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# FIRST Robotics Competition: University Curriculum Applications of Mobile Robots*

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*The FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition challenges teams to design, build and compete tele-operated mobile robots. As a mentorship program to interest high school youth in engineering, science and technology, the FIRST Robotics Competition partners high school students with volunteers from the education, engineering, business and civic communities. In 2005 nearly 1000 teams from seven countries competed in the FIRST Robotics Competition. Many universities participate in FIRST as competition hosts, student mentors and team sponsors. This paper examines interactions associated with the FIRST Robotics Competition. Four course models are presented to illustrate a developmental sequence for undergraduate courses centered on the FIRST Robotics Competition. Also, additional examples of FIRST Robotics Competition related labs and lecture instructions are presented.*

## INTRODUCTION

THE FIRST ROBOTICS COMPETITION is an annual international event that challenges teams to design and build sophisticated tele-operated mobile robots to achieve a variety of design tasks. Though competition based, the FIRST Robotics Competition (FRC) is much more than a forum to test one robot against another. Rather, FRC is one attempt to address the growing difficulty of attracting young people to careers in engineering, technology and science.

The concern about the lack of students entering the science and engineering pipeline is well recognized. Studies have documented the decline in the number of students studying to become scientists and engineers in the face of forecasts for growth in the number of jobs requiring science and engineering training [1]. At best, it is predicted that, overall, employment in engineering will increase during the current decade while the number of engineering graduates will remain fixed [2]. As described by many, though engineering is a rewarding and highly-paid career, the profession is not attracting enough students to support the profession's needs. To help combat this shortfall, colleges and universities are encouraged to expand engineering outreach programs and promote the values of an engineering profession.

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Beyond a shortage of engineering students, there is a growing need for all citizens to increase their technological literacy [3]. Our transportation, communication, food, water, medicine and energy infrastructures all rely on technology, yet its omnipresence tends to camouflage its significance to our daily lives. To participate fully in the modern world, citizens must be technologically literate.

The FIRST Robotics Competition addresses these very important problems of increasing the attractiveness of technical careers and improving technological literacy. The FRC was created in 1990 to present engineering as a profession that is rewarding, fun and achievable. By participating in the project, students are inspired to learn and, in essence, demand more education.

Robot competitions are a captivating tool for developing a visceral understanding of engineering. Subject to time, financial and design constraints, robot competitions often mimic real world engineering [4]. Robot competitions are widely used at the university level to teach a variety of multidisciplinary engineering topics including design, programming, systems engineering, and mechatronics.

One version of university-based robot competitions are those held within a single university where the competition is a component of a specific course, such as the Massachusetts Institute of Technology's Design and Manufacturing course [5] and Autonomous Robot Design Competition

[6]. Such projects demonstrate the utility of analytical tools, illustrate the interconnections between different branches of engineering, and highlight the relationship between design and manufacturing.

Engineering professional societies and engineering programs have sponsored national university-level robotics competitions. For example, the Trinity College Fire-Fighting Home Robot Contest [7], the Society of Manufacturing Engineers / Robotics International Robotic Technology and Engineering Challenge [8] and the Carnegie Mellon 'Mobot' Race [9] are robotic competitions that include university level contests. Typically, university teams are involved in these competitions as extracurricular activities, though some teams do participate as part of the engineering curriculum. For all competitions the focus is on applying advances in robotics to solve a design challenge.

International robotics competitions provide yet another venue for university level involvement in competitive robotics. The Robot World Cup is a forum for advancing intelligent robotics research by focusing on a complicated task for teams of robots to accomplish, namely robotic team soccer [11]. Though this event is not restricted to university teams, university teams make up the majority of the competitors. International science festivals provide additional opportunities for university level robotic competitions [12]. Like their national colleagues, the international university teams are primarily extra-curricular-based initiatives.

