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SPARKING A LIFELONG INTEREST IN ENGINEERING THROUGH A SUMMER ACADEMY IN ROBOTICS

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ABSTRACT

We have developed an intensive, three-week summer robotics program for high school students. The program requires special teaching methods since it is offered to rising 10th through 12th grade students with diverse backgrounds, and a low student/teacher ratio to ensure all students grasp the material. We use a project-based learning approach, assigning the students a series of specially tailored labs and projects designed to engage and challenge while preparing them for the main element of the program, the design of a semi-autonomous robotic vehicle whose mission emulates that of NASA's Martian rovers. The project culminates with testing of their vehicles on an obstacle course. A series of targeted design reviews are held as the project unfolds to keep all designs on schedule. We leverage the spirit of competition to heighten the enthusiasm of the students and sustain their interest through the long-hours required to design and build a successful robot. The students get hands-on experience with mechanism design, electronics, computer-aided-design and manufacturing, and microprocessor programming, and are engaged in discussions on applications of robotics in both academia and industry to provide a "grounding" of the material.

NOMENCLATURE

PBL	Project-Based Learning
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing

INTRODUCTION

The Summer Academy in Advanced Science and Technology (SAAST) Robotics program, founded in 2005, is an intensive, three week robotics program for talented high school students. The program, including instructor compensation, is funded entirely by a program fee paid by students (the fee for 2010 is \$5,900; financial aid is available through an alumni fund). The program fee also covers room and board, as well as all recreational activities for the students. More details can be found on the academy website [1]. Over 5 years, the program has evolved, becoming more successful and more popular, while still having a reputation as one of the most challenging of the SAAST programs. We report on the current state of the program, our teaching methods, and reflect on what changes have positively affected the success rate of the program since its inception.

The program is offered to rising 10th through 12th grade students with no required prerequisites, therefore it requires special teaching methods. We use a PBL approach, with multiple open ended problems serving as building blocks for and culminating in a comprehensive open-ended principal project. Highly focused lectures and specially tailored labs prepare students for the principal project, which encompasses 2/3 of the course. We

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use targeted design reviews to guide the students with their designs and ensure that all teams will successfully complete the principal project. The low student to teacher ratio (in 2009, the ratio was 25:8, or 25:12 including residential teaching assistants) ensures that students get the one-on-one mentoring they need.

Through this program, students get hands-on experience with mechanism design, electronics, CAD/CAM, and microprocessor programming. Furthermore, the students learn problem solving skills which they can use in the future.

RELEVANT WORK

Robotics is a canonical engineering discipline. It combines mechanical engineering, electrical engineering, and computer science in a truly comprehensive field of study. This poses challenges to teaching and learning robotics that cannot be addressed in the traditional disciplinary learning paradigms. Interest in robotics education and curriculums has been gaining increased momentum in recent years, with many workshops offered at prominent robotics conferences [2–4] as well as workshops and resources specifically for K-12 education [5,6].

Most of the literature in robotics education discusses learning through hands-on applications of open-ended problems [6–10]. We use a PBL approach [11,12], which promotes active-, collaborative-, and self-learning among the students. In PBL students work to solve an open ended problem, generating multiple artifacts along the way, culminating in the final product. In our case, the artifacts are specific subsystems of the robot, such as mechanical design, assembly, or control software for the rover. Using a project-based method for this course enables the students to bridge the gap between their classroom experience and real life [13]. In our program, the PBL approach, with a carefully integrated curriculum, has proven to be very successful.

Competition has been discussed as a method of advancing robotics, motivating the roboticist, and making the learning experience more extensive [14–17]. Robotics competitions specifically for the K-12 set have been growing. FIRST (For Inspiration and Recognition of Science and Technology) Robotics started in 1992 with 28 teams. In 2008, FIRST had nearly 38,000 high school participants, experiencing approximately 16% growth over 2007s 32,675 high school participants [18]. Other national competitions include BEST (Boost Engineering Science and Technology), which had over 10K student participants in 2008 [19], and BotBall [20]. Smaller competitions exist as as well, although it is impossible to name each competition, they cover diverse topics and exist all over the world [21,22].

In this paper, we present our intensive, three week robotics program for high school students, taught primarily by mechanical engineering graduate students. The program is structured around a principal project modeled after NASA's Mars Rovers. The students must teleoperate a semi-autonomous truck from a remote location to navigate and collect objects of interest from an obstacle course with various difficulties of terrain. The students are able to view the course via an onboard camera and an overhead camera, and control the truck using a radio controller. The mission objective is to collect as many points as possible in a fixed time, with varied points based on difficulty procuring each item. Late return to the start line and damage to the course result in loss of points. We discuss our carefully designed and well integrated curriculum, how we leverage competition, the topics we cover and how we "ground" the material for the students with discussions on robotics in both academia and industry, and how the program has changed over the years.

The paper outline is as follows. First we discuss the course schedule, the project-based curriculum, as well as how we overcome the challenges of teaching robotics to a diverse group of students. Next, we present the nuts and bolts of the material covered in the lectures and labs, then details of the principal project and how the students are evaluated. Finally, we reflect on how the program has evolved over the past 5 years and conclude.

COURSE CURRICULUM

The principal project is a semi-autonomous robot which must maneuver an obstacle course (shown in Figure 1) and collect as many objects of interest as possible, returning to the start gate in a fixed amount of time. The principal project is a very challenging problem for even high school honors and AP students. A widely differing knowledge base among the students, combined with the short three-week time frame, provides a difficult challenge to teaching robotics at the secondary school level. The curriculum is built to guide the students through the different aspects of the project even when they possess varying abilities.

