2006-574: "WHO IS THE BIGGEST PIRATE?" DESIGN, IMPLEMENTATION, AND RESULT OF A ROBOTICS COMPETITION FOR GENERAL ENGINEERING FRESHMEN

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“Who is the Biggest Pirate?”
Design, Implementation, and Result of a Robotics Competition for General Engineering Freshmen

Abstract

A systems approach to engineering topics requires an interactive process that combines instructional methodologies, coherent curricula, and learning challenges that develop student understanding over time. In the general engineering program at East Carolina University (ECU), freshmen are introduced to engineering topics that include solid modeling, mechanical engineering, electrical engineering, and design engineering. Robots inherently integrate all these disciplines. At ECU, student teams are used in a cohort learning environment to build robots. The robot building project serves as a platform for experiential learning in engineering disciplines and also serves to develop problem solving skills, interpersonal skills, and ethics. A robotics competition is embedded into the introductory class work to increase levels of participation, interest and challenge for the freshmen. During classroom and laboratory exercises leading up to the competition, students build mobile robots to compete in a treasure-hunting game. Faculty in each engineering discipline use the robot project to explain topics in their lectures while the project serves as a common platform for the students to apply knowledge learned in the classroom. When students encounter difficulty during their project, they come back to the classroom for solutions. This bi-conduit, project-driven learning process facilitates student understanding of engineering concepts and correlates these concepts to real-world applications. This paper describes the strategy to design and methods to implement the semester-long project. Assessment methodology is described in terms of inter- and intra-faculty and students evaluation.

Background

Industries distributed among the small towns of eastern North Carolina have difficulty attracting and retaining engineering talent with a range of specialties in narrowly defined fields. “Instead of the traditional engineering disciplines, these operations require engineering generalists with a strong theoretical background, broad knowledge in a range of areas, and specific skills in problem solving to give them a sound but flexible base for managing and implementing technology change and operations.”[1] East Carolina University initiated a bachelor’s degree program in general engineering (BSE) to fill this requirement. The BSE curriculum is implemented “through a concept and program identified as the Integrated Collaborative Engineering Educational Environment, or ICE3 (pronounced “ice cube”). The ICE3 program… emphasizes a broad but highly integrated foundation of engineering fundamentals and engineering sciences necessary for a general engineer.”[1]

Freshmen students of the eastern North Carolina region start their college study with very diverse high school backgrounds. Given the diversity of knowledge levels, advanced theoretical analysis is not desired in an introductory project. However, to quickly acquaint the freshman students to the cohort learning environment of ECU’s unique engineering program, the first core course is designed to introduce basic, yet important, elements of engineering practice. The introductory course requires integration of multiple disciplines including graphics, mechanical engineering, electrical engineering, as well as engineering professional practice and ethics in order to achieve program and learning objectives. The course is structured into two parallel tracks, designated A and B. While Track B deals with engineering graphics and spans the entire semester, Track A offers students a solid foundation in the general engineering disciplines of mechanical and electrical, as well as concepts of professional practice, in multi-week modules. Designing and building robots requires skills from all these disciplines and inherently helps to integrate them in students' minds. A robot project and competition was defined to integrate together these components, provide the students opportunities to learn and apply mechanical and electrical engineering knowledge, and to learn and practice skills in professional practice areas such as interpersonal communications, teamwork, leadership and followership, technical documentation, and oral presentations.

Project Approach

Benjamin Franklin's saying ─ *Tell me and I forget. Teach me and I remember. Involve me and I learn* ─ suggests ways educators should deliver knowledge to their students. Projects involving student designed and/or built robots are used in many freshman engineering classes, and there is much literature describing their implementations. Most use off-the-shelf hardware, while others[2] use custom-built designs to better match project goals. Goals for the technical aspects of these robot projects vary widely, from teaching a specific aspect such as circuit design or programming to an emphasis on the systems aspects of the project. Beyond technical goals, most projects attempt to introduce teamwork and project management concepts and to motivate students. Pomalaza-Ráez and Groff [3] reported increased retention of freshman engineering students at Indiana University - Purdue University Fort Wayne after changing their introductory course from a traditional lecture format to a project-centered course featuring a robot design-build experience.

One of the challenges in implementing any freshman-level project is to prevent students from feeling overwhelmed with the idea of designing and building anything. Hoffman et al.[4], discuss the frustration that was present among students during the first implementation of a robot project, primarily in the programming and debugging steps. Their solution was to shift the focus of the project away from the complexity of the programming to a more systems-oriented view of the entire project. This is similar to an approach call "directed constructionism" by Rosenblatt et al.[5] In this approach, lecture materials are closely correlated to the hands-on activity, while still maintaining creative, open-ended aspects of the hands-on work. This type of approach seems especially appropriate for the freshman students of ECU's program as it supports the program's systems emphasis.