These referenced university level robotics

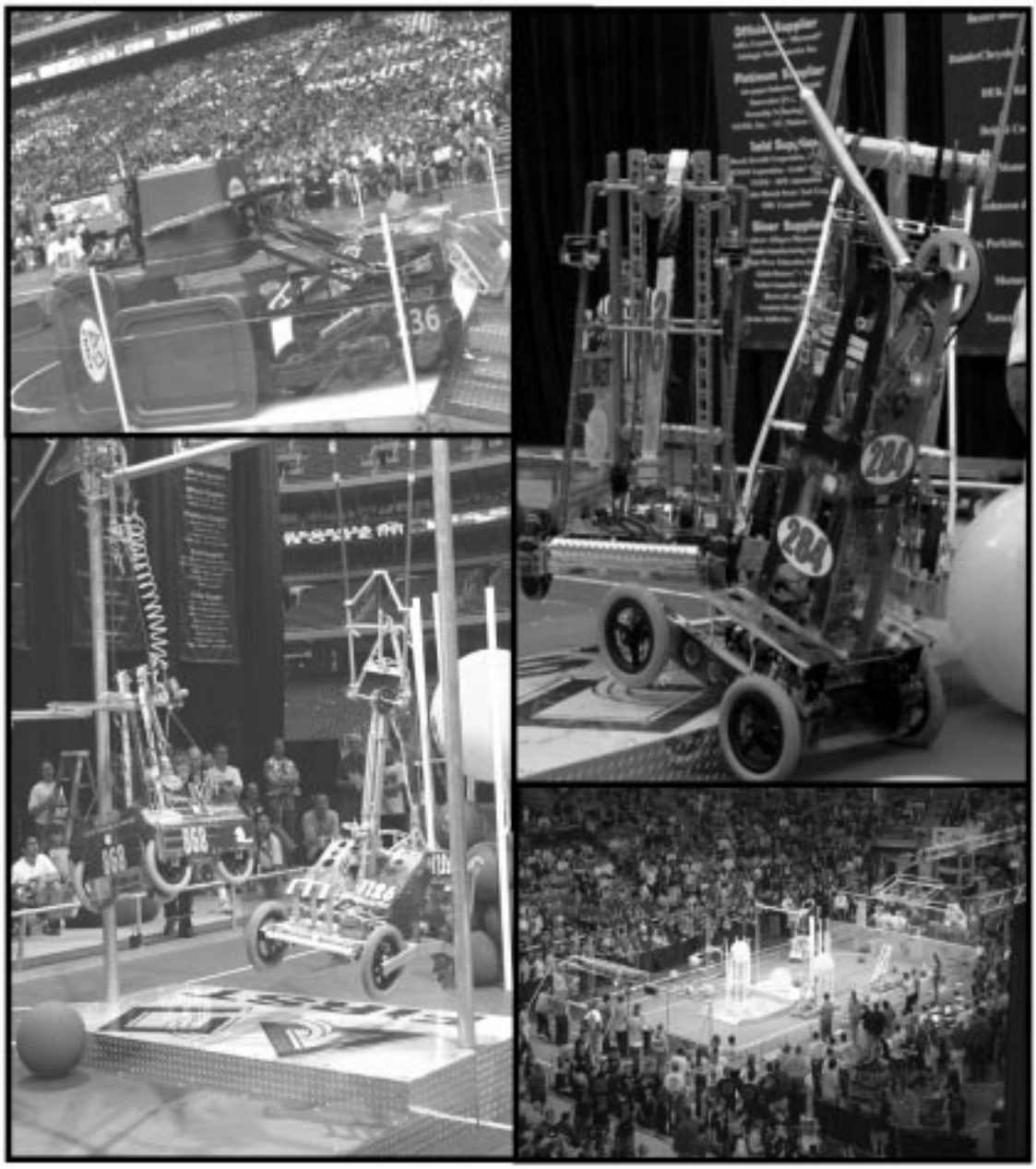

Fig. 1. FIRST Robotics Competition (most photos by Adriana Groisman/FIRST).

competitions share similar goals of advancing the state of robotics research and/or university level engineering education. Much of the university success in these competitions correlates with the fact that the competitions complement the education process in areas of team-based learning, interdisciplinary design, and systems engineering. In addition these competitions offer very concrete measurable outcomes that can be used to assess program effectiveness.

The FIRST Robotics Competition mission (to attract students to engineering and improve technological literacy) is markedly different from the goals of most other robot competitions. As a mentoring program, the FRC uses robotics as a tool to motivate youth and inspire them to continue their education. As such, there exists a symbiotic relationship between FIRST and engineering colleges and universities. This paper will address university involvement in FIRST and focus on the curriculum applications of the FIRST Robotics Competition.

## *FIRST* ROBOTICS COMPETITION—OVERVIEW

*An introduction to FIRST*

The FIRST (For Inspiration and Recognition of Science and Technology) Foundation is a US-based non-profit organization that inspires youth to pursue education, experience and careers in engineering and technical fields. By doing so, FIRST helps ignite curiosity and demand for learning, with the schools and universities then supplying that desired education. The premise of FIRST is to partner youth with practicing professionals to solve challenging engineering problems. FIRST Robotics Competition partners build sophisticated robotic devices that compete in mechanical sports under autonomous and remote control. Some examples of FRC robots and the competition venues are presented in Fig. 1. The growth of the FRC is illustrated in Fig. 2.

FRC teams comprise high school students and faculty, engineers, technicians, business leaders, university students and staff, and concerned citizens. Each year a new 'FIRST game' is developed, which requires robots to perform a variety of tasks such as moving across a field, climbing ramps, hanging from bars and placing objects in goals. In addition to being tele-operated, the robots also operate under autonomous control for segments of each match.

All robots must conform to design constraints for power, size, weight and materials. The control system is C-programmable and capable of receiving 16 digital/analog input channels and directing 16 output channels. Sensors, such as cameras, Hall-effect sensors, gyros, light sensors, current sensors, potentiometers, LED detectors, and limit switches are widely used on FRC robots. The robots typically have a mass of 60 kg, travel at 5 m/s and are strong enough to lift their frames off of the playing field floor.

After only six weeks from the time the annual game is announced and teams receive a kit of parts from which to design, build, program and test their robots, teams enter regional competitions where between 35 and 85 teams compete. The events are wildly exciting, energetic and motivating. In 2005, nearly 1000 FIRST Robotics teams were formed in the United States, Brazil, Canada, Germany, Great Britain, Israel, and Mexico. These teams competed in 32 venues in North America and Israel.

Rather than being a forum to decide which team can collect the most points on the playing field, FRC events focus on inspiring students. In that spirit, alliances of robots compete in each match, such that teams have to work together to meet the design challenges. Competition on the field is paired with cooperation between teams to create an atmosphere of gracious professionalism where teams work together to inspire students. The FRC awards structure supports this goal, as the majority of FRC awards are based on attributes such as spirit, entrepreneurship, inspiration, teamwork and effectiveness. The teams compete very aggressively, but treat one another kindly in the process.

In 2005, the entrance fee for the competition was US $6000. The entrance fee provided each team

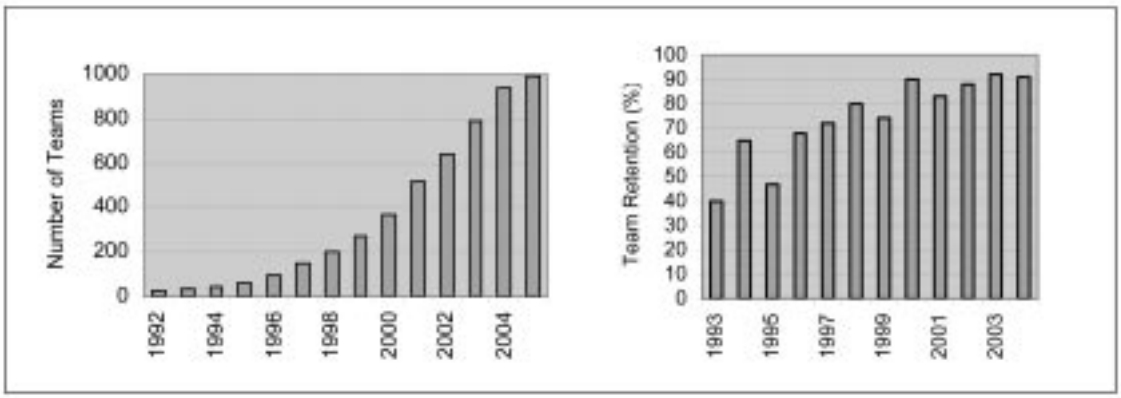


Fig. 2. FIRST Robotics Competition team growth and team retention.