The curriculum is built around the principal project, with all direct instruction, labs, and assignments being relevant to the project. The course schedule is shown in Figure 2. In the first week, direct instruction by way of foundational lectures and labs on mechanisms, electronics, programming, and design ensure the playing field is somewhat leveled and all students have the tools to solve all aspects of the problem on their own. We discuss the topics covered during these lectures and labs in the sequel. In the second and third weeks, student learning is generally self-directed, with mostly unstructured project development time. Intermittent design reviews and deliverables ensure students remain on track to successfully complete the principal project.

Dealing with differing knowledge base

Robotics is an extremely multidisciplinary field, requiring an understanding of physics, mechanical and electrical engineering concepts, as well as computer science. In undergraduate courses, students have a basic understanding of physics, and at least some exposure to design, electronics, and programming. However, at the secondary school level, the multidisciplinary as-

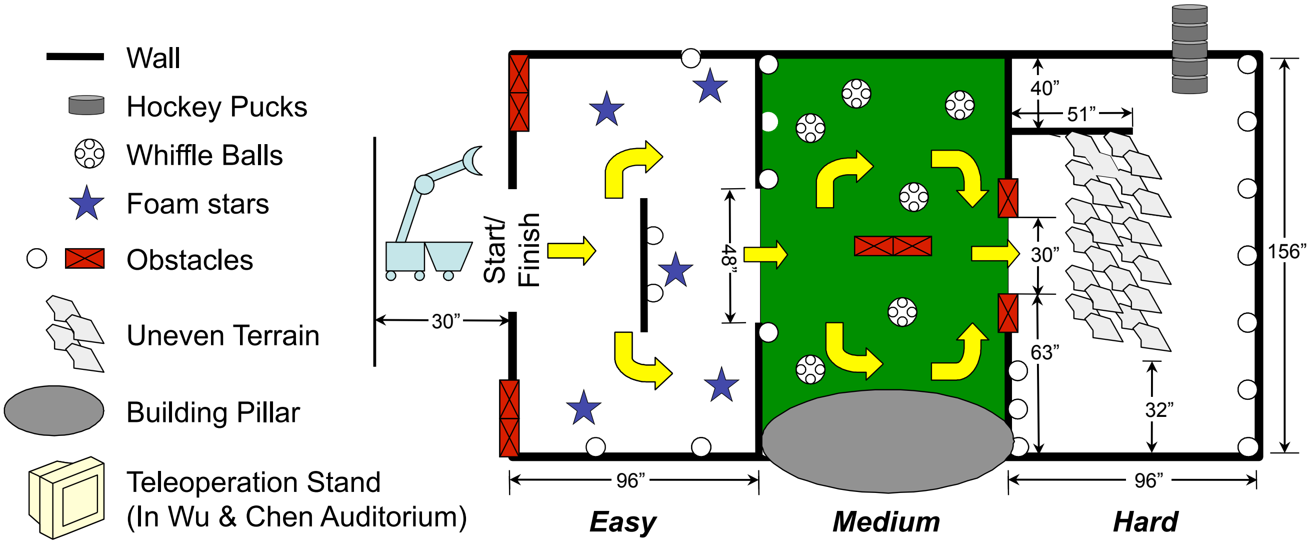


FIGURE 1: THE OBSTACLE COURSE.

pect of robotics poses unique and particularly difficult problems, compounded by the lack of prerequisites for admittance to the SAAST program. Specifically, since SAAST students are rising sophomores through rising seniors, levels of exposure to and understanding of physical concepts, CAD/CAM, and electronics are extremely varied. Furthermore, programming experience varies greatly among the students, with some students having no exposure, and some being avid programmers.

