AC 2012-4412: SENIOR DESIGN EXPERIENCE USING NASA'S LUNABOTICS MINING COMPETITION: BEST PRACTICES AND EVALUATION OF STUDENT LEARNING

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Senior Design Experience Using NASA's Lunabotics Mining Competition: Best Practices and Evaluation of Student Learning

Abstract

For the past three years, NASA has sponsored and hosted the Annual Lunabotics Mining Competition. This challenge is similar to the more familiar SAE Mini-Baja or ASCE Concrete Canoe competitions. Since its inception 2010, John Brown University has participated in NASA's Lunabotics Mining Competition and used the project as one of several opportunities in our senior design sequence. This paper describes John Brown University's experience with the NASA competition and formulates best practices for success based on data collected from multiple schools. It also demonstrates how participation in the Lunabot project helps meet the desired learning outcomes for senior design and evaluates the student learning involved in this team design competition. Formal assessments of ABET linked student learning outcomes show that the students in this competition demonstrate about the same level of proficiency as students in industry sponsored projects.

Introduction

As indicated by a recent PRISM article, competitions are a popular source for university engineering student projects.[1] In 2005, Wankat identified forty four such competitions[2] and the number has certainly grown since then. Some of the best known competitions are sponsored by SAE with their Baja SAE®,[3] Aero Design®,[4] and Supermileage®[5] competitions. Racing solar cars in the American Solar Challenge[6,7] or building a solar house in the Department of Energy's Solar Decathlon[8] have fewer participants, but are similarly well known. Also of note are small-scale robotic competitions such as the Two-Year College Model Design held at the ASEE Annual Conference and the Student Hardware Competition[9,10] held at IEEE's region three annual conference, SouthestCon. A new competition available to universities is the NASA Lunabotics Mining Competition.

As part of the Kennedy Educational branch of the National Aeronautics and Space Administration (NASA), the Lunabotics Mining Competition was developed as an initiative to encourage university students to engage in the fields of science, technology, engineering, and mathematics (STEM). The annual competition began in 2010 and universities from around the globe have participated for the past three years. The primary focus of the competition is to design and build a lunar robot (Lunabot) which can mine and deposit a lunar soil stimulant while being operated telerobotically or autonomously from a remote control center. The design challenges include the size and mass limitations, the performance of the robot in a ten minute timed competition run, the level of autonomy, and the energy/power requirements.

In this paper, we briefly describe the competition and our experience of using it in the senior design sequence at John Brown University (JBU) is highlighted. The robot that participated in the 2012 competition is shown in Figure 1, below. We also share several best practices, as learned by our university and other schools that have participated in the competition.