with a kit of robot parts and entry into a regional competition. The high retention rate (illustrated in Fig. 2) indicates that the majority of teams are satisfied with their involvement in the project. The FIRST Robotics Competition has a strong record of success motivating students to further their education. As noted in a report on colleges and universities participating in the FRC, survey results 'present compelling evidence that such engagement has a favorable effect on those individuals and institutions that are involved in the (FIRST Robotics) Competition' [13].

*University associations*

There are a number of ways colleges and universities are involved with the FRC [14]. The most common methods of involvement are (1) sponsoring FRC teams, and (2) hosting FIRST Robotics Regional Competitions. In 2005, 18 of the 30 FIRST Robotics Regional events were held on college campuses. Universities have also adopted the FIRST model for summer based engineering outreach programs, where teams of students solve design challenges. Scholarships, totaling nearly US $5-million, were exclusively available for FRC participants in 2005 with universities being the primary funding source for these academic awards.

The greatest educational benefit for a university is obtained when a program sponsors an FRC team [15, 16] where university students serve as mentors to high school students. In this role, the university students benefit from exposure to all aspects of the engineering profession, including design, project planning, manufacturing, trouble-shooting and communications. The cooperative nature of the competition allows both university and high school students to work side by side with practicing engineers, thereby providing tremendous insight into the engineering profession.

FRC team sponsorship can take on a number of different forms, including sponsorship as an engineering club, an extracurricular activity, or in conjunction with a credit-awarding course. University curricular activities associated with the FRC fall into one of two categories: courses primarily based on the FRC, and courses that apply the FRC as a component of the course, each of which will be discussed in the following section.

## CURRICULUM APPLICATIONS: COURSES BASED ON THE FIRST ROBOTICS COMPETITION

*University courses based on the FIRST Robotics Competition*

There is a wide spectrum of involvement where FRC activities are used as the basis for an entire undergraduate engineering course. These range

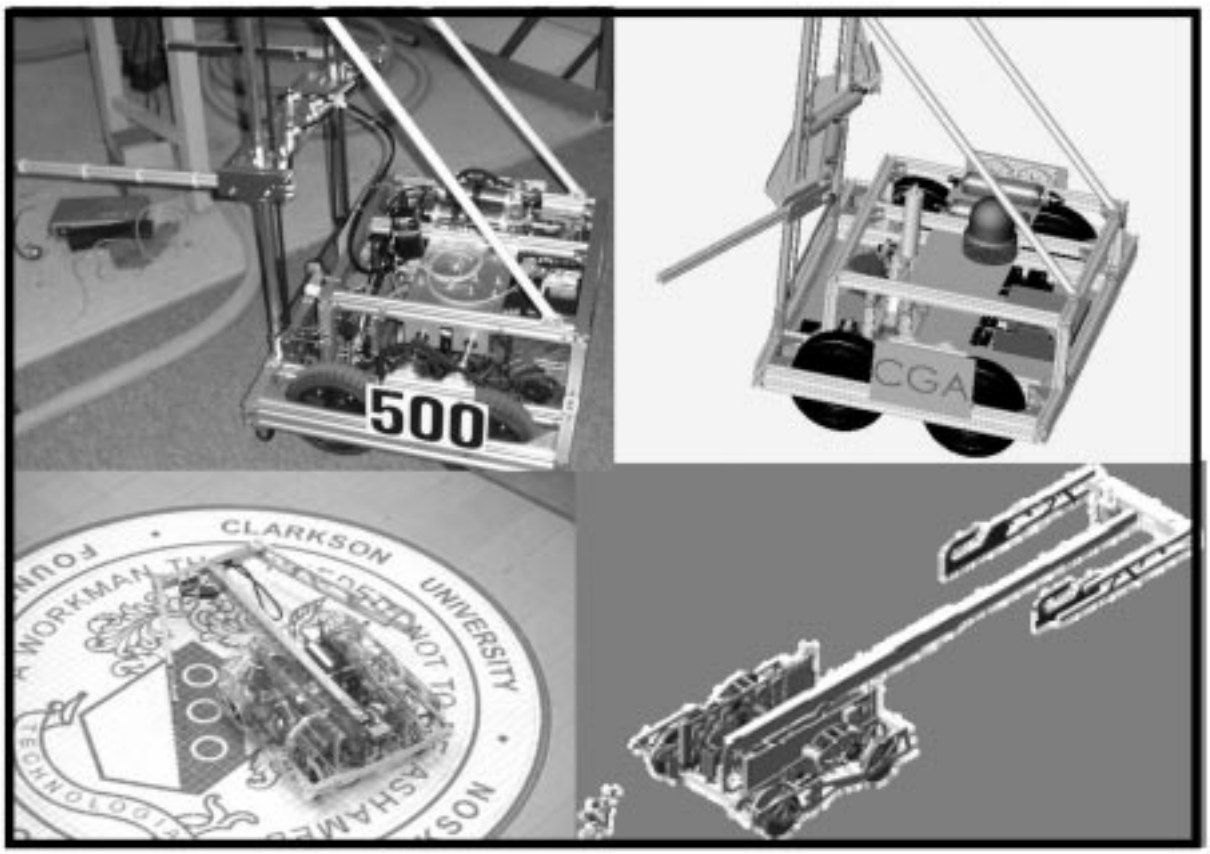


Fig. 3. University student developed CAD designs and completed robots from US Coast Guard Academy and Clarkson University FIRST teams.

from introductory classes to senior level design courses. Figure 3 presents examples of CAD models and robots from university-sponsored FRC teams. Research has found that linking FIRST activities to course-related projects or student organizations increases the number of students involved at the university level. Approximately 37% of the college students who participate in FIRST do so as part of for-credit courses [13]. For each university-associated FRC team, the participation of the high school team members varies depending on their experience. It is not unusual for high school team members to have more FIRST experience than the university participants.

