120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #6681

Computer Engineering Design Projects in Collaboration With Industry Sponsored Competitions

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1. Introduction

We present two models for effective collaboration between universities and industry in student design projects in the area of embedded computing systems. The first of these at Clarkson University is a senior capstone design project in computer engineering. The second at California University of Pennsylvania is a junior level course in embedded systems for students in computer engineering technology or electrical engineering technology. In each case the student work is based on the Freescale Cup platform offered by the Freescale Corporation. The Freescale Cup platform is used in the Freescale Cup competition sponsored by the Freescale Corporation that challenges students to design an autonomous model race car that must follow a black line track as fast as possible. Beyond the actual course work students may optionally choose to participate in the Freescale Cup competition, which is held in many locations around the world including regional competitions in the United States. The competition serves as a strong motivating factor, and the community of students from all over the world involved in these competitions fosters a sense of being a part of a larger project than a typical course project.

2. Review of Design Competitions

Each year there are many student design competitions available, many of which are aimed at senior design projects [1]. Perhaps the best known competition in the area of autonomous robotics is RoboCup [2]. RoboCup is an international organization, registered in Switzerland, to organize international efforts to promote science and technology using soccer games by robots and software agents. RoboCup has several levels of competition that range from advanced, graduate student level competition to RoboCup Junior for students up to age 19. The more advanced levels require significant investment of resources and time for teams to be competitive.

There are also many paper design competitions each year [3]. While these require significantly fewer resources to support student participation, they lack the hands-on aspect of projects that produce physical objects, and do not provide the experience of actually having to make something work.

For the purpose of engaging students in the complete process from initial design to project construction, involving mechanical, electrical and software components, we believe it is imperative to have a design project in which students must carry through from design to a completed project that can be demonstrated and tested against performance requirements. We feel it is important for students in computer engineering, computer engineering technology, and electrical engineering technology to work with a complete system and not simply program an otherwise prepared kit. To do this in the time frame of one semester, the project and platform used must be carefully selected.

The Freescale Cup is at the core a line following robot, but it should be emphasized that as the speed increases the level of difficulty increases. There are many examples of products such as Lego NXP, Parallax Scribbler, or the Make Rovera all of which are capable of slowly and methodically following a line. Competitions do exist; most are locally organized and run by an area academic institution. Some evolve into sumo, maze, or similar challenges.

The Freescale Cup is unique in providing a platform that is standardized, but still has sufficient flexibility for variations in student design. Moreover, the competitions are international, involving undergraduates from across the globe. Freescale supports a set of web pages that provide background information and forums for students and faculty to exchange ideas about all aspects of the competition.

3. Capstone Design Projects

At Clarkson we have an ABET accredited degree program in Computer Engineering with a senior design experience that requires teams of students to design, build, test and demonstrate a fully functional embedded system. The course is a one semester, six-credit hour course with both scheduled lecture and laboratory time. For the past two years we have used the Freescale Cup platform as the basis for student projects in this course. We discuss our course objectives, the Freescale Cup car platform, our assessment process, and we present assessment data from these past two years. We believe the Freescale Cup platform and competition provide a meaningful design experience for students and meets the objectives for a capstone design experience in computer engineering.

3.1 Course Objectives and Organization

Capstone design projects often have several objectives in addition to providing students with a major design experience, including fostering the development of teamwork skills and providing an opportunity to work on a multidisciplinary project. Our student learning outcomes for the senior design course are:

1. Specify, plan, design, build and test a digital system requiring integrated hardware and software subsystems that utilize embedded computing in a real-world system subject to prescribed specifications.
2. Demonstrate that their project designs satisfy constraints imposed by industry and government standards, regulations, concern for public health and safety, and professional codes of ethics, and are completed within the required time and budget limitations.
3. Demonstrate the ability to work effectively in a team with other individuals having diverse backgrounds, interests, and abilities, and will demonstrate teamwork skills including cooperative sharing of workload, individual responsibility for the overall team effort and interpersonal communication.
4. Work on projects that require knowledge of components, devices, and systems from disciplines outside traditional computer engineering.
5. Express their understanding of professional and ethical responsibility by formulating a code of ethics for conduct as a team member.
6. Develop their technical writing and oral presentation skills through the production of written progress reports, design reviews and oral presentations.
7. Evaluate their project designs in the context of "technology serving humanity", assessing both the benefits and possible adverse impacts of their design.