The above considerations led to the selection of these strategies for the robot project:

- The project must be closely related to the classroom topics in order to motivate the student study. Ideally, the students find that their project is an application platform where they apply knowledge obtained from lectures, and whenever a project problem emerges, lectures will provide guidance.
- The project tasks must be within the ability of the ECU college freshman student, yet challenging to facilitate problem-solving skills.

- The project must combine technical learning effort and play, i.e., the project must be a fun and enjoyable experience for the students. Project progress should be visible thereby helping to embed learning into playing.
- The project should include significant hands-on work activities. Hands-on activities include use of design software as well as hand tools for construction.
- The project must encourage team member collaboration. With freshman students of widely varying skills, collaboration is necessary for facilitating member contributions of individual strengths and compensation for any technical weaknesses.
- The project must nurture inter-team communications and build both oral and written communications skill sets.

For the ECU freshman course, a treasure-hunting competition was introduced to take advantage of the stimulus associated with a robot competition. The slogan of “Who is the Biggest Pirate?” was developed as it naturally includes the East Carolina University’s athletics program mascot into the competition and serves to build on the eastern North Carolina pride in ECU. This addition seemed to add excitement to the competition and gave the students a greater sense of personal engagement with ECU, the engineering program, and the robot project. Further, a treasure-hunting theme was developed for the competition to augment the connection with ECU collegial environment. This theme made the activity enjoyable and also made developing the contest rules straightforward, i.e., the group collecting the most treasure wins the competition.

Because this was the first engineered system project for the ECU freshmen, an additional strategy was to guide the student more at the early stages of the project and offering progressive student control as the project developed over the semester. Initial guidance required the students to follow printed instruction accompanying the commercial robot kits that were the basic robot system platform. This guidance provided a fixed scope for tools and other required resources. Following the initial guidance period, the students were given great flexibility in designing robot customization and performance enhancements consistent with the treasure hunt rules. This progressive control strategy resulted in wide ranging variability in robot design and operation.

Project Details

In the project, students were divided into teams. The teams varied in size from between 5 to 9 members due to class/lab scheduling constraints. The robots were soon referred to as ‘pirates’ as the spirit of the competition permeated the early design/build stage of the project. The pirates were required to grab small objects, identified as treasures or jewels for the competition. While having the same general size, the jewels were of different shapes and each shape carried a unique monetary value. The pirates, operated by team drivers, were to land on treasure islands (see Figure 1) to hunt for jewels. Jewels were placed on bases scattered on several treasure islands. Each island had a variety of the differently valued jewels. Navigating in the islands, the pirates approached the jewels, grasped/collected the jewels, and carried them to the team’s “jewel chests”. The square-shaped jewel chests were designated floor areas fenced on all four sides with one-inch high barriers. To be successful, the pirates had to be carefully controlled by the team driver so as to not hit the bases which would cause the jewels to fall to the ocean floor as the grippers were not able to pick up jewels from the floor. The competition was a timed event and the team collecting the highest jewel value was declared the ECU engineering program's Biggest Pirate". Table 1 provides additional competition details.

Table 1 Competition Details

Treasure hunting time	5 minutes
Treasure area	16' × 16'
Treasure types and values	See Figure 1
Number of treasures	16 gems of each value
Gem base size:	1.5" × 1.5" ×1.5"
Treasure chest:	Size: 2'× 2' 1" high barrier on 4 sides

To maximize competitiveness, the competition activity was designed with preliminary rounds based on class/ lab scheduling. In the preliminary rounds, teams from a single lab session competed for the hunt-off in the final round. Local media provided press coverage of the final round of competition. Figure 2 shows the finalist teams competing head-to-head.