At the freshman level, the FIRST Robotics Competition has been applied as the basis for 'Introduction to Engineering Design' courses [17]. The high intensity hands-on experience of a FRC-based course gives new engineering students valuable knowledge that can be reinforced later in the curriculum. These introductory courses generally are centered on the engineering design process and in this case use the FRC as a term-long semester project.

By experiencing all aspects of a demanding design and fabrication process, students have the opportunity to understand the many intricacies and associations of the engineering design process. West *et al.* [7] emphasize that 'even the most elementary hands-on experience teaches a profound lesson and the difference between what you can conceive and what you can build.'

Freshmen who have a wide variety of majors are usually enrolled in this type of course. Credit can be awarded for a core course in a specific engineering program or as a technical elective. Typically, lecture instruction is augmented with a practicum experience in the lab/workshop where the robot is designed, manufactured and assembled.

In this scenario, the university students are associated with the design process, but it would be unreasonable for them to lead the project and manage the design process. Similarly, the analysis associated with the robot design could be beyond the abilities of freshmen students. In this case the university and staff must direct the analysis and design process, involving the university students as apprentices in the work.

Since the FRC design challenge is 6 weeks long and typically begins the first week of January, the design aspect of the introductory course is usually the first course topic. University students apply the FIRST Robotics game challenge to all elements of the engineering design process, including problem definition, research, criteria and constraints, alternative solutions, analysis, decision making, specifications and communications. The classroom instruction can be used to introduce the material and the lab sessions could be devoted to applying the design steps to a FRC robot.

The remainder of the semester could be devoted to other topics that are traditionally addressed in design courses, such as engineering ethics, engineering economy, standards, project management and design analysis. The FRC robot could be used as the basis for these course concepts. For example, assignments for engineering ethics could be based on reviewing the ethical aspects of the FRC, such as following published rules and developing strategies with other competitors.

As with a typical engineering class, assessment of student performance could be accomplished using homework, lab reports and tests. In addition, the contributions of each university student to the design and construction process of the robot might be evaluated and used as a factor in the course grade.

*Engineering Tools Course Model*

Sophomore and junior level courses on elements of machine design are another example of FIRST Robotics Competition-based courses. While the previous example emphasized the design process, this group of courses addresses the analytical, computer modeling and machine shop skills required to design electromechanical systems. It is important to note that this collection of courses is distinguished by the fact that a robot is not designed and constructed during the course, but rather the robot design process is used as the running example to base the course content on.

One challenge of using competitions within the engineering curriculum is the students' strong desire to immediately start constructing a solution before devoting the necessary analysis and planning required by such projects. Student desires are often motivated and driven by competition deadlines, such that if a device is not created, one cannot compete. These mid-level courses attempt to address this issue and present engineering design analysis and manufacturing skills before they are needed to construct a complete system. By decoupling the acquisition and application of these skills, there is an increased probability for success later applying these skills during a competition cycle. An example of an engineering analysis tool developed to support an FRC-based university course is presented in Fig. 4.

Enrollment is usually restricted to engineering and physics majors with the courses offered during the fall semester or quarter. Three credits are generally awarded for completing the course, and the course usually can serve as a technical elective. The instruction format can be a combination of lectures, lab/practicum experiences and service requirements.

The material covered in these courses can parallel that of junior level machine design courses. Lecture topics include material properties (stress, strain, yield strength, buckling and fatigue), mechanical elements and power transmission components (gearing, bearings, shaft analysis, shaft coupling). Instruction on sensors (limit switches, potentiometers, shaft encoders, light