We assess these outcomes along with outcomes in each of the other required courses as part of our assessment process to meet the ABET requirements for continuous improvement. For the purposes of this paper, we will focus on outcomes # 1 and # 4 that are specifically supported by the collaboration with Freescale Corporation.

In the first week of the semester, students are grouped into teams of three or four members. Students submit a one page resume that summarizes their grades in prerequisite courses, summer internship experience, and specific areas of interest. Team assignment is done by the instructor based on forming teams with a balance of student ability, interests and backgrounds on each team. Teams are given a Product Concept document describing the basic requirements of the project. Teams are encouraged to expand the capabilities of their project beyond the minimum requirements set out in the Product Concept. Each team is given a budget of approximately $150 with which they may augment the set of supplied hardware.

3.2 Project Description

For the past two years we have based our project on the Freescale Cup platform. We do not require participation in the actual competition, but in the first year we had one team who participated and won the regional competition. For our project we use the Freescale Cup car platform and most of the rules of the competition, including the description of the track which is composed of modular pieces. The use of a modular track allows for a variety of configurations and prevents attempts at "pre-programming" the car for any one specific layout. A typical track configuration is shown in Fig. 1. Each track piece is two feet wide with a one inch black line in the middle; the straight sections are four feet in length, and the curved pieces are cut from a three foot square giving a right angle turn of radius 20 inches. One straight section has the start/finish line with two short segments of a black line perpendicular to the primary track line.

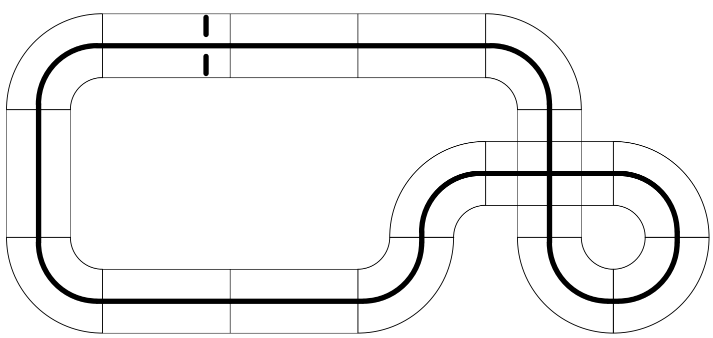

Figure 1: Typical track configuration

Our minimum requirements include two performance measures:

(1) Accuracy, defined as keeping the black line in the center of the front wheels, as the car navigates the track with no timing requirements, and stops after making two laps.

(2) Speed competition in which each team is given two chances to run their car around the track as fast as possible, without leaving the track and stopping after two laps; the single best lap time is used to rank the teams. Points are awarded in proportion to each team's placement in the speed competition.

The first of these measures is non-competitive and is based only on individual team performance; this portion represents about 40% of the course grade. The competition portion accounts for about 10% of the course grade. The remaining 50% is determined by individual and team performance on design reviews, progress reports, meeting milestone deadlines, etc.

Teams may earn extra credit points by completion of optional capabilities that enhance the overall capability of their car. Points are awarded for these based on the additional capability that is attained and the cost of additional hardware, if any, that was used. Typical options include Bluetooth communication with the car for the purpose of obtaining real time data from the car as it moves around the track or additional sensors to aid in detection of the track and finish line. Extra credit points are worth at most 10% of the total points available for the project.

3.3 Freescale Cup Platform

The Freescale Cup platform consists of a model car, a microcontroller system, a motor control board and a line scan camera. The model car is a four wheeled vehicle, about 31 cm. in length and 17 cm. in width, with two DC drive motors, one for each rear wheel, and a servo to control the steering. There are two choices of microcontroller systems; we chose the Freescale Tower System with a Kinetis K40 microcontroller. The K40X256 board is shown in Fig. 2.