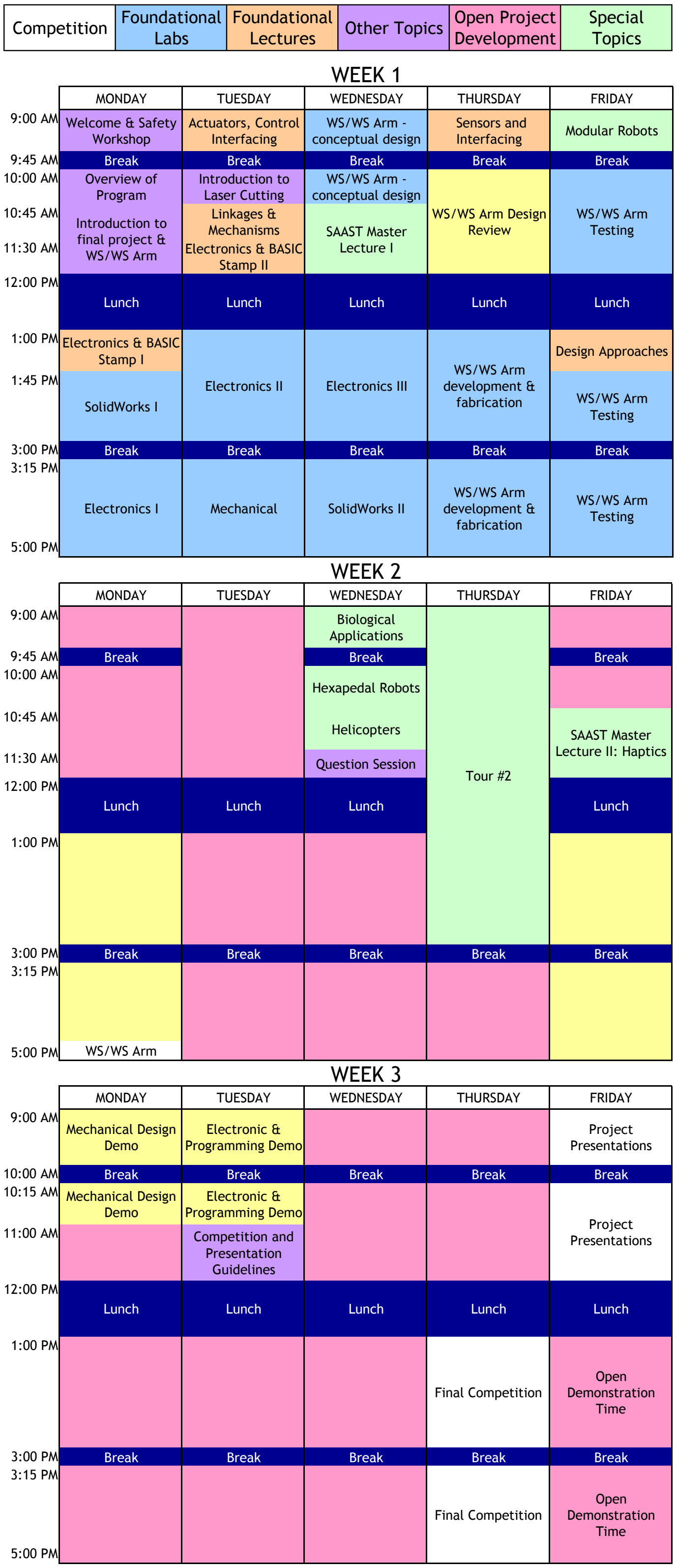
We address this problem by carefully choosing groups, ensuring the student to teacher ratio is small, and teaching basic concepts tailored specifically to the principal project.

Assigning Groups Assigning effective groups is critical to ensuring success. To teach effectively, groups should be designed most importantly on diverse ability [23,24]. In order to gauge the students' abilities, each student fills out a survey on the first day of the course (Table 1). The survey collects information about the students' past experiences, previous coursework, and any relevant hobbies. We use this information to form the most diverse groups of three possible, by dividing students based on their strongest of three subject categories: mechanical, electrical, and programming. We further divide the students into experience categories: novice, intermediate, and expert. Finally, we create the groups by combining one novice, one intermediate, and one expert, making sure to include a person from each subject group.

In any setting, it is possible that one or more groups fail to work together effectively. This can occur if students have clashing personalities, or if a student had embellished their experience on the survey. To overcome this, we reserve the right to change groups at the end of the first project, the World's Strongest, World's Smartest (WS/WS) Arm, which concludes in a competition on Monday evening of Week 2. Since the arm designed in this project does not have to be carried over to the principal project directly (not all final robots included an arm), there exists an opportunity to switch groups if necessary without much disruption. Indeed this is still not a guaranteed method. In

TABLE 1: THE SURVEY USED TO GAUGE STUDENTS' PREVIOUS EXPERIENCE AND KNOWLEDGE OF RELEVANT CONCEPTS.

Robotics Experience	Do you have any previous experience in any types of student competitions (i.e. FIRST Robotics, Trinity Fire Fighting, etc.)?
Subject Experience	What type of experience do you have in electronic design or fabrication (PC board creation, wire wrapping, soldering, testing, etc.)? What type of experience do you have in mechanical system design or fabrication (robotics, automotive, RC vehicles, machine shop, wood working, etc.)? Do you have any experience writing software? What language?
Other Experience	Please list any other unique experience you may have that we should consider.



Competition	Foundational Labs	Foundational Lectures	Other Topics	Open Project Development	Special Topics

WEEK 1

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
9:00 AM	Welcome & Safety Workshop	Actuators, Control Interfacing	WS/WS Arm - conceptual design	Sensors and Interfacing	Modular Robots
9:45 AM	Break	Break	Break	Break	Break
10:00 AM	Overview of Program	Introduction to Laser Cutting	WS/WS Arm - conceptual design	WS/WS Arm Design Review	WS/WS Arm Testing
10:45 AM	Introduction to final project & WS/WS Arm	Linkages & Mechanisms	SAAST Master Lecture I		
11:30 AM		Electronics & BASIC Stamp II			
12:00 PM	Lunch	Lunch	Lunch	Lunch	Lunch
1:00 PM	Electronics & BASIC Stamp I	Electronics II	Electronics III	WS/WS Arm development & fabrication	Design Approaches
1:45 PM	SolidWorks I				WS/WS Arm Testing
3:00 PM	Break	Break	Break	Break	Break
3:15 PM	Electronics I	Mechanical	SolidWorks II	WS/WS Arm development & fabrication	WS/WS Arm Testing
5:00 PM					

WEEK 2

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
9:00 AM			Biological Applications	Tour #2	
9:45 AM	Break		Break		Break
10:00 AM			Hexapedal Robots		
10:45 AM			Helicopters		SAAST Master Lecture II: Haptics
11:30 AM			Question Session		
12:00 PM	Lunch	Lunch	Lunch		Lunch
1:00 PM					
3:00 PM	Break	Break	Break	Break	Break
3:15 PM					
5:00 PM	WS/WS Arm				