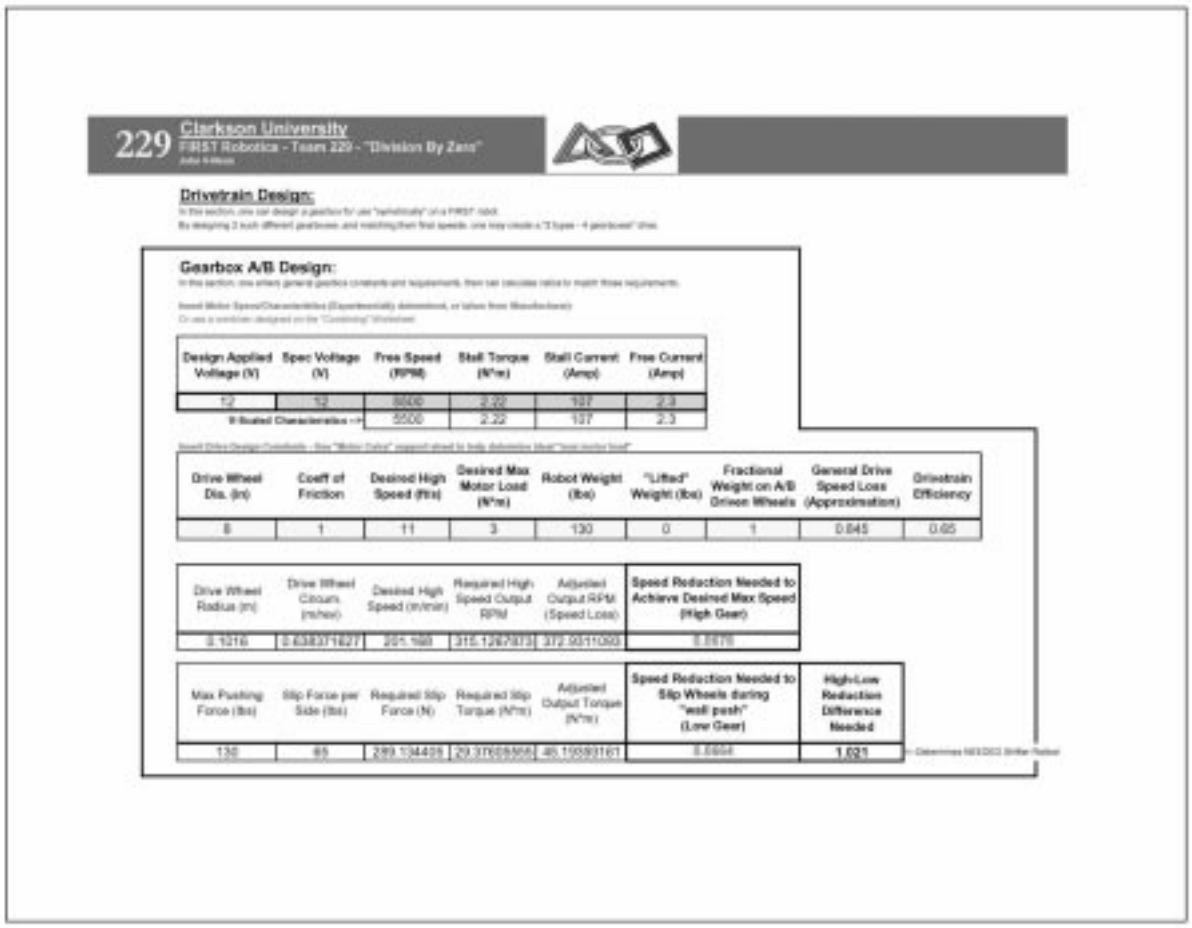


Fig. 4. FIRST Robotics Competition drive train calculations (courtesy of John Vielkind-Neun, Clarkson University).

sensors, and gyros), DC motor characteristics and Computer Aided Design software is also often included in these mid-level courses [18, 19].

Machine shop use can serve as the lab/practicum components of the course to provide an introduction to using standard machinery such as lathes, drill presses and milling machines. It is not uncommon for the courses to include a service component where university students provide instruction to high school students on engineering fundamentals and machine shop procedures.

Previous robot designs might be used as the subject of reverse engineering investigations of drive, lift and control systems. Similarly, previous designs could be used to determine the resulting stresses in a robotic arm, the power needed to achieve a desirable speed, or the force required to lift an object while avoiding tipping.

Student performance can be assessed using homework, exams, class participation, lab reports and by measuring the effectiveness of the instruction provided by the university students to the high school members of the team. A letter grade can be assigned for the course, or the course may be evaluated using a Pass/No Entry option (where the course only appears on the transcript if the passing grade is recorded).

*Robot Design Course Model*

The follow-on course based on the FIRST Robotics Competition is one where students apply analysis and design skills acquired in earlier courses to design and construct a competitive robot. Second and third year university students are most likely to be enrolled in this form of an FRC-based course, with 1–3 credits awarded for the course. Enrolment would primarily be students majoring in Electrical Engineering or Mechanical Engineering, and to a lesser degree, Computer Science/Engineering.

There are two forms of robotics projects used in this type of course: one where robots compete in an FRC event and one where robots compete in smaller scale, university sponsored robotics competitions. In both cases, this course requires students to apply engineering fundamentals to design and construct robotic systems. Systems integration and project planning are important components in this form of an FRC-related course.

When this type of course is used to create a robot for the FIRST Robotics Competition, it is generally a forum to enable university students to receive academic credit for participating in the very demanding design/build phase of the FRC. In this scenario the course is primarily lab/practicum

based with very little lecture material presented. The focus of the course is to design and manufacture a robot to participate in the FIRST Robotics Competition. University students generally participate as a regular member of an FRC team, with the more experienced students assuming leadership positions within the team.

The structure and format of this type of robot design and construction course can differ when the focus of the course is the creation of a robot for a university level 'FIRST-like' competition. Such competitions are generally similar to the FIRST model in that a tele-operated robot must be designed from a standard kit of parts to play a mechanical sport, but the scale of the project is generally much smaller and the time frame for the work is usually longer than the 6-week FRC design/build period. In this version of the course, lecture material on the design and fabrication of robotic components, including drive trains, lift mechanisms, manipulators, pneumatics, control systems, power distribution and sensors, can be presented and then applied as a course project. Some universities have used FIRST-inspired tele-operated, programmable rapid prototyping robotics kits as the kit-of-parts to support these types of courses [20].

Applying all aspects of the design process, including subcomponent design, prototyping, systems integration, programming and debugging, is the fundamental attribute of these courses. Figure 5 presents an example of an experiment (to determine the torque-speed characteristics of an FRC motor) that might be conducted in this type of course. In addition to the design process, the course would require the application of project management, critical/creative thinking, and conflict resolution skills to create a working robot in a prescribed time period. Assessment for the FRC-version of this course is generally based on the level of participation, while more standard assessment tools, such as tests, homework, and lab reports, could be used when the course project is an internal robotics competition. Performance of individual subcomponents and/or the completed robot can also serve as assessment criteria.

*Capstone design course model*

The FIRST Robotics Competition has been used as a project for numerous capstone design projects in Mechanical Engineering and Electrical Engineering [21, 22] where groups of seniors work on some aspect of a FIRST robot as a single-term or multiple-term project. Typically, 3 or 4 credits are awarded for this type of course, with the majority of course activity being lab/practicum experiences augmented with lecture material. The student teams may lead the entire FRC team through the robot design and construction, or they may be responsible for a single component of the design that is essentially independent from the high school student team.

Compared with the previous version of the FRC-based course focused on the creation of a competitive robot, the focus of the capstone course is much broader. As the culminating design experience, students must apply the knowledge from earlier courses and incorporate engineering standards and realistic economic, environmental, sustainability, social and political constraints [23].