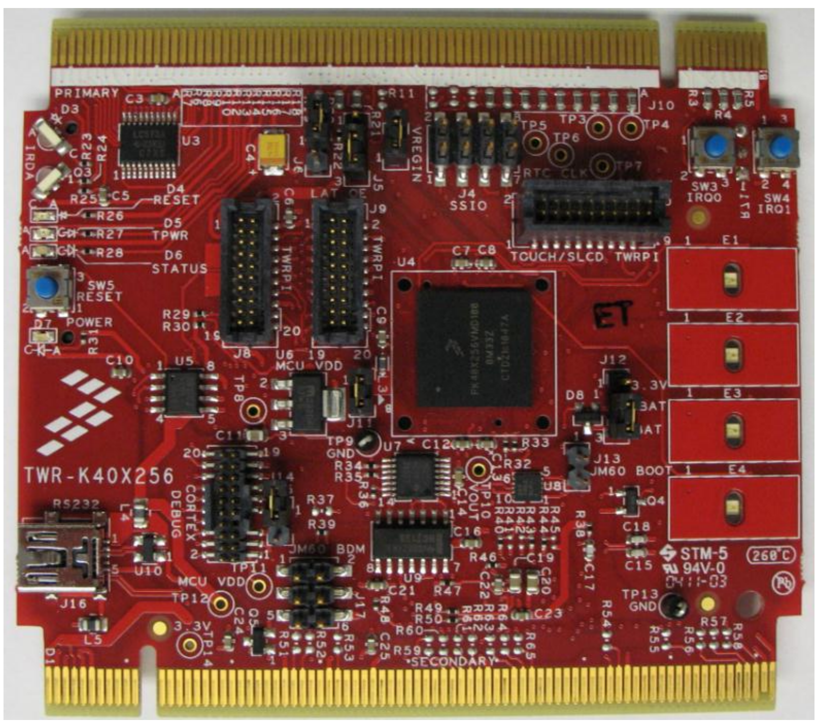

Figure 2: Tower System K40X256 Board

A significant advantage of using this board is that it includes the hardware for programming and debugging. Using the mini-USB connector, the board may be connected to a PC on which Freescale's CodeWarrior development software is run. Freescale provides a free version of this software for small projects on its web site. This allows students to have a fully functional system for embedded software development in C and/or assembly. The debugging capabilities include memory inspection, breakpoints, and step-by-step execution at either the assembly or C code level. The CodeWarrior suite includes many example code segments for use in writing drivers for the on-chip peripherals as well as chip initialization.

The K40X256 microcontroller is a 32-bit ARM Cortex M4 processor with DSP instructions and a maximum clock frequency of 100 MHz. The on-board memory includes 256 Kbytes of program flash memory, 256 Kbytes of non-volatile storage that may be used as additional program flash or data flash, and 64 Kbytes of static RAM. The integrated peripherals include general purpose digital input/output pins, 16 bit analog-digital converters, 12 bit digital-analog converters, a variety of timer modules that may be used for pulse width modulation, input timing capture, quadrature decoding, or periodic interrupt generation, UARTs, and interfaces for USB, CAN, SPI, I2C, and SDHC. In addition to the K40X256 chip, the board includes a digital accelerometer, LEDs, pushbuttons, and capacitive touch pads. A daughter board is included that provides a 28 segment LCD for simple display output. Many of the K40 input and output signals are brought out to the edge connectors; these signals are accessible using the tower system.

The tower system provides a modular environment in which students may interface with the K40 inputs and outputs using either available tower module boards or with a wire-wrap prototyping board for custom hardware development. An example tower system is shown in Fig. 3 with a bare prototyping board on top and a K40X256 board mounted below. The prototyping board is used to provide access to signals on the K40 via the edge connectors and is also used for construction of the power supply components and any optional hardware as part of a team's extra credit design. The tower is a cube with sides of 9 cm.