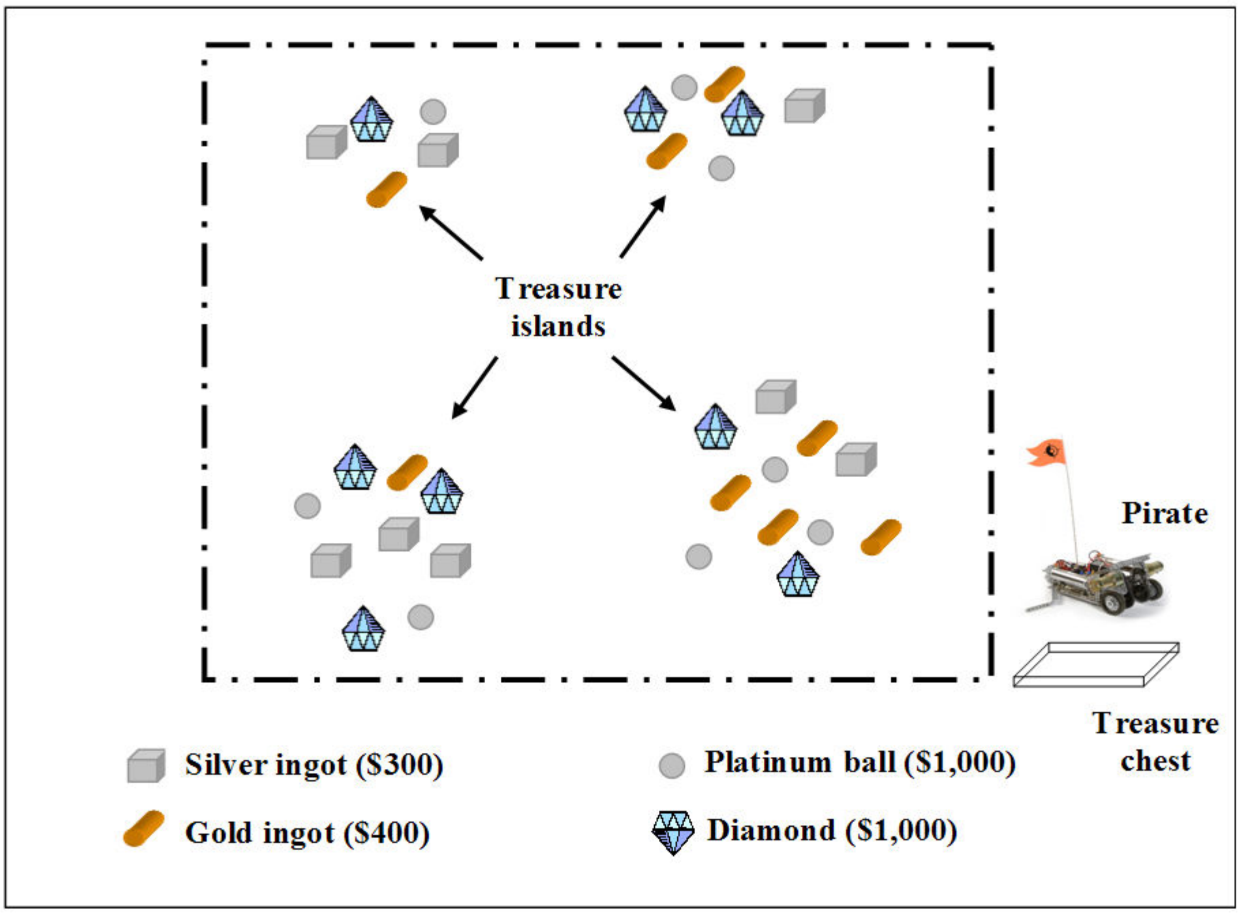

Figure 1. Layout of the "Who is the Biggest Pirate" treasure-hunting competition.