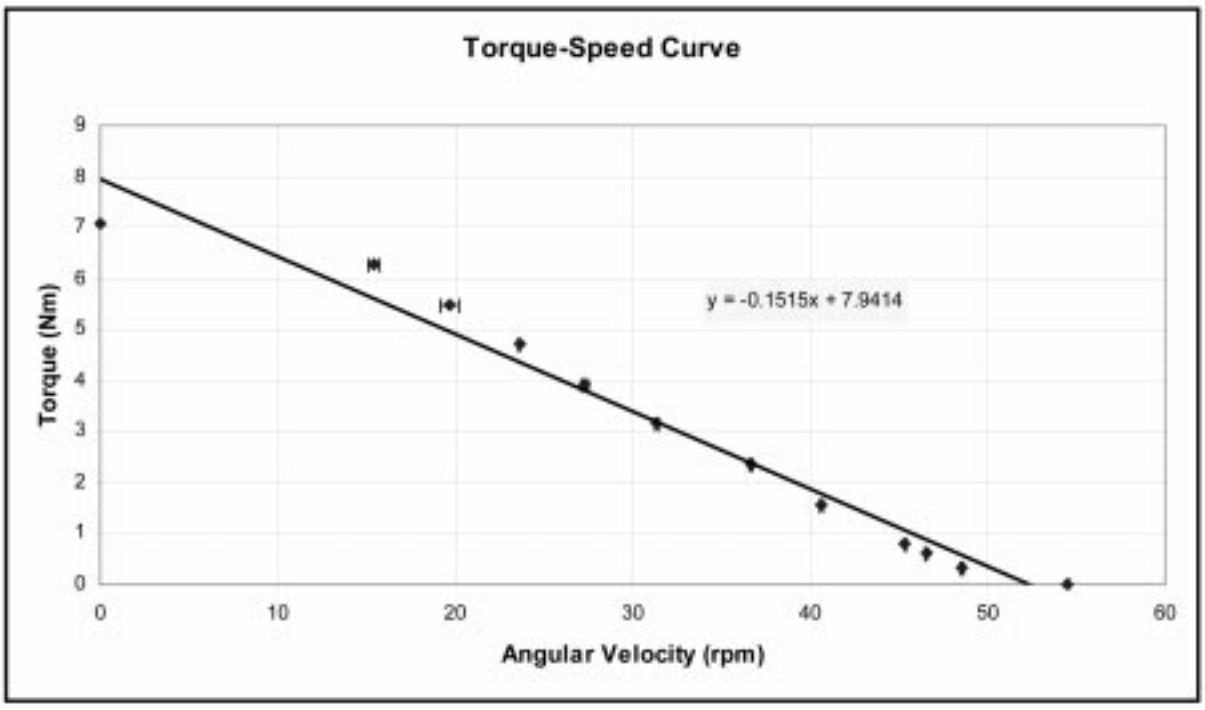


Fig 5. Student developed torque-speed characteristics of a FRC motor.

As a front-loaded senior design experience, an FRC capstone design project is very different from typical end-of-term-loaded capstone projects. With the FRC design/build phase occurring in January and February, capstone design teams pursuing this project are extremely busy during the first part of the semester. The remainder of the semester can be devoted to post-design analysis and experimentation (such as that presented in Fig. 6), examination of relevant engineering standards and reviewing pertinent criteria related to the project. For example, the Engineering Code of Ethics might be reviewed with students writing an ethical case study based on their FRC experience.

Assessment of the FRC capstone project can be based on preliminary and final design review presentations, projects reports, component and/or robot performance and peer reviews by student team-mates. Assignments on ethics, experimentation, analysis, engineering standards and project planning can also be used in a grading algorithm.

*Progressive model of FRC courses*

Collectively, these courses define the progressive model of FRC-based undergraduate engineering courses displayed in Fig. 7. Here the four forms of FRC-based courses (learning the design process, acquiring engineering skills, applying engineering skills, and design integration) present a sequence of courses that require students to apply their design, analytical, planning, and manufacturing skills.

This progressive model serves as a guide for creating an instructional technique that can work well for each specific university program. Rather than simply starting an FRC team and finding some way to include that team experience in the curriculum, the presented model outlines a series of options on which an instructor can build a course. If the program focuses on freshmen, an introductory course is most logical, while mid-level courses based on the FRC are more appropriate for creating a real world context for machine design and engineering analysis.

Most universities that incorporate FIRST in the curriculum follow a single course format at their institution. Clarkson University is unique in that all forms of courses identified in Fig. 7 are offered at the institution. A single FIRST robotics team is sponsored by Clarkson University as one component of the university's 'Student Projects for Experiential Engineering Design (SPEED) Program', which facilitates team-based engineering design project experiences to promote cooperative, hands-on, student-directed group learning [24].

At Clarkson, undesignated elective credit is available for freshmen (1 credit), sophomores (2 credits) and juniors (3 credits) in a fall semester course (Multidisciplinary Project) that prepares students to participate in the FIRST Robotics Competition or a spring semester course where a robot is designed and constructed. The topics of the fall semester course are very similar to those detailed in the engineering tools course model previously described. All Clarkson University FIRST team members must be registered for this course, and the course presents a formal method for ensuring the university students are involved in the robotics project. Grading is based on attendance, participation in team activities, documentation in an individual project journal and the preparation of a portfolio of the sub-team's accomplishments [25].

A directed study option is available for Clarkson juniors or seniors involved in the FIRST Robotics Competition to receive credit toward their degree requirements. In this case students register for Directed Study (Electrical Engineering) or Independent Study (Mechanical Engineering). Like