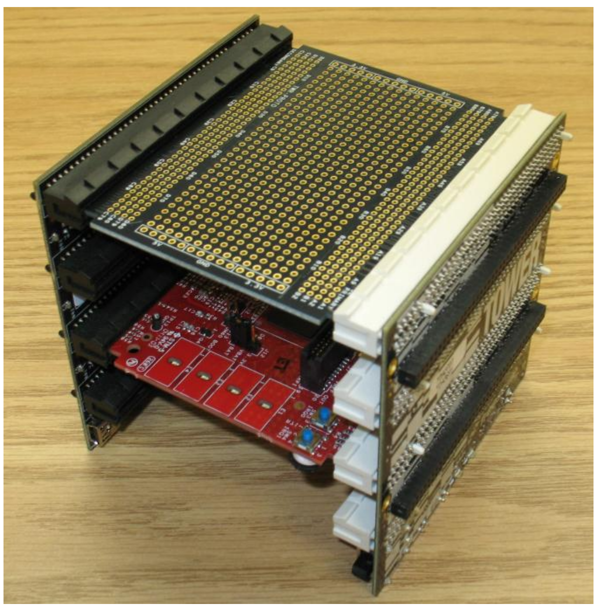

Figure 3: Tower System with Prototyping Board and K40X256 Board

The motor control board consists of a simple dual H-bridge IC and binding posts for the battery inputs and leads to the motors. The DC motors are supplied with 7.2 volts from the battery using the H-bridges controlled by pulse width modulation (PWM) signals generated by the microcontroller. Students have a design choice to either drive both DC motors with the same PWM signal or to generate two separate signals. While it is more complex, there may be a slight advantage to drive the wheels independently on the turns. Some teams have elected the single PWM approach, while others have used two independent PWMs.

The car is steered based on inputs from the line scan camera. The camera is a CMOS linear array of 128 pixels with an adjustable lens. The camera requires a clock signal and a timing signal generated by the microcontroller to initiate a single horizontal scan of the field of view and to control the integration time of the CMOS pixels. The camera output is an analog voltage proportional to the light input at each pixel during the integration time. The microcontroller must convert this to an array of digital values and then process these to detect the black center line and also to detect the stop/finish line. Development of these processing algorithms is one of the more significant technical challenges for each team.

3.4 Assessment Process

Assessment of student outcomes is based on measures of student and team performance during the semester and overall performance by each team's final product. We also use a student self-evaluation at the end of the semester in which each student is asked to assess anonymously her attainment of the course outcomes.

Individual student performance is measured by a written and oral design review and weekly progress reports. Each team is responsible for submitting design documentation and test results at five milestones during the semester; grades on these materials are considered as "team shared" grades. At the end of the semester each team's product is evaluated on the basis of the performance measures for accuracy and rank in the speed competition as described above in section 3.2. Any options are assessed for extra credit. Each team is responsible for submitting a final design report and making a "lessons learned" oral presentation. The final report, oral presentation and product grade are also team shared grades. Each student's final course grade is a weighted combination of her individual grade and her share of the team shared grade. Each student's share of the team shared grade is determined using a peer evaluation instrument.

As noted above in section 3.1, one of our course outcomes is a demonstrated ability to work in a team. A key part of our assessment of this outcome is the use of a team peer evaluation instrument known as CATME (Comprehensive Assessment of Team Member Effectiveness) [4]. CATME is a web-based tool for self and peer evaluation designed for use by student teams. CATME uses a behaviorally anchored rating scale that measures individual contribution to overall team effort along five dimensions:

1. Contributing to the team's work
2. Interacting with teammates
3. Keeping the team on track
4. Expecting quality
5. Having related knowledge, skills, and abilities.

CATME was developed under an NSF grant and has been extensively tested and validated; it is available online as a free tool for faculty at http://www.catme.org.

