com/minnesota2004hs.php	HS	T
5	Botball Research and Design Website Competition (robotics)	KISS Instit. Practical Robotics, Amer. Honda Fnd, NASA, Naval Research Lab, Farifax Education Fnd., Hawaii Space Grant Consortium	B	http://www.botball.org/about_botball/research_design.html	MS/HS	T
6	ROV Competition (Underwater Robotics)	Marine Adv. Technol Educ. Center, Marine Technol. Soc., Aquatic Sci. Inc., Borland Software Corp., Busch Gardens, Carrillo Underwater Syst.	B	http://www.marinetech.org/rov_competition/index.php	HS/col.	T
–	Ranger class (off-the shelf parts) and Explorer class (design and build parts)					
7	K'NEX K*Bot (robotics) Championships	K'NEX	B	http://www.kbotworld.com/	A 7–14, 8–16	I
8	Robofest	MPC Computers, Lawrence Tech, ABB, IEEE, LEGO,DENSO	B	http://www.robofest.net/default.htm	MS/HS	T
–	Competitions: Lego Robot, Advanced Robot, Laptop Robot					
9	BEST Robotics, Inc. Texas & South	TI, Boeing, Raytheon, SMU, Auburn Univ., Southern Co.	B/P	http://www.texasbest.org/#best_results www.southsbest.org	MS/HS	T
10	West Point Bridge Design Contest	American Society Civil Engr. (ASCE), West Point	P	http://bridgecontest.usma.edu/	JHS/HS	T/I
11	Intl Conf Software Engr HS Programming Competition	IEEE, ACM Sigsoft, ACM	Pr	http://www.cs.wustl.edu/icse05/StudentInformation/HighSchoolCompetition.shtml	HS	T
12	Amer. Computer Science League (ACSL) Computer Science Contest	ACSL, Prentice Hall, Microsoft, Addison Wesley, New Riders, O'Reilly & Assoc.	Tt/Pr	http://www.acsl.org	MS/JHS/HS	T/I
–	Junior, Intermediate, Sr., Classroom—Non-programming Problems, All-Star					
13	ThinkQuest	Oracle Foundation	W	http://www.thinkquest.org/	A 9–19	T
14	Exploravision	Toshiba, NSTA	P/W	http://www.exploravision.org/2004/index.htm	All	T
15	Univ. Colorado HS Programming Contest	CS & NSBE @ Univ. Colorado-Boulder	Pr	http://eas.uccs.edu/nsbe/Programming_Contest/about_hspc.htm	HS	T

Table 1. (*cont.*)