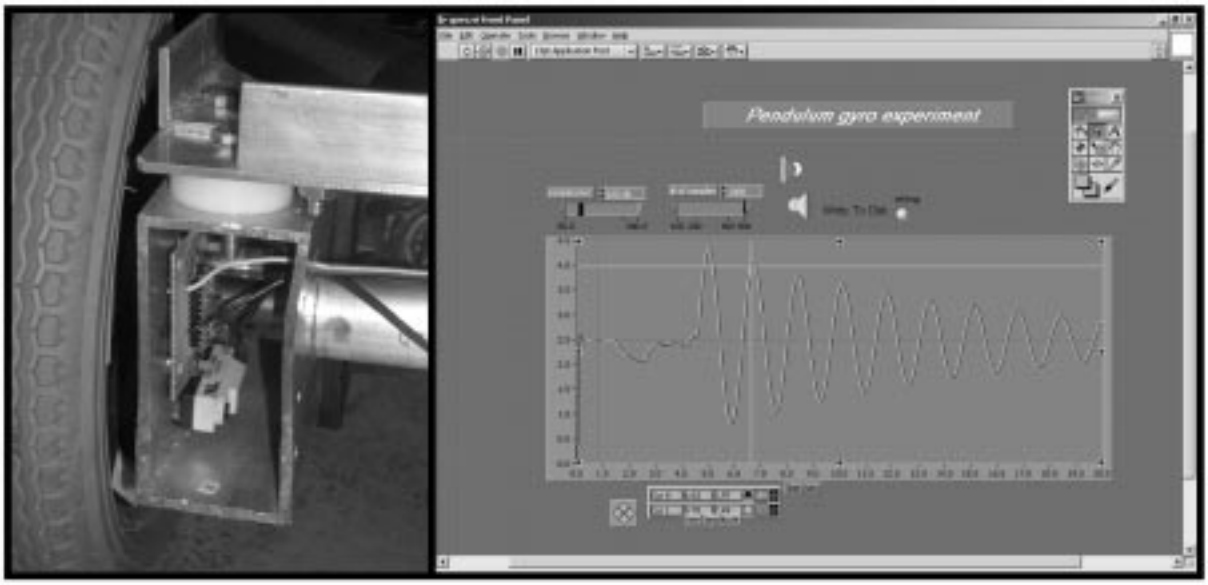


Fig 6. An example of FIRST technology used for engineering experimentation: gyro mounted on an FRC robot and a student designed data acquisition tool to investigate the output of the gyro.

other directed study courses based on FIRST, Clarkson students submit a written plan of study and take the course for a letter grade. Compared with those enrolled in the undesignated elective credit course, the directed study students must exercise and document rigorous analytic thought and design methodology in this class.

The FRC project is one of several projects available for Electrical or Mechanical Engineering seniors in Clarkson's capstone design courses (i.e. Integrated Design I and Integrated Design II). A series of project milestones on project planning, design specifications, concept alternatives and concept selection are the basis of the fall course, which culminates in prototype development and the creation of a design–manufacturing plan. The spring semester is devoted to carrying out the design–manufacturing plan for some component of the FRC robot. The students enrolled in this course provide technical leaderships and serve as technical consultants to Clarkson's FIRST team. It is expected that the subcomponents designed in this course will be used on the Clarkson University FIRST robot.

The FIRST Robotics Competition has also been used as an independent student design project at Clarkson University for junior and senior level students majoring in engineering. Like the Integrated Design course, students pursuing FRC-related independent study projects generally concentrate on a single robot subsystem and are responsible for all aspects of that subsystem and its integration into the completed robot.

## CURRICULUM APPLICATIONS: INSTRUCTION BASED ON THE FIRST ROBOTICS COMPETITION

*University instruction derived from the FIRST Robotics Competition*

In addition to entire courses based on the FIRST Robotics Competition, the FRC has inspired instruction in a wide variety of undergraduate engineering education courses. Such instruction has been derived from, enabled by, or based on the FIRST Robotics Competition process and technology.

While some programs have used the actual FIRST Robotics Competition as a course project for introduction to engineering design courses, the FRC model has also been used as a team project within similar introductory design courses. Small-scale versions of the FRC have been created, very similar to the original inspiration of FRC itself [6] as a means of engaging students in all aspects of a design challenge. Such courses have used a FIRST-inspired rapid prototyping robotics kit [20] that includes all components to build a tele-operated programmable robot.

The FIRST Robotics Competition has been a valuable learning platform at universities that sponsor FIRST teams. In these instances, students and faculty with FIRST experience have creatively applied the project to existing courses in their disciplines. For example, Worcester Polytechnic Institute requires all undergraduates to complete a series of three projects on the humanities and arts,

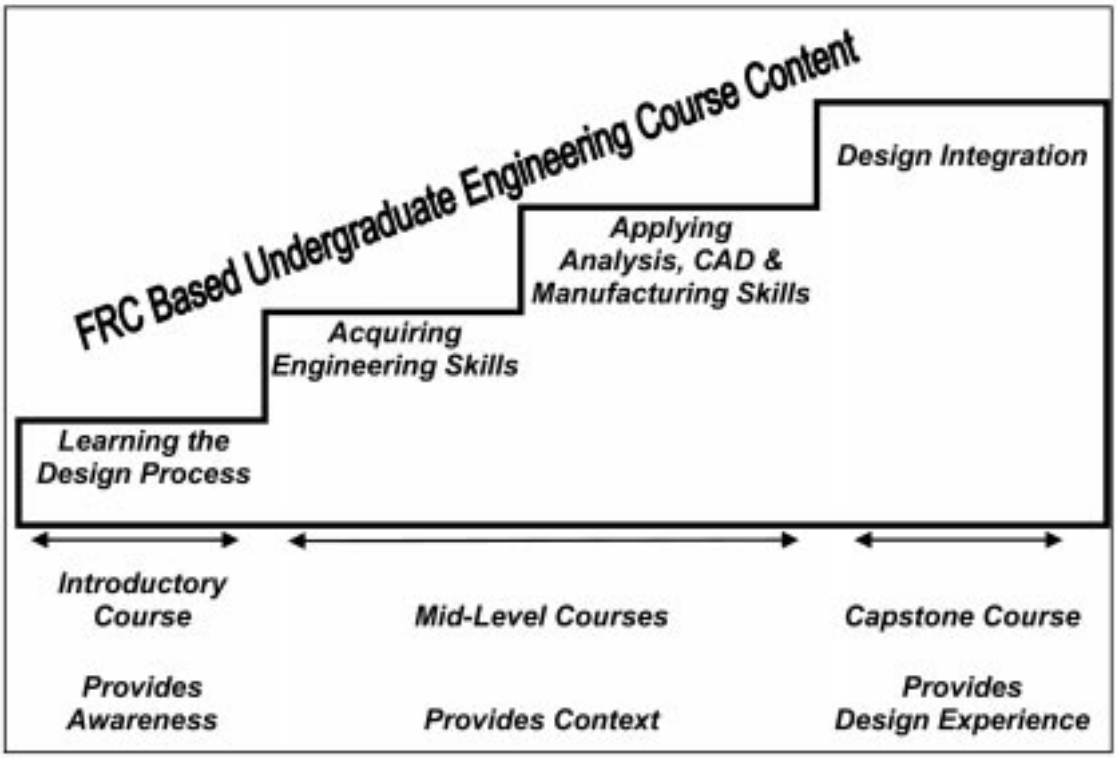


Fig 7. FIRST Robotics Competition based curriculum model.