We use CATME six times during the semester. After each milestone due date and at the end of the semester, teams are asked to complete an evaluation. The instructor has complete data showing how each student rated herself and her teammates. Each team member is able to view her self-rating, the average rating of herself by her teammates, and the overall team average. This provides feedback to the team throughout the semester of how each team member is contributing relative to other teammates. It also assists the instructor in identifying any potential team problems early so that they can be discussed and resolved before getting out of control. At the end of the semester, each team member is assigned a team share value that is the average of her standing relative to other teammates over all of the evaluations. For teams that work well together, these numbers are usually quite close to 1.0, indicating each member is contributing fairly to the overall effort. In cases when one or more team members are not contributing, those who do perform will get a higher share of the team shared points than those who are not contributing. Since we started using CATME several years ago, we have had far fewer complaints from students about team members who do not contribute their fair share. The students are also aware that when this happens, the team member will be graded accordingly.

As part of our assessment of student achievement of course outcomes, we employ an online anonymous survey at the end of the semester in which each student is asked to answer questions about achievement of the course outcomes using a five-point Likert scale. These are detailed in the next section on results.

3.5 Assessment Results

We have used the Freescale Cup as the basis for our capstone senior design course for two years. Each year we have had four teams of three or four students each. The use of the Freescale Cup has directly contributed toward having students attain two of our stated outcomes.

The first of these outcomes is:

Specify, plan, design, build and test a digital system requiring integrated hardware and software subsystems that utilize embedded computing in a real-world system subject to prescribed specifications.

In the self-assessment survey, students were asked the following question:

In completing this course I successfully planed, designed, built and tested a digital system requiring integrated hardware and software subsystems that utilize embedded computing in a real-world system subject to prescribed specifications.

The results for each year are shown below:

	Agree Completely	Agree	Neither Agree nor Disagree	Disagree	Disagree Completely
First year	100 %				
Second year	80 %	20 %			

In these two years all teams have successfully completed a working project with a car that was able to navigate the track with reasonable accuracy. In previous years with other projects, it was sometimes the case that one team would not have a fully functional project at the end of the semester. The use of the Freescale Cup platform has provided a complete software/hardware package that is a challenging real-world task in embedded computing and is attainable in a one semester course.

The second of these outcomes is:

Work on projects that require knowledge of components, devices, and systems from disciplines outside traditional computer engineering.

In the self-assessment survey, students were asked the following question:

My work in this course involved projects that required knowledge of components, devices, and systems from disciplines outside traditional computer engineering.

The results for each year are shown below:

	Agree Completely	Agree	Neither Agree nor Disagree	Disagree	Disagree Completely
First year	67 %	33 %			
Second year	80 %	20 %			

The Freescale Cup requires teams to do much more than just computer software or hardware design. There are mechanical aspects of mounting the various components, understanding how vehicles track and are steered, signal processing of the vision signals, and interfacing with various electrical components such as DC motors and servos.

4. Engineering Technology Junior Course Project

At California University of PA, we have a "Microprocessor Engineering" junior-level course in our ABET accredited Computer Engineering Technology and Electrical Engineering Technology programs. This fourth course in the digital/microprocessor track is preceded by digital electronics design, introduction to microprocessors, and microprocessor interfacing with each of these being a semester-long, laboratory course. Although this course has always featured a major term-long project, we have adopted the Freescale Cup concept as the project for the past two years with notable successes from doing so.

4.1 Course Objectives and Organization

Required in both of our engineering technology programs mentioned above, this course targets a number of student learning outcomes including:

- application and enhancement of learning outcomes from previous courses,
- integration of hardware and software to achieve a typical embedded system solution,
- experience with the engineering design process of a major, semester-long project,
- development and appreciation of team dynamics skills, and
- methodology for engineering project documentation and presentation.

To no surprise, some of our students have described the true objective of this course to be the preparation for our actual capstone senior project course. Addressing the above outcomes at the junior level provides the advantages of better matriculating transfer students from two-year programs and to focus on other objectives in the senior project course such as ethics, human factors of engineering, industrial standards and processes, etc. Additionally, this course better prepares our CET majors for their senior project proposal course which is actually a software engineering course.