	Competition	Sponsors	B/P	URL	A/G	T/I
16	University of Utah High School Programming Contest	Univ. Utah, Xmission, Microsoft, Electronic Arts, Novell, Evans and Sutherland, HP, McGraw-Hill	Pr	http://www.cs.utah.edu/outreach/contest/	HS	T
–	Tee shirt design		P		HS	I
17	HP Create-A-Calculator Contest	HP, Scholastic, Inc., ASEE	P	http://www.hp.com/calculators/contest/index.html	HS/col.	I
18	MCC HS engineering competition	Monroe Community College (MCC)	B	http://www.monroecc.edu/depts/eng&phy/highschl.htm	HS	T
–	Contests: Bridge, auto safety, sumobot (robotics), & sumocar					
19	Christian Brothers Univ. (CBU) Engineering Competition for High School Students	CBU Engineering, Institute Packaging Professionals, Medtronic, Wright Med. Technol.	B	http://www.cbu.edu/engineering/highschool.html	HS	I
–	Contests: Egg Drop, Balsa Wood Bridge, CO2 Car, Human Reaction Time					
20	Boston University Design Competition	Boston University	B	http://www.bu.edu/eng/design/	HS	T
21	South Dakota State University HS Contests	South Dakota State University	B/P	http://www3.sdstate.edu/Academics/CollegeOfEngineering/redirect/ StudentOrganizations/CollegeofEngineeringExpo/HighSchoolContests/Index.cfm	HS	T/I
–	Contests: Hill Climber, Human Wallpaper, Scrambler, Rocket Car, Write it/Do it					
22	KSU Engr. Open House, LEGO Mindstorm Robotics Design Competition	Kansas State University (KSU)	B	http://www.engg.ksu.edu/STEELRING/OpenHouse2005/OH_Contests.html	HS	T
–	ASCE HS Balsa Bridge Competition	KSU student chapter of ASCE	B	http://www.engg.ksu.edu/ASCE/balsa/	HS	T
–	Structural, Craftsmanship & Overall					
23	Univ. Illinois Urbana-Champaign Engineering Open House	UIUC, Ford, Abbott Labs, Kimberly-Clark, Microsoft, Caterpillar, John Deere, Boeing, Lockheed Martin	B	http://eoh.ec.uiuc.edu/eoh.cfm?page=0001	All	T
–	Contests: Rube Goldberg (HS), Spaghetti bridge (MS), Toothpick & Marshmallow structure (ES)					
24	Tulsa Engineering Challenge:	Tulsa Engr. Fnd., Chem. Engr at Univ. Tulsa, Tulsa AIChE	B	http://www.tulsaengineer.org	MS/JHS/HS	T/I
–	Contests: Chemical Switch, Aluminum Foil Boat, Mini Math—JHS/HS, Paper Airplane Duration & Distance-MS/HS, Toothpick Bridge—MS/HS, Rubber Band Powered Vehicle—MS/HS, Ping Pong Ball Launcher—MS/HS, Electric Motor—MS/HS, Electric Robot—MS/HS, Wacky Wonder Works—MS/HS					
25	Illinois HS Rube Goldberg Machine Contest	Argonne Natl Lab, UIUC, Rube Goldberg Inc.	B	http://www.anl.gov/Careers/Education/rube/rubechteams.htm	HS	T
26	HS Drafting CAD/G.I.S. Technology Competition	Rio Hondo Col., Paton & Assoc., Autodesk, Archway Syst, Bentley Syst,	P	http://www.riohondo.edu/tech/cad/events.htm		I
–	Contests: Basic mechanical drafting, basic architectural drafting, CAD mechanical, CAD architectural, advanced mechanical & architectural drawing.					
27	Tech Challenge (design challenge)	Intel, San Jose Technical Museum of Innovation	B	http://www.thetech.org/learning/challenge/tech/index.cfm	MS/JHS/HS	T
28	Team America Rocketry Challenge	Aerospace Industries Assoc., Natl. Assoc. of Rocketry	B	http://www.aia-aerospace.org/aianews/features/team_america/index.cfm	MS/HS	
29	TOY Challenge	Hasbro, Southwest.com, Sally Ride Sci., Sigma Xi	B	http://www.toychallenge.com/	MS	T
–	Contests: Remarkable Robots, Toys that teach (Preschool & School age), Family Games, Incredible Creatures, Crafty Creations, Fun for Furry Friends, Builders of Tomorrow, Get Out & Play					
30	Dell-Winston Solar Challenge (solar car race)	Dell Computers, Texas, Motor Speedway, Winston School, others	B	http://www.winstonsolar.org/race/	HS	T
31	Tests of Engineering Aptitude, Mathematics, and Science (TEAMS)	JETS	P	http://www.jets.org/programs/teams.cfm	HS	T
32	Detroit Science and Engineering Fair	Daimler Chrysler, Ford, Toyota, GM, Comerica Bank, Harlan, DTE	B	http://www.sefmd.org/	JHS/HS	I

Table 1. (*cont.*)