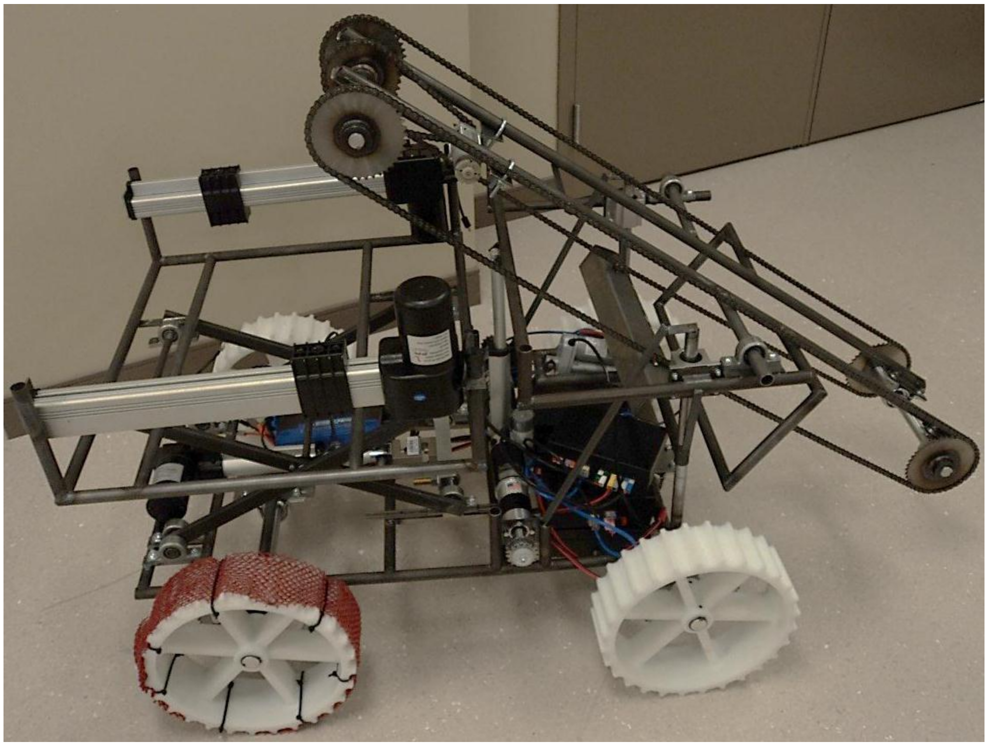

Figure 1: JBU's Lunabot for the 2012 competition

Lunabotics Mining Competition

The goal of the NASA sponsored competition is two-fold. First, NASA benefits from the competition by receiving innovative new ideas from the entries that they can use to improve and enhance their own designs for interplanetary autonomous robotic excavation design and operation. The second goal is to encourage students to engage in fields of study that are essential for NASA's programs. In response to these goals, the rules and regulations of the program have developed over the three years NASA has hosted the competition. Points are awarded based on a team's ability to meet and exceed the requirements in various areas. Therefore teams are encouraged to create innovative designs which will surpass the requirements. Additional learning challenges in this competition make the student outcomes comparable to other senior design projects. The students are required to meet the design requirements given by NASA, follow all of the deadlines listed in the competition rules[11], write a systems engineering paper, raise funds to build and test the robot and to attend the competition.

NASA modified the rules for the 2012 competition to better meet the goals, making the restrictions more realistic and by awarding points accordingly. The main size constraint requires the Lunabot to initially fit in a maximum space of 0.75m (width) x 1.5m (length) x 0.75m (height) and, while competing, the Lunabot may not expand beyond a 1.5m height limit. The maximum weight of the Lunabot is 80kg, but each kg of weight costs the team points. The Lunabot must be able to cross an obstacle course, simulating a lunar surface, and collect a minimum of 10kg of BP-1, the lunar soil stimulant. A diagram of the Lunarena, where the competition takes place is shown in Figure 2, below. Each competition run is 10 minutes long and points are awarded based on the amount of BP-1 collected and deposited in a bin, located on the opposite side of the obstacle course as the digging area. Additional points are awarded based on the bandwidth required to operate the Lunabot from the remote control center, the level of autonomy of the Lunabot, the ability to measure power consumption, and the dust tolerance of the design.

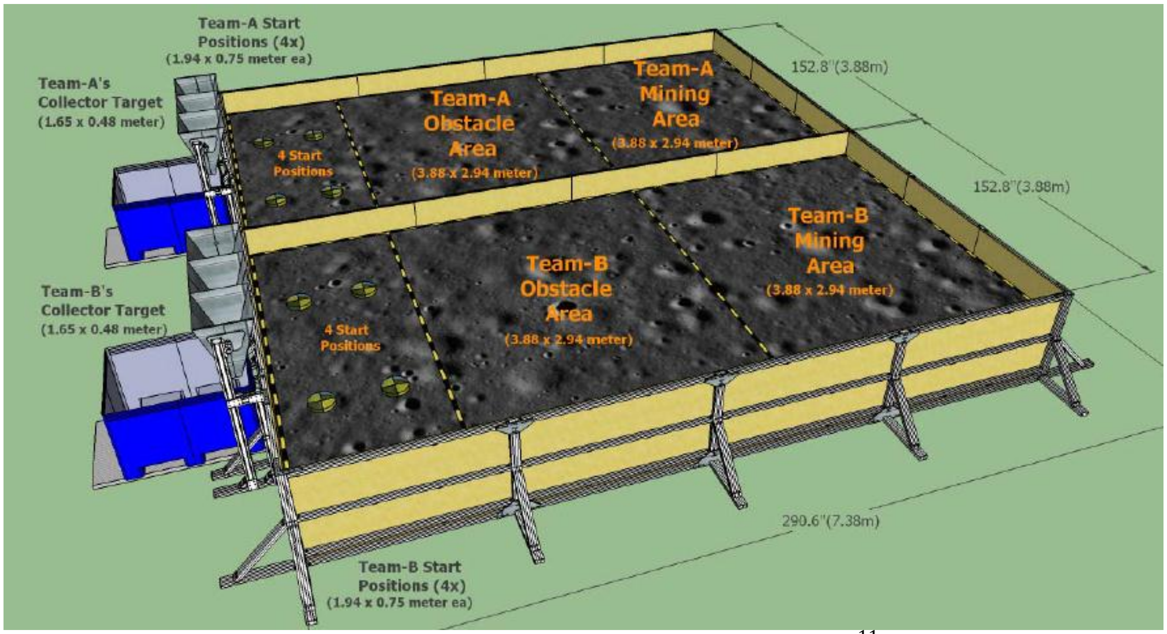

Figure 2: Isometric diagram of the Lunarena[11]

In addition to the physical design and performance of the Lunabot, NASA established several sub-competitions that factor into the overall points a team earns. These features allow further student learning, enhancing the design process. If a team can show by November that they are collaborating with a Minority Serving Institution, they earn extra points. In January, each team is required to submit team rosters, and schools are awarded points based on the number of disciplines that make up the members. This encourages multi-disciplinary teams. By the end of April, each team is required to submit a Systems Engineering paper, showing the method and design that was used to build their Lunabot. This causes students to learn more than just how to create a design, it forces them to examine the design method and integration of the various parts. Also by the end of April, each team must submit an outreach paper, documenting how they encouraged K-12 students to pursue STEM fields. This unique requirement causes students to not only focus on the design, but also on teaching and coaching others. Additional categories of the competition include a presentation, a team spirit competition, social media and networking competition, and an innovation award. Teams are required to provide written and video documentation of their Lunabot by the end of April and must be present to participate at the competition, held at the Kennedy Space Center in Orlando, Florida during the last week of May.