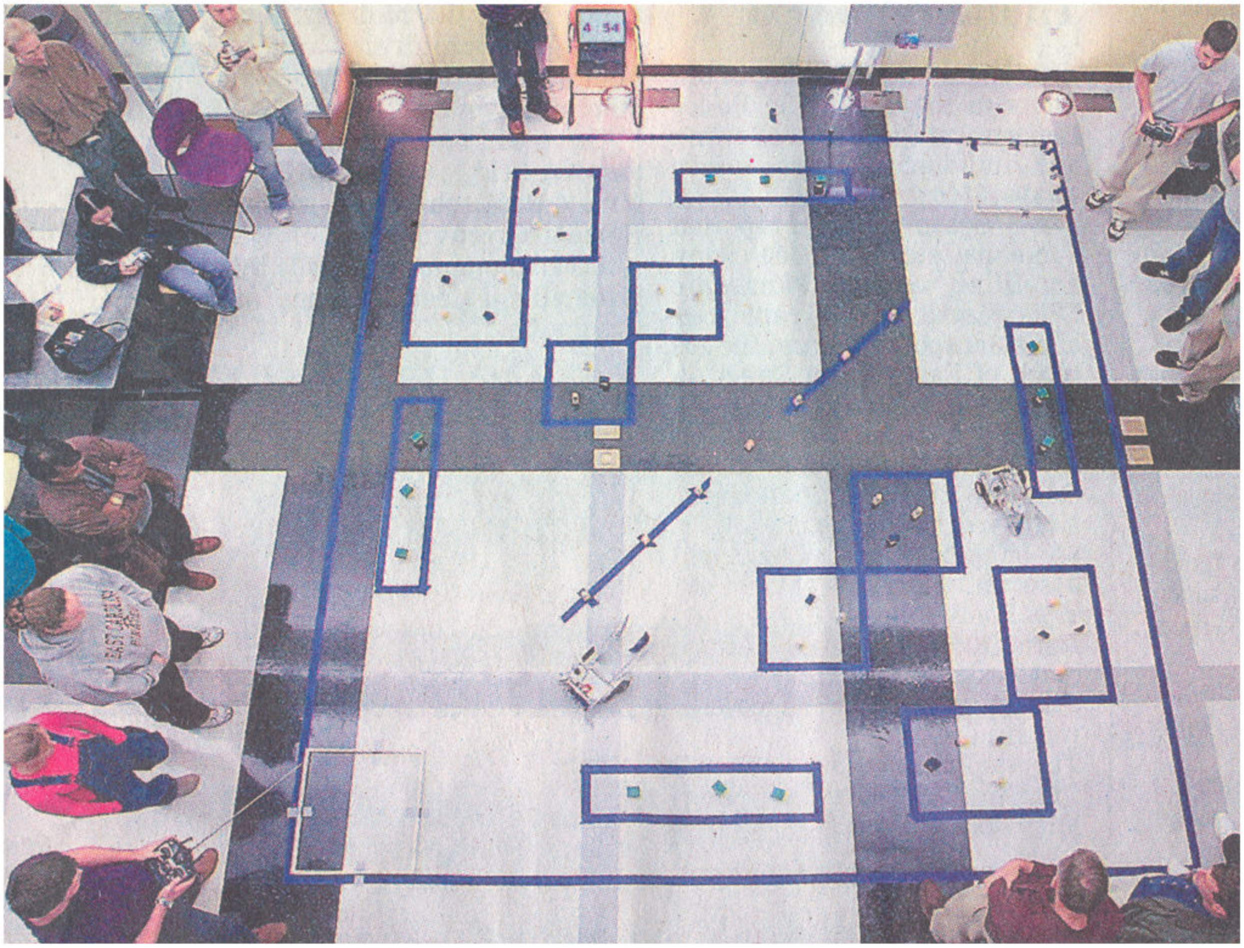

Figure 2. The "Who is the Biggest Pirate?" Treasure Hunting Contest.

Project Implementation

The ICE3 freshman class was randomly assigned into eight teams. The students met with their team every Friday throughout the fall semester during open lab time to work on their project. The project was explained to the students during the first lab meeting along with an elementary discussion of the concept of robots. Two specific requirements were emphasized:

- *Teamwork requirement*: All students had to work within a team structure. Every team member had to contribute. As the semester evolved, peer evaluations were introduced to aid garnering full participation.
- *Technical requirement*: Each team had to design a customized part with solid modeling software and with the help of faculty, the part was built with rapid-prototyping technology.

At the beginning of the project, students followed instructions for assembling a basic chassis and drive train. The instructions were provided with the GEARS-IDS^{TM} robot kits purchased from Gears Educational Systems, LLC.[6] The kits allowed the design component of the project to be primarily focused on the gripper design. Each GEARS-IDS^{TM} robot kit contained:

- Mechanical hardware: plates, bars, brackets, shafts, collars, wheels, chains, etc.
- Electrical components: 12 V battery/charger, DC motors, servo motors, etc.

- Pneumatic components: tanks, cylinders, regulators, valves, lines, etc.
- Remote controller: a 4-channel FM remote control set with radio transmitter/receiver and speed control modules.

With these tools, students were able to construct a basic drive train and chassis. Students were first instructed to build a preliminary chassis (including the power train) exactly following the manual. After the initial build experience, students were encouraged to modify their initial chassis/drive train configuration to a team-developed configuration that would support their jewel gripper concept. This re-configuration process became an iterative process as gripper design and development progressed.

The teams were also offered the opportunity to use Basic Stamp® microcontroller kits to improve their robot's control and operation. Although it proved difficult for the freshman students to develop real motor control using the microcontrollers, they were able to use these electronic devices to enhance the 'pirate' appeal with microcontroller regulated sound and light effects. The use of the microcontroller was mandated for one team because its member size (9 students) was greater than all other teams. This requirement provided additional opportunity for all members to participate in the robot build. Figure 3 shows two students working on their robot.