	Competition	Sponsors	B/P	URL	A/G	T/I
33	Siemens Westinghouse Competition in Math, Science & Technology	Siemens, College Board	R/ P/O	http://www.siemens-foundation.org/competition/	HS	T/I
34	Intel International Science and Engineering Fairs	Intel, ASU, Univ Arizona, N Arizona Univ., Ricoh, Science Service, Aligent, Univ. Phoenix, others	R/B P/O	http://www.intelisef2005.org/ and http:// www.sciserv.org/	HS	T/I
35	Intel Science Talent Search	Intel, Science Service	R	http://www.sciserv.org/sts/about/background.asp	HS	T/I
36	Discovery Channel Young Scientist Challenge (DCYSC)	Discovery Communication, Science Service	R/ P/O	http://www.sciserv.org/dcysc/	JHS	T/I
37	Science/engineering fairs	Science Service, Intel (item #34)	R/PO	http://www.sciserv.org	JHS/ HS	I
38	FFA Agri-Science Fair (Experimental projects)	FFA (Future Farmers of America), Pioneer, Ford	R/ P/O	http://www.ffa.org/programs/ag_sci/index.html	JHS/ HS	T/I
39	Junior Science and Humanities Symposium	US Army, Navy & Air Force	R/ P/O	http://www.jshs.org	HS	I
40	Ecybermission	US Army	B	www.ecybermission.com,	JHS	T
41	Future City Competition	Natl Engineers Week, Bentley Systems	P	http://www.futurecity.org/home_mission.shtm	JHS	T
42	NASA Space Settlement Contest	NASA	P	http://lifesci3.arc.nasa.gov/SpaceSettlement/Contest/ index.html	All	T/I
43	NASA Student Involvement Program (space journalism)	NASA	P/B	http://www.nsip.net/competitions/index.cfm		
–	Competitions: My planet earth, Science and Technology Journalism, Design a Lunar-Based Mission to Mars and Beyond, Watching Earth Changes, Space Flight Opportunities, Aerospace Technology Engineering Challenge					
44	JPL Post Exploration Space Settlement Design Competition	Jet Propulsion Laboratory, Post 509		http://home.earthlink.net/~spaceset/	HS	
45	Destination Imagination (formerly Odyssey of the Mind)	Sam Goody, National Dairy Council, 3M, Philips, Best Buy	B	http://www.destinationimagination.org	All	T
–	Team Challenge (long term) & Instant Challenge (brainstorm)					
46	TSA Competitions and Challenges	Technology Student Association (TSA)	B/Ph/ P/Int/ Tt/ PrO/ Q/W	http://www.tsaweb.org/	HS/MS	T/I
–	HS Competitions: Ag & Biotech Design, Architectural Model, Career Comparisons, CAD 2D-Architectural, CAD 3D-Engineering, CAD-Architectural Animation, CAD-Engineering Animation, Construction Systems, Cyberspace Pursuit, CO2 powered Dragster Design, Electronic Research & Experimentation, Engineering Design, Extemporaneous Presentation—Technical, Flight Endurance, Imaging Technology, Manufacturing Prototype, Medical Technology, Radio Controlled Robotics, Structural Engineering, System Control Technology, Technical Research & Report Writing, Technical Sketching & Application, Technology Systems, Technology Bowl, Rube Goldberg Challenge, Technology Problem Solving, CO2 Vehicle Transportation Modeling MS Challenges: Agricultural & Biotechnology, Career, Technology Issues, Computer Applications, Construction, Cyberspace Pursuit, Dragster Design—CO2 powered, Electrical Applications, Environmental, Flight, Inventions & Innovations, Manufacturing, Medical Technology, Problem Solving, Structural, System Control Technology, Technical Design, Technical Writing, Technology Bowl, Transportation—battery powered vehicle					
47	JWOD/JETS Natl Engr Design Challenge	JETS, NISH		http://www.jets.org http://www.nish.org	HS	T
–	Designs for Severely Handicapped New!					
48	Citizen Scientist Writing Compet. Sustainable Development	SustainUS	P	http://www.sustainus.org	A 13–26	I
49	Mathcounts (Math competition)	CAN Fnd, NSPE, NASA, Natl Council Teachers Math, others.	Tt/O	http://www.mathcounts.org/	MS	T/I
50	American Mathematics Competitions	Math Assoc. America, Microsoft, U.S. Army	Tt/P	http://www.unl.edu/amc/	MS/ HS	I/T
–	Competitions: AMC8, 10 & 12, Amer. Invitational Math Exam, Amer. Math Olympiad, Internatl. Math Olympiad					
51	Science Olympiad Tournament (tests & problem solving)	Science Olympiad Inc., DuPont, Discovery, Communications, AEP, Nextel, NASA, others	P/Tt/B	http://www.soinc.org	All	T/I
52	USA Biology Olympiad International Biology Olympaid (IBO)	Center Excellence in Education, George Mason Univ., others	P/Tt	http://www.cee.org/usabo/	HS	I
53	Chemagination (innovative writing)	American Chemical Society (ACS)	P/O/V	http://www.chemistry.org/oca	HS	T