WEEK 3

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
9:00 AM	Mechanical Design Demo	Electronic & Programming Demo			Project Presentations
10:00 AM	Break	Break	Break	Break	Break
10:15 AM	Mechanical Design Demo	Electronic & Programming Demo			Project Presentations
11:00 AM		Competition and Presentation Guidelines			
12:00 PM	Lunch	Lunch	Lunch	Lunch	Lunch
1:00 PM				Final Competition	Open Demonstration Time
3:00 PM	Break	Break	Break	Break	Break
3:15 PM				Final Competition	Open Demonstration Time
5:00 PM					

FIGURE 2: THE COURSE SCHEDULE. NOTE THE EMPHASIS ON DIRECT INSTRUCTION IN WEEK 1, WITH WEEKS 2 AND 3 FOCUSING ON OPEN PROJECT DEVELOPMENT TIME, WHICH FOSTERS COLLABORATIVE LEARNING.

the past, we have been able to overcome poorly designed groups with close mentoring, equipping the students involved with techniques for overcoming disputes fairly, and advising the students to assign each team member specific roles and stick by them.

Teaching basic concepts Since there are no prerequisites for SAAST, some students have never taken a basic physics course. Programming, which may be offered in most secondary schools, is not often a required course, although approximately 20% of students in the SAAST Robotics program have experience programming. Courses which would further prepare students for robotics are engineering, electronics, and CAD/CAM, which are less available, and therefore need the most attention.

Since most direct instruction occurs in the first week of the course, it is important to actively engage the students in the material right away. To keep the students engaged, "chalk-and-talk" is minimized, and kept to short bursts. Within a lecture, active learning techniques such as asking the students questions, assigning short problems to be done in the classroom and reviewed, and fun pop quizzes keep students engaged in the material. Demonstrations are used as often as possible, especially for difficult concepts such as linkages.

Carefully integrated projects

Completing the principal project successfully in a three week period is extremely challenging and taxing on the students. By dividing the work into smaller, more manageable projects which integrate easily into the principal project, we are able to increase success rates and keep the students on track.

The first project, the World's Strongest, World's Smartest (WS/WS) Arm immediately engages students in linkages, gear ratios, programming, and electronics. The goal of this project is to build an acrylic arm outfitted with an electromagnet that can autonomously pick up an object and deposit it on a target using a servo-powered rotating arm base, an ultrasonic range sensor, and either servos or a DC motor to raise and lower the arm. We use a hockey puck with a ferrous plate glued to it as the object so that its mass is an important design factor. The target is located at a 70° offset from where the object is placed, at a radial distance chosen by the student team. To ensure a pre-planned solution is not viable, their arm is randomly positioned in azimuth with respect to the object and the target. Their design must use the ultra-sonic sensor to detect the location of the object so that it can be lifted by the electromagnet. Points are based on accuracy and each team gets 5 trials. The team score is the sum of all 5 trials, so a design must be capable of repeated precision to win. The most successful teams will realize error and required torque increases as the arm gets longer. Those with shorter arms had more time to optimize the system, and ended up winning the competition. The winning arm is shown in Figure 3.

The WS/WS Arm utilizes concepts taught in all labs and lec-

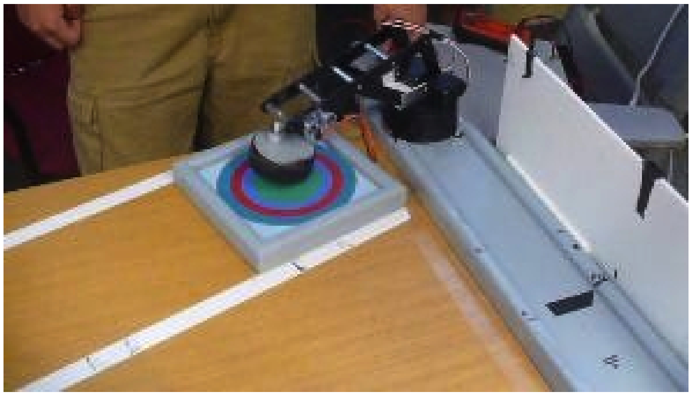


FIGURE 3: THE WORLD'S STRONGEST, WORLD'S SMARTEST ARM COMPETITION WINNER.

tures, but in a smaller proportion than the principal project. This way, students have time to familiarize themselves with wiring, linkages, CAD/CAM, and torque calculations before it is time for the principal project. Furthermore, it gives teams the opportunity to learn about each other's strengths and weaknesses before they truly begin working on the principal project.

Periodic targeted design reviews of robot subsystems ensure the students have a goal to work towards a few times a week, and motivates them by giving them a sense that they are progressing.

Sparking student interest

In such an intense course where students are prone to burnout, it is important to keep students interested. We provide "grounding" of the material used in class by presenting special topics. We also using competition to foster a desire to improve designs above the minimum required to meet the course requirements. While it is impossible to gauge if we have truly sparked a lifelong interest when we only have a five year baseline of experience, we believe we are achieving success with respect to this objective. Exit polls conducted each year provide us with near unanimous favorable feedback but we attribute this to more of an emotional appeal. To fathom a longer term, more balanced result, we recently conducted an anonymous survey of past students. Responses are compiled in the Results section.

Special topics To provide some real-world applications of robotics, we present special topic discussions on ongoing research on at the GRASP lab. These special topic discussions are presented mostly in Week 2, to break up some monotony and provide some time where the students do not actively work on their robots. To effectively engage the students in these special topics, the discussions are in rotations of 1/3 of the students at a time. The small group format facilitates discussion among the students, and has sparked healthy lunchtime and break time discussions with the instructors and fellow students.

SAAST-wide Master Lectures present research going on outside of robotics, and a tour of the American Helicopter Museum, which includes displays of autonomous vehicles, provide much needed mental breaks.