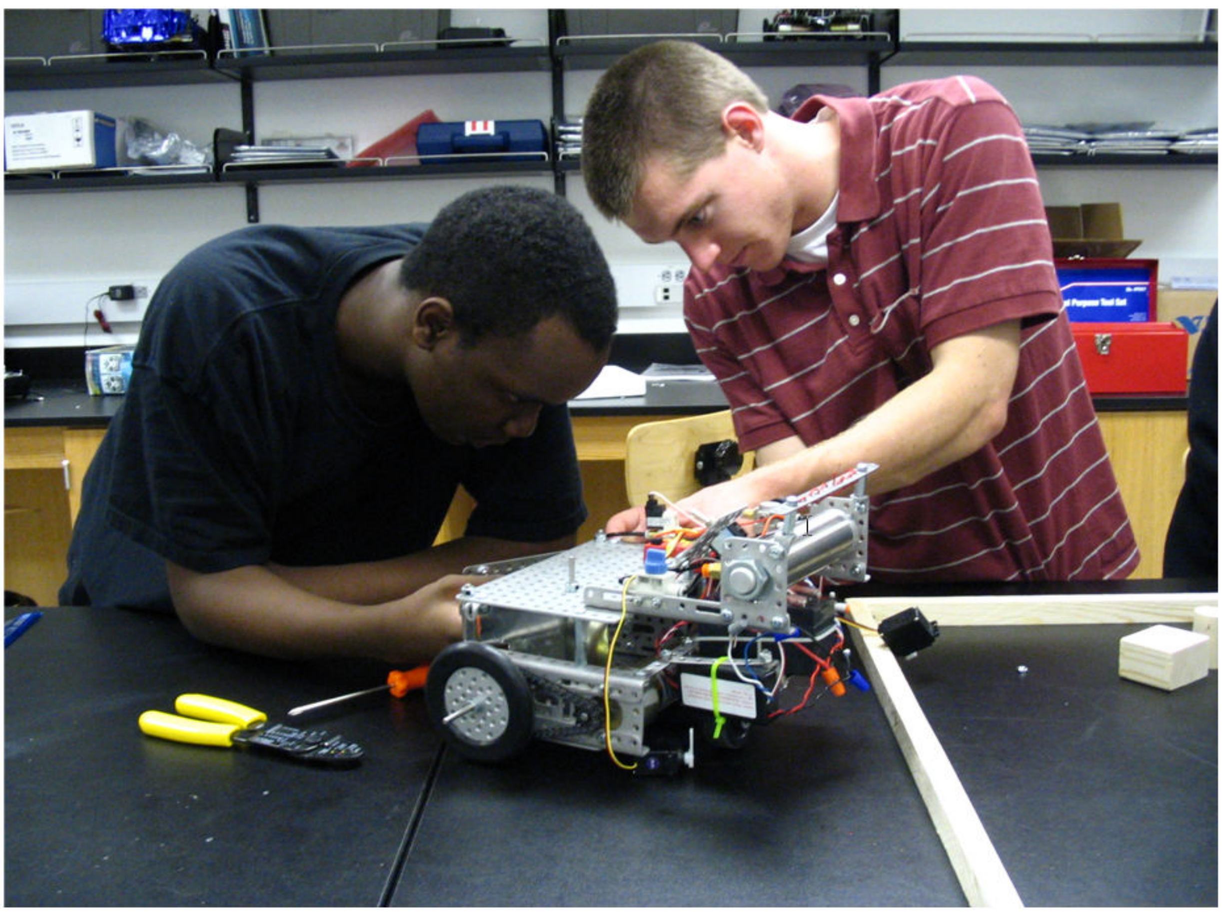

Figure 3. Students Working on a Robot.

The project was closely associated with the following course content areas:

Engineering Graphics: Students were required to design a customized gripper that was not provided in the robot kit yet was needed for the treasure hunt competition. The gripper design, in consideration of chassis capacity, servo-motor application and/or pneumatic system capacity, had to be an efficiently designed part. As the part was to be built from rapid prototype technology existing within the engineering program, material and physical size constraints mimicked real-world project constraints. Students were required to develop their gripper design model with solid modeling software—AutoDesk Inventor®—and, with help of the faculty, build the gripper using rapid prototype equipment.

Professional Practice: The project provided an effective platform for students to apply professional practice skills also taught and demonstrated during course lectures. Lectures emphasized teamwork skills such as leadership, followership, role assignment, trust, accountability and performance assessment.

All teams were required to give a 20-minute presentation in order to reinforce lectures and outside reading assignments related to these professional skills. The impact and importance of oral skills was emphasized by using external judges during oral presentations. One judge had a corporate training background, and the other had a marketing management background with a Fortune 500 company. At the end of each round of presentations the judges provided direct and pointed critiques to each team. The critiques were professionally presented as if from an employer's perspective. Each team was also required to provide a written technical report of their team's project. The report was required to follow a codified format and required students to summarize their project, the project design, and describe the teamwork in terms that reflected lecture and outside reading material. Students were expected to demonstrate some rudimentary-level research skills in their technical report.