Table 2. Examples of multiple winners in particular competitions.

Contest			Awards
#1	FIRST Robotics	Team 71, Hammond IN. Consortium of schools.	Robotics Competition Championships 04, 02, 01, 1997
#31	Teams (JETS)	Hettinger H.S. ND Morgan Co. H.S. MO	04, 1st; 03, 2nd 03, 3rd; 02, 3rd
#18	Monroe Com. Col. H.S. Engr. Competition	Fairport H.S.	04, 1st & 2nd; 02, two 1st; 01, 3rd
#5	Botball R&D Website	Santa Fe South H.S. NM Norman North H.S., OK	04, 3rd; 03, 1st 03, 2nd; 02, 1st
#8	Robofest	Christ the King Separate School, Windsor Cranbrook Kingswood	04, 1st; 03, 3rd, 02, 3rd 03, 1st & 2nd; 02, 2nd
#9	Best Robotics	Austin H.S., TX	04 & 03, 1st
#16	Univ. Utah Programming Contest	West H.S. Fremont H.S. Alta H.S.	04, 2nd; 03, 3rd; 01, 2nd 04, 3rd; 01, 1st 03, 1st; 02, 2nd
#14	Exploravision	La Jolla H.S. CA Lake Braddock Secondary School, VA	04, 1st; 03, 1st 04, 2nd; 03, 2nd; 02, 2nd

note: I strongly agree with this statement. One has to experience the energy level and excitement at competitions to believe it.] The students can also meet and learn from students from other states and countries, and they meet engineers and CEOs. Also, since society is competitive, learning how to react to winning and how to react to losing is part of growing up.

Q2 (g). How important is support (or resources) including money, space, equipment and tools?

Clearly, a significant amount of resources are needed for the FIRST robot, and even more money is required to send the team to regional and national competitions. Having sufficient money removes worries and allows the team to focus on the technical challenges. The FIRST organization is aware that money can be a problem and is developing VEX as a lower cost alternative, but does not plan to replace FIRST robotics. FIRST does limit the amount of money that can be spent on electronics. A space to build the robot, tools, and storage are all necessary. A dedicated space can increase the students' sense of ownership.

FIRST is somewhat unusual since the adult advisors, mentors and parents are allowed to help build the robot. Since different teams choose to utilize the adults associated with the teams in different ways, this question on support elicited strongly held differing opinions. Team 71 from Hammond Indiana, the only team to win the robotics championship more than once (see Table 2), has extensive parental and mentor involvement. The work space and tools are provided by Beatty Machine and Manufacturing. Students from the four Hammond high schools travel to the central administration building or to Beatty's facility for meetings. Brainstorming ideas can be contributed by anyone connected to the team but final decisions are not always made by the students. The team strategy has been consistent—look for a key aspect that will allow the robot to control the competition and design for that. Since the team has the resources, it builds two robots so that practices can continue after the competition robot is shipped. Some teams have all of the building done by students, some have mentors do all of the building, and some use a mix (the practice of team 71). All of these aspects are within the FIRST rules, but there was disagreement over whether they should be.