Using Competition We use competition as a motivating factor. Although students are not graded directly on how well they do in the competitions, they are motivated by winning "bragging rights" on who had the most superlative (fastest, most repeatable, longest, etc.) design. Even teams with excellent designs can lose a competition. For example, one team which was able to collect the most difficult items from the most difficult terrain had difficulty navigating back to the start point, and destroyed their robot along the way. The students who were RC hobbyists or gamers generally did the best in the competition whether or not their designs were the best, since they had an easier time with the remote and were able to navigate back to the start line without destroying their robot or the course.

COURSE CONTENT

The instructional portion of the course is designed to provide the students with a basic understanding of the tools necessary to complete the principal project. The lectures and labs fall into these categories: linkages and mechanisms; actuators, sensors, control, and interfacing; electronics and the BASIC Stamp; the engineering design process; and SolidWorks. Since this is a three week course, the information presented to the students is tailored specifically to the principal project. However, the students learn skills that they can apply to problems outside our lab.

Engineering Design

The engineering design process is a critical tool for students working on engineering problems. The students are taught the importance of properly articulating the design problem, considering all possible solutions, prototyping and evaluating the best solution, and repeating the cycle. Poorly articulated design problems are presented, and the students determine what is wrong with the problem definitions. Students learn that it is important to be specific while writing a design problem and that one should define success but at the same time not limit solutions.

The principal project reinforces all of these ideas. The importance of iterative design, considering non-obvious solutions, and prototyping become clearer as the students model and prototype their designs and realize they may not work as expected.

SolidWorks

The introduction to SolidWorks takes a bottom up approach. Students learn to compose assemblies beginning by creating and defining sketches, then features, parts and finally assemblies. Instruction is divided into two classes: Parts and Assemblies. Each class begins with an overview giving students an introduction to the SolidWorks interface and a basic understanding of defining parts and assemblies with dimensions and relations.

The tutorial portion of the class is key to developing student understanding of SolidWorks. Students work individually through a tutorial that gives step by step instructions for creating a universal joint crank assembly. When a student reaches a step and is uncertain how to proceed, instructors work one on one with the student to clarify how to continue. By working hands on with the program, students become more comfortable understanding the various methods for defining components from basic dimensioning to more complex relations and feature creation tools. Students complete the tutorial project by creating an animation of the crank assembly turning.

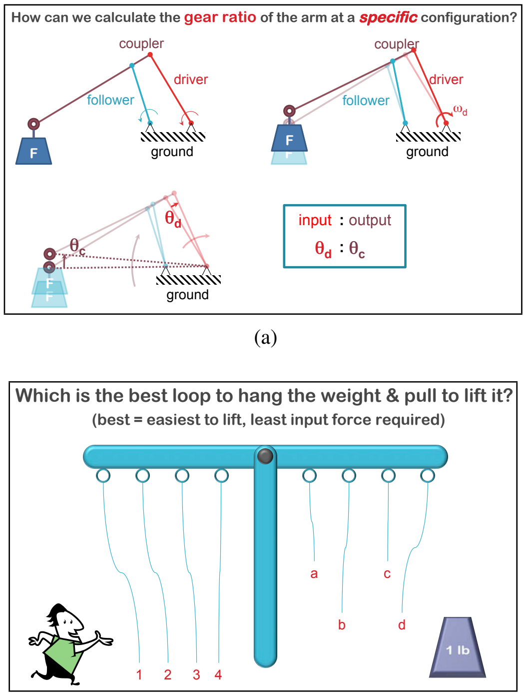
Developing the components for their four bar linkage arm and principal project robot further reinforces student understanding of SolidWorks. This laboratory experience emphasizes that careful design in CAD can reduce prototyping time. By creating full assemblies of their robots, students gain intuition about the kinematics and workspace of their robotic arms.

Linkages and Mechanisms

The basic concepts taught in linkages and mechanisms include degrees of freedom (DOF), four-bar linkages, gearing, and torque. All topics are covered in lecture with interactive examples, and in lab with hands-on activities.

Gruebler's equation is used to calculate DOF for multiple systems. At first, the students are asked to intuitively guess how many DOF are in a system. Then, an interactive example which walks through Gruebler's equation for a particularly difficult system engages the student at each step of the calculation. Grashof's theorem is used to categorize linkages. With a demo linkage in hand, the students can quickly grasp different types of linkages.

Gearing and torque are also introduced to the students. These are important concepts the students need to understand to guarantee that their mechanism is capable of picking up the objects of interest from the obstacle course (some students may not learn these concepts until they have designed a failing mechanism). Basic examples of gearing are used, as well as an example specific to the WS/WS Arm (Figure 4a). With instructor guidance, students uncover how to empirically calculate gear ratio at a specific configuration for a varying gear-ratio system (the WS/WS Arm). Torque is presented via an interactive example (Figure 4b), asking the students to determine where to best place a mass on a lever, and where is best to push on the lever to exert the minimum force required to lift the mass. Students answer according to their intuition, then work through the example with all possible solutions. A short homework assignment on gearing gives the students a bit more practice.



(a)

(b)

FIGURE 4: EXAMPLES USED IN CLASS TO TEACH GEARING AND TORQUE.

These concepts are explored in a laboratory to design a four-bar linkage arm that meets certain specifications. In this lab, the students design a four bar linkage to achieve their desired reach on paper, then prototype it using foam core. The students use the prototype to determine the gear ratio of their arm at its fully extended state. Many groups continue to use this arm while designing their WS/WS Arm, as well as their principal project arm, adjusting links or creating new ones as needed.