Assessment

The student learning outcomes were evaluated by several measures including student/faculty surveys, student self/peer evaluation, technical assessment, and an external review.

Student and Faculty Surveys: Students voluntarily participated in a survey at the end of the semester to evaluate their perspective in meeting the course objectives. Two questions, one closed-ended and one opened-ended, were used. The multi-part closed-ended question evaluated the teamwork component of the robot project using a Likert scale format. Using the closed-ended student survey question the students evaluated the teamwork component of the robot project as the second highest in meeting the objective. Only their mastery of the solid modeling software ranked higher.

The opened-ended question was stated as "What were the most valuable and least valuable aspects of the robotics project?" This question provided more insight into what the students liked, disliked, and learned from the project.

The largest responses for the most valuable aspects of the project by the students were:

- Teamwork

- The freedom to design their own gripper
- The hands-on aspect

The largest responses for the least valuable aspects of the project by the students were:

- The report and presentation
- Time management and project organization issues
- Attendance problems (of teammates. Note: due to poor attendance on one team, two members designed, developed, constructed and operated the robot. The non-attending members were isolated from the oral report, the written report and the competition by the participating members. During the oral presentation judging, the external judges noted the anomaly and queried the students. The students, both participating and non-participating, provided direct, honest feedback which the judges used to relate to real-world examples and career impacts.)

The robot project was also evaluated through the use of an instructor survey. This survey was administered to the four faculty members comprising the instructing cohort immediately following the end of the semester. The most valuable aspects of the project for the faculty cohort were:

- Teamwork
- The presentation including the outside evaluators' feedback
- Opened ended gripper design

The least valuable aspects of the project for the faculty cohort were:

- The written team report
- Lack of integration of project management concepts (i.e. poor time management by the students)

Student Self/Peer Evaluation: Students were asked to perform intra-team assessments. These assessments were conducted for two purposes: 1) have students take responsibility for their team's performance and 2) to provide an experiential learning opportunity leading on conducting personnel performance assessments as engineering professionals. Both objectives were met as students readily performed the assessments. The assessment process was developed by a faculty member and was intended to provide an introductory exposure to performance assessments in concert with the professional practices portion of the course. Students were encouraged to complete the surveys in about the last ten minutes of each lab period. The robot project students performed two assessments during each lab setting, a *self-assessment*, and an assessment of each team member or *peer assessment*. A third assessment area, *team assessment*, was developed, but due to logistics in completing the required team discussion and the time commitment, this assessment was not implemented. The assessments were reviewed by a faculty member after each lab period and points of interests were documented so that students could be coached either individually or collectively based on patterns of responses. Observations by the faculty indicated that in the latter stages of the robot project as work and participation patterns became more defined, the students were tiring of the assessment process. This was deemed a teachable moment and a review of corporate assessment practices and issues was provided in the form of a mini-lecture. The students were asked to relate their personal experience with their assessment to illustrations from industry-experienced faculty in an open discussion.

For self-assessment, students were asked to make qualitative and quantitative assessments of their personal performance using basic questions. The qualitative questions included:

1. What strengths did I demonstrate during today's lab?
2. How could I have improved the team's performance today?
3. What weaknesses do I need to work on based on today's lab?
4. How could today's activities be applied in engineering work?

There were two quantitative questions evaluated on a Likert scale

1. Did I do my share in today's robot build lab?
2. Do I have a general understanding of what was completed and can explain it to a visiting faculty member?

Faculty reviewed each response and provided feedback on conducting self-assessments and the use of action verbs, assessment honesty and assessment work loads for the practicing professional. Teaching assistants were also coached on guiding the students in completing the self-assessment surveys.

For the peer assessment, team members were asked to assess the performance of each team member for each lab period. The peer assessment was conducted with quantitative and qualitative components. The qualitative component was assessed using three Likert scale questions. The assessment form was designed so that each team member could be assessed against each of the following:

1. How effectively did *team member* contribute to the team's goals for this lab period effectively?
2. How effectively did *team member* spend adequate time contributing to the goals?
3. How effectively did *team member* work with the team to achieve the goals vice acting independently?

In order to provide students an opportunity to expound on any team member issues the qualitative portion of the assessment included the following questions:

1. What strengths did *team member* demonstrate?
2. What weaknesses that negatively impacted the team performance did *team member* demonstrate?
3. How could others on your team improved your team's performance?