discovery and design within an academic major. The FIRST Robotics Competition has been the subject for each of these project areas. The FRC has been also been used for distributed design where a team with members located in different geographic locations designed and constructed electromechanical devices using the Internet as their principal communications tool [26].

In other examples, participation in the FRC has led to team-based robotic projects as part of Mechanical Engineering and Electrical Engineering classes. The FIRST Robotics Competition has also been a factor in the creation of a Robotics Exploration Studio class at a liberal arts college as a means of increasing science and technology awareness [27].

The FIRST Robotics Competition kit includes electronics and controls that provide reliable, safe high-current applications. The kit of parts also contains a variety of sensors, all of which have utility in the curriculum beyond the FIRST project. Faculty have used FIRST control systems and sensors to create bench-top lab experiments and as the building blocks for automatic control systems. By applying FIRST technology in other courses, students are better prepared to use the systems during the very short FIRST design/build phase.

## NON-CURRICULUM ACTIVITIES RELATED TO THE FIRST ROBOTICS COMPETITION

While this paper has addressed the curriculum applications of the FIRST Robotics Competition, it is essential to recognize the FRC impact beyond the curriculum. Many universities associated with the FRC support university-wide robotics clubs that provide an avenue for students to explore robotic technologies further. Some of these clubs serve as the formal mechanism to allow university students to participate in FIRST as an extracurricular activity.

FIRST-like engineering outreach programs, intended to draw high school students to science and technology, have been created by a number of universities that sponsor FIRST teams. During the summer these university-sponsored outreach programs host visiting high school students who work in teams to solve a design challenge. Universities also sponsor post-season robotic competitions for experienced FIRST teams. While these competitions are not official FIRST events, they follow the FIRST game rules and provide an opportunity for teams to use their robots after the competition season has concluded. These engineering outreach programs and post-season robotic competitions provide avenues for the university to recruit technically strong high school students, thus justifying the investment in such programs.

## RECOMMENDATIONS

The FIRST Robotics Competition is a forum that can effectively and efficiently be used in the engineering education curriculum. As a program popular with tens of thousands of worldwide participants, there are many examples of how the FRC can be used for undergraduate engineering instruction. Some specific recommendations are presented for engineering educators interested in starting a FIRST team.

The FIRST community is extremely cooperative and all existing teams are encouraged to mentor new FIRST teams. A new university-sponsored FIRST team can easily be partnered with existing teams who are willing to help new teams get started. Student-student and faculty-faculty dialog between new teams and their mentors significantly reduces the learning curve associated with the FIRST Robotics Competition. Existing web-based discussion forums promote information exchange and provide a mechanism for student and faculty intercollegiate FIRST communications and networking.

Surveys of university-sponsored FIRST teams indicate that the benefits of participation in FIRST outweigh the costs. Survey results stress the necessity to 'make curricular connections to increase success' of university sponsored FIRST teams [13]. As such, new university-sponsored teams are highly encouraged to incorporate the FIRST program into the curriculum to secure the needed level of university student involvement and to help enable faculty to be recognized for their personal investment in FRC activities.

It is recommended that engineering educators who are new to FIRST implement a single aspect of the progressive model for the FRC-based curriculum. The FIRST project is a complex and demanding activity and it is helpful to find an application where the FRC can be used as the principal activity of a course. The incremental approach proposed in the developmental model encourages the sequence of understanding the design process, followed by learning engineering tools, and then applying that information to design an engineering system. This sequence provides a reference and template applicable to all design activities.

Instructional materials are needed to help university faculty members incorporate FIRST in the curriculum. Presently there is no single source of information that presents the engineering analysis and design of a FIRST Robotics Competition robot in a format that can be readily used in a university course. The existence of an authoritative source for the design and construction of a FIRST robot, including the design process, fundamental engineering calculations and analysis, material selection, sensor technology and programming techniques, would benefit faculty and students. Such a text would greatly reduce the time required to assimilate, prepare and disseminate instructional material for FRC-based courses.

Forums for university student analysis and design papers/presentations would advance the state of the design aspect in the FIRST Robotics Competition. By including documentation of design decisions as a component of the FRC, the educational component of the competition could be further showcased and emphasized. Similarly, increased levels of communication between university participants would strengthen university involvement in FIRST.

## CONCLUSION

The FIRST Robotics Competition is an international program that is increasing technical literacy. Though created as an engineering outreach program to interest high school students in science and technology, there are many ways universities participate in the FRC.

A four-step development model provides a template for engineering educators to follow when implementing FRC-related instruction at their home institutions. The model starts with introductory classes where university students are exposed to the design process and concludes with capstone design classes where students apply their engineering education to design a competitive robot.

Other examples of using the FRC in the university curriculum demonstrate the utility of the FRC in project-based engineering courses. These applications demonstrate how the FRC project has migrated into other traditional engineering courses, thereby capitalizing on the student and faculty investment in FRC technology and processes. Further examples of university relationships with the FRC, such as hosting competitions and using the competition as a model for engineering outreach activities further demonstrate the value of FIRST—university partnerships.

It is clear that university involvement with FIRST is by no means a narrow experience strictly related to the design and construction of a robot. Instead, universities have found their associations with the FIRST Robotics Competition to be very broad and rewarding, with applications and impact within as well as external to the curriculum.

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