Actuators, Sensors, Control, and Interfacing

This section is structured to convey the importance of integrating a robot with the environment in which it operates. We emphasize that robotics is not a video game exercise in that the robot must contend with the physics of the real world rather than a virtual one. The takeaway message we present is that computers can only enable robots if they have the sensors to credibly respond to the environment and have the "muscle power" to actually accomplish these interactions. We present a variety of sensor and actuator types and with details on the types available for their designs. We provide them with three types of electric motors: DC gear motors, stepper motors, and servo motors to emphasize that it is important to select the appropriate actuator in terms of performance, weight, power required, etc. We provide a vary strong DC gear motor, two sizes of steppers, and two sizes and strengths of servo-motors that they can use, so understanding specifications and selection becomes a natural dimension of the curriculum. In these lectures, we introduce math models as a way of understanding the way the hardware works and as a methodology to integrate hardware with the software that ultimately controls it. The basics of feedback control are also discussed so that they design their own servo-mechanisms for their project. The motor control amplifiers we use have generous but still constrained peak DC current, so the students are shown how to select a motor and integrate it with the mechanisms they learned earlier in order to be sure their subsystems will function as intended. Our staff designed and procured a set of circuit boards to facilitate the use of standard H-bridge amplifiers and stepper controllers. The BASIC STAMP® is capable of direct control of servo-motors.

Electronics and the BASIC STAMP®

Having provided the students with a targeted understanding of what sensors and actuators they can use, the last puzzle piece is the embedded computer used to control their robot. Since many students have yet to learn programing languages applicable at the microprocessor scale, we selected the BASIC STAMP® by Parallax Inc. Its programing language is easy to master and it is a good stepping stone to C or C++ languages used by more sophisticated microcontrollers. We start by introducing them to binary and fixed point arithmetic on the 8-bit microprocessor. Then, through a series of labs, they are shown the rudiments of programming. Since the STAMP® is not a multi-threading device, nor does it support interrupts, we also show them how to use peripheral devices to emulate parallel processing so they can smoothly control their actuators. The STAMP® is capable of supporting 16 input or output channels or pins. It is fully digital so one of their first labs is to integrate an analog to digital converter using serial communication.They are also shown how design and build rudimentary electronic circuits such as voltage dividers and RC circuits so these can be used in conjunction with the microprocessor. Once the students are shown how to interface the radio controller we use for tele-operation, the students have the necessary building blocks to create a very capable robot.

PRINCIPAL PROJECT

As mentioned above, the program is structured around a final project modeled after the NASA Mars Rover. The students must tele-operate a semi-autonomous truck to navigate and collect objects of interest from an obstacle course with various difficulties of terrain. The students are able to view the course via an onboard camera and an overhead camera, and control the truck using a radio controller. The mission objective is to collect as many points as possible in a fixed time, with varied points based on difficulty procuring each item. Late return to the start line and damage to the course result in loss of points.

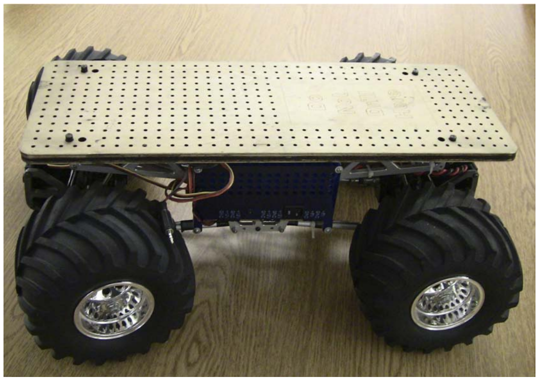


FIGURE 5: THE TAMIYA TXT-1 CHASSIS WITH PRE-DRILLED WOOD BASE.

Each group is provided a 1/10 scale Tamiya monster truck (TXT-1 chassis), outfitted with a pre-drilled wooden base designed for easy mounting (Figure 5). The students tele-operate the truck with a model airplane radio controller, via a wireless video interface (they have no line of sight to the vehicle or the obstacle course). We choose the BASIC Stamp 2 microcontroller since it is easy to program and has adequate performance capabilities and constraints for our project [25]. Although using a prepackaged robotic kit (such as the Lego Mindstorms® or Parallax Boe-Bots®) would perhaps give both students and instructors some more free time, they would not give the students the same feeling of accomplishment that comes from designing your own robot from the base up.

GRADING AND EVALUATION

The duration and structure of our program present challenges with respect to grading. Our intent is to immerse each student into a creative robotics design project that achieves a measurable level of performance at the end of the program. The program is not a “robot camp”, where projects are sufficiently formulaic and students simply have to follow the instructors’ lead to be successful. Rather, it is a true open-ended creative task which requires a combined skill set that none of the students fully possess before the program. Therefore, no matter how advanced an entering student may be, we believe our program is structured to be challenging. At the onset of the program we disabuse the students of any expectations they may have had that program will be structured entertainment.