The intention of the peer assessment design was again to provide an experiential learning opportunity relative to performance assessments. Additionally, this portion of the assessment was intended to provide students a method of sharing participation issues with the faculty. The faculty, when reviewing the peer assessments, were sensitive to trends related to group or individual performance. Outside of lab attendance issues, which for the most part were corrected with the assessment process itself, one student intervention was conducted. The results were a stellar performance by the student during the oral presentation.

Student reaction in course feedback data indicated the assessments became repetitious and laborious. Attendance data indicated that lab attendance increased with the introduction of the assessments and thereby provided an immediate justification. Additionally, each of the assessment comments— students were required to provide comments—and their participation in the quantitative questions were assigned numerical value which contributed to a participation component of their final course grade.

Technical Assessment: The technical aspects of the project were assessed by a cohort survey instrument utilized during presentations as well as through the team-written technical reports. During the presentation, the students were expected to present a solid model of their gripper design. Two members of the faculty cohort evaluated each team in the areas of technical presentation, gripper design, robot/chassis layout, appearance/workmanship, uniqueness/innovation, and the use of rapid prototyping technology. A 30 point scale was utilized for the technical portion of the oral presentation in which the solid model presentation was weighted ten points and all other categories were weighted five points. The scores for the eight teams ranged from 24/30 to 30/30. What was perhaps most interesting about the technical design was the design diversity among the eight teams. The faculty expected that the term "gripper" would bias the designs, but six truly unique approaches to retrieve the jewels and transport them to the treasure chests were developed by the teams. Only one of the designs actually gripped the jewel. It should be noted that all eight robots were successful in achieving the design goal of retrieving jewels and transporting them to the treasure chest.

A team-written technical report was utilized as an experiential writing opportunity designed to expose the students to the technical writing that will be expected throughout their academic and professional careers. The students were given written format and content requirements for the team report. The reports were evaluated by two faculty members from the cohort. The reports generally met the format requirements, but lacked depth and continuity. In particular, the students did not adequately describe the technical aspects of their gripper design. The lack of continuity was attributed to the team writing with an "I'll write this section, you write that section" mentality. While the goal was for a team report, most teams apparently did not assign an overall report coordinator or thoroughly plan, outline, write, proofread, and re-write the report. The timing of the report (due during final exam week) also led to the inability to provide the students with any meaningful feedback.

External Review: The assessment process culminated with the oral presentations held during the last day of labs. Using presentation critique forms developed by Dixon[7] students were asked to peer-review team oral presentations. The students took to the task readily and provided unexpected meaningful insights on the presentations. The oral presentations also occurred during the last lab period which prevented compiling and providing team feedback in a team setting. This process will be modified for similar project presentations in the future to facilitate inter-team feedback.

The external judges also used the critique forms developed by Dixon.[7] The judges were excellent in quickly assessing each student's performance. Each student was required to have an active speaking role during the 20-minute timed presentation. The teams developed and controlled their presentation with the only 'rules' being the 20 minute time limit and the requirement that each team member speak (Note: This rule was violated, with the faculty cohort's knowledge, for the one dysfunctional team described above). The teams therefore controlled how much each student participated in a speaking role.

The critique form with its Likert scale format was readily translatable into a numeric score. Each student received a grade based on the compilation of the external judges' score and a member of faculty who also assessed the oral presentation. At the close of each section's oral presentations, the judges provided immediate verbal comments on each of the teams' oral presentations. The judges were complimentary of those teams showing a strong introduction, a recognized presentation outline (tell 'em what you're gonna tell 'em, etc.), a description of the competition, and demonstrated enthusiasm.

The perspective of the external judges seemed to provide a refreshing point of view for the students as a representative of industry provided immediate and direct feedback on a work-like assignment. At the same time, the judges reported that overall the ECU students showed excellent skills for freshmen and were impressed with the teams to the point they requested videos of the robot competition occurring the following day.

The semester-long robotics competition project successfully integrated different aspects of engineering issues into a cohort course when viewed qualitatively. Student feedback and instructor evaluation both indicated that through the project the students understood the importance of teamwork within the engineering workplace. The graphics requirement for the project was a clear discernment of the students' mastery of the solid modeling software (see Figure 4). The project also provided an excellent platform for students to apply skills taught during lectures based on faculty cohort discussion.