Q4. What sort of things do students learn?

The students develop confidence and learn to manage time, work with other people, improve their communication skills (e.g., by talking to a judge), learn to work and trouble-shoot under pressure, and improve the skill set of whatever aspect they work on (e.g., programming, welding, machining). Students learn about themselves and what they like to do. The one point that was mentioned over and over was the students become better in working with people. They learn to work with people they don't particularly care for and they learn to resolve conflicts.

Q5. About how much time do team members put into the team?

Typical time requirements over the course of a year are in the range from 200 to 400 hours for each student. In the fall during the training and planning period students may spend from 4–8 hours a week. In the spring, particularly during the six week build period, time demands escalate—20 hours per week was often cited as average. Since student grades can drop, it is probably appropriate to have periodic grade checks.

Q6. Does being a member of the team have an affect on the likelihood that students will matriculate in a STEM discipline in college?

The average impact of FIRST on students' career decisions was unclear. Although many students major in engineering or technology, most of them were interested in these fields before they joined FIRST. FIRST (or as one interviewee noted, FIRST and other competitions such as BEST, Botball and Super Mileage) appear to strengthen the motivation of those who are already interested in STEM disciplines. However, there is anecdotal evidence that FIRST can have a major impact on individual students since it gives them a chance to see if they might like and excel at engineering and/or technology. For example, I heard a story about a student who initially had no interest in engineering who is now majoring in engineering because she learned through FIRST the joys of design, a story about a student who was ready to drop out of high school who is now studying technology at a community college because FIRST excited him and kept him in high school, and a story about an at-risk student who overcame his extreme shyness because of his involvement in FIRST. FIRST does not appear to serve as a recruiter for science except for computer science.

Q7. If the team wins or places high, does this have long-term effects on the students? Does not winning have a long-term effect?

Winning positively affects the team's emotions and not winning is disappointing, very disappointing if the team expected to win, but both of these effects appear to last only a few months. The interviewees thought that learning to cope with both winning and not winning were important. The advisors and mentors can be very helpful with this aspect. Winning a regional Chairman's award did have a big effect on one team and the team was motivated to do better in the robot competition at the championship round than it had done before. Students on teams that have won in the past want to duplicate past teams and will work to ensure that this happens again. However, there was concern that winning should not dominate the involvement of the team.

Q8. Are students who study engineering being set up for disappointment because the first few years are often not hands-on?

Although there was one modest dissent, the general feeling was that FIRST alumni did not have unrealistic expectations of college and the FIRST experience seemed to motivate them to get past the first year courses. Since FIRST alumni have worked with engineering mentors, the alumni may have a more realistic idea of what studying engineering is like than students who don't know any engineers. Alternatively, FIRST alumni may be more motivated to look for hands-on opportunities such as co-op, internships or college competitions (e.g. mini-Baja, SAE, and ASCE concrete canoe).

Q9. What do you personally gain from being an advisor?

One interviewee noted that FIRST can revitalize teachers. The enthusiasm and excitement of the students carries over into their teaching. Several interviewees noted they enjoy watching students learn new things and mature. One of the college student mentors appreciated his opportunities to practice leadership and to network at competitions. The college professors appreciated the opportunity to recruit students.

Q10. Any other comments?

Other issues surfaced when interviewees were asked for other comments. Several interviewees noted that FIRST teams tend to be significantly less than half female. Even when there are a significant number of female students, the prestigious drive team tends to be male-dominated. Teams that have made a significant effort to recruit more females are often successful; however, the male students may sabotage recruitment efforts for females and find ways to discourage female drivers. As an interested outsider, the author suggested that a possible solution to the under-representation of females is to require each team to field an all male drive team for half the competition rounds and an all female drive team for the other half. Since the males want to win, they will be motivated to help recruit and train the female drive team. One of the interviewees thought that FIRST could be more effective in working with at-risk students. This requires sensitivity from mentors or advisors. Several interviewees noted that starting new teams can be difficult, particularly if strong advisor, mentor and parent support are not available. One interviewee noted that there are a number of other effective extracurricular competitions and that PLTW (Project Lead the Way) is an effective curricular method of introducing interest in technology in secondary schools. This thought was echoed by another interviewee who thought there was too much focus on robotics and that FIRST only recruits for a limited number of engineering disciplines.