To enable the students, we first present a targeted set of concepts intended as prerequisites of the principal project. We assess their mastery of these through introductory projects and lab reports. While these reports do contribute to their grade, the primary purpose of the reports is to ensure all students acquire the skills required to accomplish the main design project. (Note, we

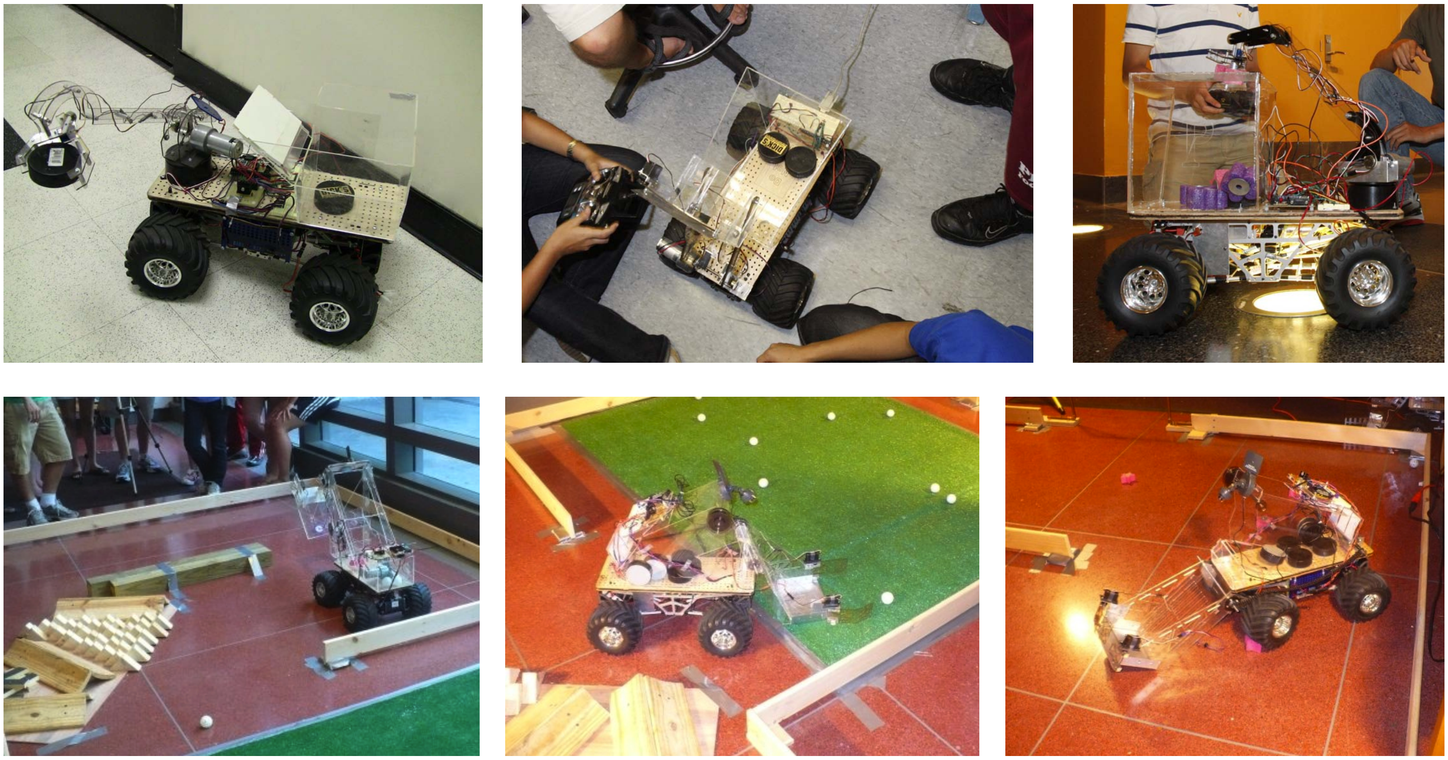


FIGURE 6: THE ROBOTS DESIGNED BY THE STUDENTS IN ACTION ON AND OFF THE OBSTACLE COURSE

are also focused on generating a sustaining interest and not providing a foundation for future core curriculum courses, so we believe we have a wider latitude in evaluation and grading.) The core areas we expect the students to master are:

1. microprocessor programming;
2. computer-aided design;
3. mechanism design and analysis;
4. motor selection;
5. overall design integration.

We ask students to dedicate a lot of time, energy, and concentration, so these are also factored into our grading. The overall weighting of our grading is 30% lab reports and 70% principal project. As noted, the project is a team effort, so grading the individual based on their performance largely in team setting must be addressed. While peer assessment has been shown to be effective in these circumstances [24], we believe our program permits the teaching staff to effectively assess all students. Whereas most group projects involve a substantial amount of time where the group is working on its own, our group projects are fully executed in a lab setting that is staffed full time by either instructors, technical specialist teaching assistants or resident teaching assistants who live with the students. The resident teaching assistants are typically engineering students themselves, so the entire staff has a high level of expertise. In most cases, all of the preceding are actively supporting student teams to ensure all have adequate support throughout the program, so there is more than ample time for the staff to spot “hitchhikers” or “slackers”.

In place of a final examination for the course, we ask each team to conduct a final design review presentation. We provide a rubric to the students for content in this presentation and ask that it be developed and presented with equal shares of participation in the effort. The students are briefed that this presentation is their opportunity to provide us feedback on what they learned. It is conducted on the last day and students’ families are invited, so it a congenial atmosphere, not a high stakes test. The clarity with which students can describe their own efforts in the context of final review in conjunction with their ability to answer questions is a significant indicator of their mastery of the material.