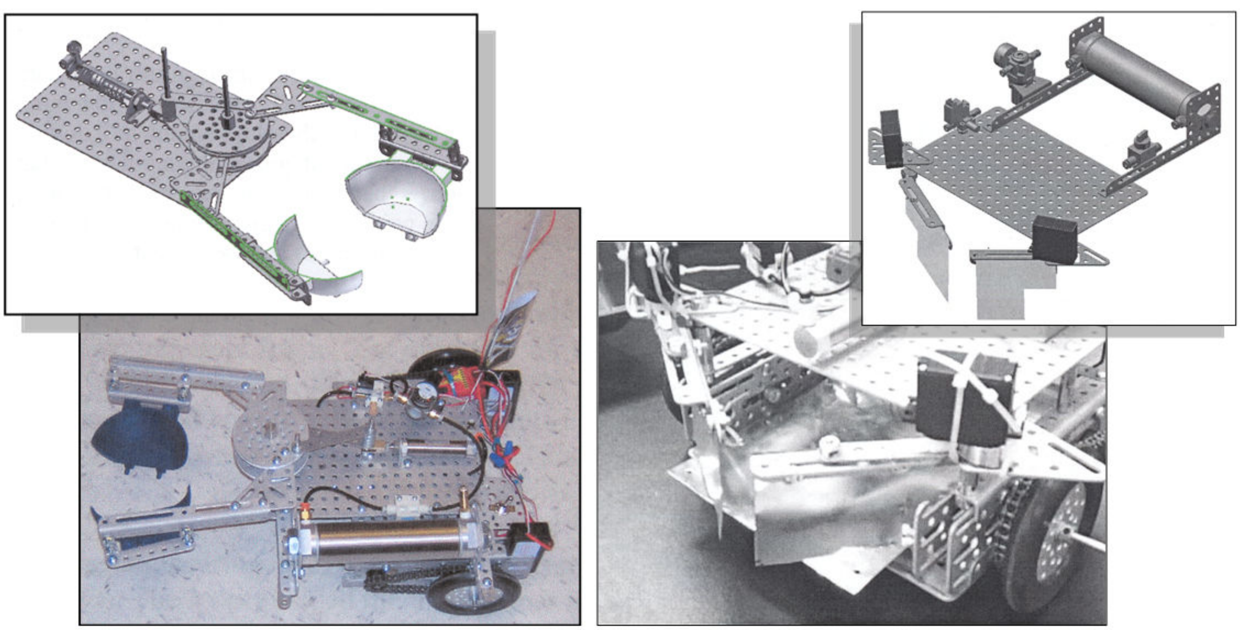

Figure 4. Two Examples of Robot Designs and Their Solid Models.

Recommendations

Upon reflection, opportunities for improving future freshman projects are evident from the ECU engineering program robot projects. In addition to logistical considerations (large groups, limited resources), not enough attention was paid to the management of the projects by the students. While a course in project management is required later in the curriculum, some basic concepts – creating a timeline, regular progress reports, etc. – could be effective in helping the students plan and execute their projects without the last-minute flurry of activity that was typical for most teams. Summers and Edmonson[8] make a convincing case for introducing project management skills early in the curriculum and encouraging and expecting their use in all projects. Specific recommendations for future offerings of the course include:

Phase Plan: For this project, the faculty coordinator provided a general outline when the project was first assigned. The general outline, which helped the students plan their tasks, lacked specifics that could have helped students ramp up the projects' pre-conceptual and conceptual phases. In retrospect, more specific requirements/expectations for each project phase would make the implementation of each project phase easier to monitor.

Milestone Reports/Presentation: The project workload and deliverables were back-loaded against the semester end. During the week before the competition, the students needed to finalize the robots, prepare presentations, pull together the technical reports, and complete a course-required graphics portfolio. A mid-term milestone report/presentation would not only help to distribute these loads along the semester, but should also improve the quality of the final course-required deliverables.

Lab Session Size: Significant differences were noticed in the student performance of open lab sessions with widely varying team sizes. The session with the smallest number of students working simultaneously in the lab naturally led to each student getting more personal attention, and these lab sections and teams perform the best based on faculty assessment; however, they did not win the competition.

Hardware Resources: During the early stage of the project, the project coordinator realized that limitations on the availability of components might affect design flexibility and creativity. This was subsequently verified by student feedback at the end of the semester. Future projects will require additional resource availability.

Conclusion

The first freshman engineering robot project at ECU was a qualified success. The project serves as a good medium for introducing several engineering topics in a manner that students enjoy. In particular, when responding to the survey performed at the end of the semester, 19 out of 47 students thought the teamwork experience from the project was the most valuable aspect. Ten appreciated the opportunity of designing and building their own grippers. Many agreed that the project improved their problem-solving ability, as well as hands-on skills with mechanical and electrical components. The project will be repeated next year, incorporating faculty and student suggestions for improving the effectiveness of the project.

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