In a simplified version of a senior project course, students are self-grouped into teams of four or five members. Team roles include team leader, hardware specialist, software specialist, and team assistant(s). Each team is responsible for completing all phases of the project including project proposal, design, implementation, documentation, and presentation. For presentation, a “mini” Freescale Cup of sorts is held during the final week of the semester wherein time trials of two laps around the track are ranked by team for both project completion points and for bragging rights.

In a fashion similar to that described in section 3.1, we also assess student performance in this course with respect to overall program outcomes as part of our continuous improvement process per ABET requirements. For course grade, 40% of the grade is determined from the lab performance while 60% is determined from exams and assignments. Team achievement of project goal, quality and completeness of documentation, meeting of milestone dates and individual project contribution memos are factored into the lab performance assessment.

4.2 Project Description

Our implementation of the term project is similar to that described in section 2 with some differences as follows. Our project was derived from an earlier version of the Freescale Cup platform which includes only a single drive motor and lower overall battery drain, particularly helpful during project debugging phases. Prior to going with strictly camera-based line sensing, Freescale had an “optical sensing” division as an alternative to the then emerging camera-based sensing division. In consideration of overall course objectives and time constraints, we have elected to employ this simpler method for line sensing for the course project. Our project uses the Pololu QTR-8 Reflectance Sensor Array featuring eight IR emitter/detector pairs as shown in Fig. 4.

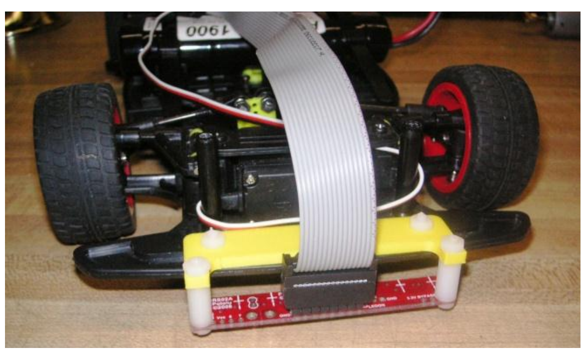

Figure 4: QTR-8 Sensor Array mounted to car

For processor solution, we use the Wytec Firebird32-Nano microcontroller module (www.firebird32.com) which is a Freescale Coldfire V1 microcontroller adapted to a 40-pin DIP form factor. This MCU features a 32-bit RISC processor running at 50 MHz, 128 Kbytes of flash, 16 Kbytes of static RAM, 4 Kbytes EEPROM, and a variety of integrated peripherals such as USBOTG, 12-bit ADCs, UARTs, CAN, SPI, IIC, RTC, eight timer/PWM channels and 66 GPIOs. The carrier board adds LEDs, user input switch, speaker, voltage regulators, and an LCD header. This combination allows for a "breadboard on wheels" configuration as shown in Fig. 5 and has proven to be highly motivational for the students.

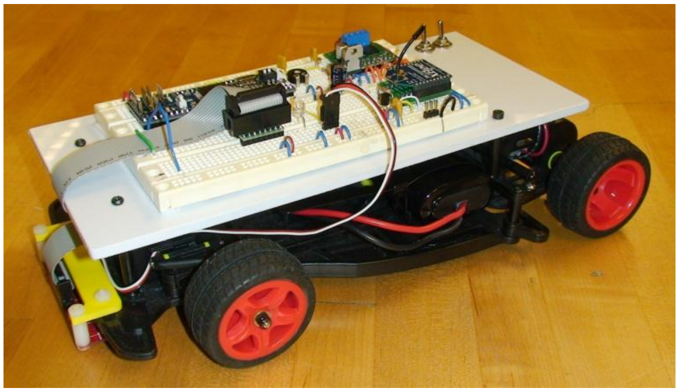

Figure 5: Freescale Cup "breadboard on wheels"

Teams are issued a standard component set including the Freescale car platform, a microcontroller module, and relevant interface components. Laboratory support includes the typical instrumentation suite along with the Freescale CodeWarrior IDE environment for software development in C. One highlight of this course in its current version is the concept of dividing the overall project into a number of engineering sub-problems and assigning each team one problem for which they become the "expert" in the technology behind that problem and present their finding to the rest of the class. The sub-problems are laid out as follows.