After the program is over, each staff member ranks the students, then the individual rankings are merged to form a consensus ranking. This stage can be contentious, since each student may not have interacted with every staff member, especially in the most productive final days. Nevertheless, we have sufficient redundancy in our staff that corroboration inevitably leads to a consensus. Here is where students who have demonstrated a pronounced interest throughout the program and have strived to maximize their learning experience are rewarded with additional consideration. The top grades are awarded the best and brightest of the class but not far behind we place those who achieved nearly the same level of mastery with hard work. In this regard, we look for students who demonstrated an insatiable appetite to learn rather than those who finessed the program with relatively little effort. Since our groups are highly motivated for the most part or they would not be in the program, we seldom have issues with poor performers. Our overall grades reflect this and tend to range from C- to A+. The distribution in this range is based on an informal assessment of teach student's mastery of all the concepts they were presented. We acknowledge the grades and distribution tends to be skewed towards the upper end, however, we believe it is consistent with our mission to motivate students to continue onward to study engineering at the university level.

DISCUSSION

The 2009 program was the most successful out of the 5 years the program has been offered. Every team competed in the final competition and was able to pick up an item. This is probably due to a number of reasons, including the lowest student to teacher ratio, the most integrated curriculum (labs, lectures, small projects, and design reviews all tailored toward the principal project), and the most limitations on manufacturing methods. Perhaps most surprisingly to us, the design parameters were also some of the least restricted in all 5 years of the program.

Lower student to teacher ratios have improved success rates. More instructors are available more of the time (generally from 7:30am to 10:00pm, and even longer hours near the end). This enables instructors to constantly monitor all teams, guiding them away from dead ends, and providing mediation in team-member disputes. Low student to teacher ratios are difficult to achieve since graduate students form a majority of the teaching staff.

Over five years, the curriculum has evolved into a very well integrated collection of labs, lectures, and projects. Previous to 2009, the curriculum included the World's Strongest Truck competition, which used a gear box kit to explore gear ratios and torque, and taught design principles by having the students design a truck around the gear box to haul items up an incline [8,9]. Although this taught the students a good deal about design and torque, it was not directly applicable to the principal project, and took the entire first week of the program.

In 2008, with the intention to make the project easier on the students, the robot was required to use an arm to gather magnetic items. Although the students could design special mechanisms to pick up other things, our intent was to have them focus on the arm and get it done. In that year, not all teams were ready for the competition. In 2009, we had very few restrictions on the mechanism design, but all teams had a working arm by the first day of week 2, which was the WS/WS Arm competition. Some decided not to use an arm for the robot and started from scratch. With the additional freedom, each team was successful. (It is possible that forcing every team to use the arm put some teams at a disadvantage. We have not explored this.)

The lectures were also more specifically tailored to the material necessary to complete the project successfully. For example, past lectures on gears and mechanisms went over specific details about different types of gears, and their attributes. In 2009, different types of gears were briefly discussed, but the focus was on the types of gears we had available. This way, the students were not preoccupied with details irrelevant to the project.

Finally, beginning in 2008, the robot had to be made mostly out of laser-cut acrylic. Previously, the teaching assistants and instructors had to spend many hours in the machine shop, custom-making parts for the robots. Some brackets and specialized parts must still be made in the machine shop, although some parts, such as motor and servo mounts, have been standardized. Although we have severely reduced the number of parts which must be machined, too much time is still being spent in the machine shop. This year (2010), we plan to require students to use standardized hole patterns for all parts.

One part of SAAST Robotics that has not changed much is student evaluation. Design reviews have always been used, although the frequency has increased. Grading has not changed much, as the students are evaluated mostly on their final presentation, which demonstrates their understanding of the material, and presents justification for their choices in the design process.

To gauge our success at sparking student interest, we recently conducted an an anonymous survey of students since 2007. Approximately 30% of students responded. Perhaps not surprisingly, most respondents were those now studying at the university level (all but 12%). All but one now studying at that level reported that the SAAST program was a positive factor in helping them select their direction of study. These students have predominantly selected Engineering but they also listed Applied Mathematics, Applied Economics, and Physics as their majors. Of the respondents, 60% noted they have participated in other robotics programs since SAAST. One even started a local robot club. We are pleased to say they rated the program an average of 4.8 on a scale of 5, so we believe the positive exit polls we receive do accurately reflect the success we are achieving. Another positive statistic is that at least one SAAST student per year has been accepted and has matriculated into the School of Engineering and Applied Science at Penn. As we enter our sixth year, we believe we have helped many students select their college majors, where they are pointed towards careers in the applied sciences.

CONCLUSION

The breadth of material which must be covered to enable students to design, assemble, and control a semi-autonomous robot provides a serious challenge to instructors and students alike. What distinguishes our course from similar robotics academies is the open-ended project, in which students must make design decisions, choose between various components, and build a unique robot. In a successful year, all teams will be able to run their robots on the course, picking up at least one item (although robots may not return to the start line in one piece). Though this does not happen every year, over the years we have improved the design success ratio while supporting increasing complexity.

The key aspects to ensuring a successful outcome are a well integrated curriculum, frequent design reviews, assigning well balanced teams, and, if feasible, a low student to teacher ratio. A well integrated curriculum is of paramount importance for such a short, intensive course. Concepts should be taught using lecture materials, labs, and projects that add value to the students' principal project. These carefully integrated mini-projects ensure that the students are working towards the principal project without sacrificing the quality and breadth of instruction. By scheduling frequent design reviews, we prevent the students from falling behind and setting unrealistic goals. Assigning teams based on diverse abilities ensures that all teams have an equal distribution of expertise. Finally, a low student to teacher ratio allows instructors to continuously monitor team progress and provide the mentoring and one-on-one help the students need. This year, we plan to reassess our evaluation methods, including considering student self-evaluation. All in all, we believe we have a successful program, which benefits both student and instructor.

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