DISCUSSION AND CONCLUSIONS

Unfortunately, it is difficult for students and other non-engineers to visualize what engineers do. "The *characteristic* activity of the engineer is one of intellectual effort, basically directed toward creative design." [1] Because intellectual effort is difficult to showcase, there is a strong tendency to show engineers doing activities that are not "really characteristic of engineers in their professional capacity." [1] Instead, activities such as an electrical engineer "sitting in the lab, twisting dials or instruments . . ." [1] will be shown. These activities are more commonly done by the sub-professionals that engineers supervise. Most "engineering" competitions at the primary and middle school levels use these types of activities and a limited amount of typical engineering activities; thus, they are really technology competitions.

At the high school level, winning many of the engineering-related competitions requires the students to do most of the intellectual activities included in the definition of engineering plus activities commonly done by people supervised by engineers. Most high school competitions do not separate pre-technology and pre-engineering students through the need for more rigorous mathematics such as pre-calculus and calculus.

For example, the FIRST Robotics competition, one of the more highly technical competitions, can be won without extensive use of mathematics although advanced mathematics is useful in developing control structures.

Based on the evidence collected here and in the literature [6, 10–17], it is not possible to unequivocally determine if engineering-oriented competitions at the primary and secondary levels have a major impact on encouraging students to study engineering, although the evidence is consistent with positive effects. Students who have an initial interest in engineering do not appear to be demotivated by the competitions and in many cases their motivation appears to be strengthened. The competitions help students become technologically literate and appreciate the contributions of technology and engineering to society [6, 10, 15, 16]. Finally, although it may not be possible to prove statistical significance, the anecdotal evidence points to a very significant impact of competitions on the career aspirations of a limited number of students. Of course, this type of very specific effect is difficult to determine from a statistical analysis.

In my opinion, engineering colleges should encourage student competitions at all grade levels. For primary students hands-on or simulation technology/engineering activities that engage the students are appropriate. Even at this level, competitions should require some ingenious designs that must take constraints into account. For secondary school competitions, particularly in the upper grades, sponsors need to ensure that winning entries must utilize ingenuity, design under constraints, and use appropriate mathematics to achieve a superior design. One approach that encourages students to use theory is to provide a final piece of information (such as how far a car has to travel or the total weight of a bridge) only a short time before the competition begins. Both hands-on and computer projects work well. Similar criteria can be applied to the analysis of projects done for secondary school courses, particularly if the courses are meant to prepare students for studying engineering in college.

There are a number of ways engineering colleges can encourage and strengthen these competitions. Many undergraduate students are interested in working with primary and secondary students. Extracurricular and curricular (e.g. service learning) activities that provide this opportunity should be nurtured. The resources required for this are modest. Since every competition needs judges, students and faculty should be encouraged to serve as judges. Faculty and students can volunteer to help competitions develop new challenges. Colleges should also offer to host competitions—the expense can easily be justified as a recruiting cost.

The results of this study and of the previous study on college competitions [18] show that the playing fields in competitions are generally not level. Teams with enthusiastic advisors, parents, and mentors have an advantage and are more likely to win. This advantage is particularly marked if a team has resources (money, space, tools, and access to experts) that other teams don't have. Competition organizers can partially level the playing field by having strict limits on the amount of money that can be spent on the competition and on the roles of advisors, parents and mentors. Colleges can help level the playing field by providing engineering student volunteers as mentors for teams that don't have expert mentors.

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