1. *Line sensing* - how to acquire line position data
2. *Steering* - how to control car heading via steering servo
3. *Motor drive* - how to control car forward speed via motor RPM control
4. *Power system* - derivation and distribution of required platform voltages from given 7.2V battery
5. *Line tracking* - goal is to "know" where line is immediately ahead of car and to control steering to keep car centered over line
6. *Speed sensing* - real-time tracking of the car's moving speed
7. *Wireless communications* - how to implement wireless data link from car to monitoring PC
8. *Mechanics* - how fit, locate, and connect things

This approach gives each team a sense of "ownership" of a part of the project and in effect a "pre competition" prior to the race day event. This also provides the students with a much-appreciated opportunity to practice/refine their oral communication skills within their peer group prior to senior project.

4.3 Observations

The adoption of a version of the Freescale Cup into a junior course project at California University of Pennsylvania has revealed a number of benefits. Current students in our engineering technology programs tend to be quite hands-on and desire to engage in projects that involve multiple disciplines. A project such as the Freescale Cup that transcends the boundaries of sensing, control, hardware, software, mechanical and data communications provide rich territory for student involvement and motivation. The competitive aspect, something atypical of higher education, adds a new dimension to collegiate instruction. By engaging juniors in such a project promotes the level of sophistication and accomplishment of senior projects; indeed we have seen an increase of senior project complexity and achievement in the past two years. Adopting this project into our Microprocessor Engineering course has undoubtedly contributed to our continued recent growth as our CET and EET student enrollment has increased from about 90 to 160 in the past five years.

5. Mutual Benefits for Industry and Universities

Freescale created the competition to drive the use of 32-bit processors into education. Increasingly more applications in industry are moving from the use of 8- and 16-bit devices to 32-bit architectures, capable of complex power management, connectivity, and human machine interfacing. As such, a demand exists for new engineers to be able to rapidly build complete solutions using the latest technologies and standards.

Collaboration with other industry partners helps reinforce the importance of the competition and how it will prepare students for the work place, as well as helping to facilitate logistics, sourcing key talent, and sponsors for elements of the competition. For example, the partners use their supply chain to pull together the parts from various sources and obtain competitive prices to create a kit of mechanical, electrical, and software components integrated as a single platform suitable for student competition. Sponsorships help with discounting and donating kits so that Freescale is able to keep investment by students and schools low. And, talented students have an opportunity to showcase their abilities not only to Freescale, but partners, customers, or co-sponsors such as AMS and ARM.

A community and wiki-like web site dedicated to the Freescale Cup competitions are maintained by Freescale and include faculty, student and industry produced tutorials, code and how-to videos. Training has been divided into multiple areas to address specific key elements in designing a successful project. A ‘swap-meet’ section has been created for participants to advertise ‘enhancements’ such as 3D-printer capable camera mounts or useful custom board connections. Because of the worldwide-nature of the event, students are able to see videos, review questions and monitor conversations that are happening on the other side of the globe that spur ideas, find answers to their own questions, and develop new approaches. While the communities service their respective local competitions, they offer the capability for cross fertilization among regions around the globe.

The Freescale robotics kit is available to anyone whether in the competition or for self-use. Participation in a Freescale Cup event is completely optional and intended to further motivation and collaboration among students who have the option of participating in any of the regional competitions sponsored by Freescale for prizes and recognition. Regions are established in centralized areas to bring together as many teams as possible.

Many industries talk about the need for global diversity in upcoming engineers. At Freescale, we really want to bring students together from different countries to not only experience the culture, but leverage student talents from other regions. Speed and technology are a universal language that allow students to get past language barriers. Starting in 2013, the first official global competition has been announced. Top teams from countries will meet to compete against each other. This provides students a very unique experience and global insight into diverse cultures, work ethic and communication.

References

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