NASA's Educational Outreach

Part of NASA's goal is to encourage students, educators, and institutions in their pursuits of the STEM fields[12]. In 2012 NASA created the new STEM Education and Accountability Program, which is requested a budget of $94.4 million for the first year, and they fund competitions like the Lunabot Mining Competition with these program appropriations[13]. This comes out of NASA's general funding, allotted to them by Congress. A portion of the appropriations are used to give grants to participating schools. These grants provide part of the money needed to design, build, and test the Lunabots. Additional NASA funding provides monetary awards for various categories of the competition. The grand prize is the Joe Kosmo Award for Excellence, a cash award of $5,000 and a trip to one of NASA's remote research and technology tests to the team with the highest overall score.

John Brown University Application

JBU participates in the Lunabot competition primarily by using it as a senior design project. At JBU senior design is a two semester course, and this sequence aligns well with the competition timeline, allowing students to begin design work and fundraising in the fall semester, while finishing the building, testing, and documentation phases in the spring.

At the beginning of the fall semester, the seniors must submit a short essay explaining why they would like to be a part of the Lunabot team and highlighting the specific skills they are able to contribute to the team. This serves several purposes: the students must show initiative and dedication at the beginning of the project, it gives the students practice articulating and presenting themselves, and it helps the professors select the team of students for the project. Creating the team at the beginning of the semester allows the team to use the maximum possible amount of time for brainstorming, designing, and receiving feedback from design reviews.

At JBU, the seniors on the team are assisted by underclassmen at various times throughout the year. In the spring several junior students are selected, based on interest and commitment, to attend the Lunabot competition at the Kennedy Space Center. These juniors then become members of the senior team the following year. Throughout the year, freshmen are able to participate with the team in a variety of ways, which have included building a model Lunarena in which to test the Lunabot and helping with building and testing.

Each year that JBU participates in the competition, we apply for and have received a grant from NASA to provide base project funding, but additional funds are also raised. The faculty sponsor and the students work together to find, apply for, and receive additional funding and donations of material and equipment. This provides the students with a unique learning experience that is unparalleled in other senior design projects. Writing grant applications and letters to industry sponsors provides valuable practice for real world jobs and creates relationships between the students and industry professionals.

The students are required to write a design proposal and have several design reviews during the fall semester. This allows the students to brainstorm and receive valuable feedback from professors and industry professionals who attend the design reviews. Also, by completing most of the design and basic travel preparations by the end of the first semester, the team knows the approximate amount of money to raise for the project. Each year that the university competes, valuable lessons are learned and these influence the next design. While each team has the opportunity to learn from the previous projects, they are expected to design their own systems. Any system that is reused from a previous design must be analyzed and adjusted so that it can be adapted to the new design.

The second semester is used to build and test the robot. This involves the students gaining experience with various equipment and machinery such as software programs, welding equipment, etc. The students must design tests for the Lunabot in order to accurately determine the Lunabot's mass, performance, and communication abilities. As the Lunabot is assembled, the various subsystems are tested individually. The final tests are performed on the full Lunabot assembly. This phase gives students experience with developing tests, performing tests, interpreting results, and problem shooting the design. The final goal is a functioning Lunabot, which can be refined until the time of the competition where it competes against other schools' designs. A functioning Lunabot can also be used for outreach projects. The outreach, which occurs both semesters, involves presenting the design process to students ranging in age from elementary to collegiate as well as allowing the students to operate the Lunabot.

2012 Team Experience

The 2012 team from JBU consisted of five senior engineering students from two disciplines. On the team were one electrical engineer and four mechanical engineers, with one of the mechanical engineers functioning as the systems engineer and team lead. The work was divided so that the electrical engineer designed the power, control, and communication, the three mechanical engineers designed the frame, mobility, excavation, storage, and ejection sub-systems, and the systems leader facilitated team communication, budgeting, administration, testing and sub-system integration.

After the team was formed in August 2011, they began setting team goals and brainstorming design ideas. Two of the team members had attended the previous competition, 2011, and were able to describe to the other team members the competition and the concepts that demonstrated potential based on their observations. This work culminated in a conceptual design review in early October with professors and industry professionals giving feedback and helpful suggestions about the designs presented. By mid-October, the concepts for the design were established and research, design, and modeling began. Each system created a mass and monetary budget to ensure the Lunabot would meet the team goals.

For the electrical systems, the team chose to use very similar equipment and software the previous JBU team used. However, the team added the challenge of partial autonomy and decreased bandwidth. By replacing cameras with infrared sensors, the team was able to accomplish both of those objectives. Full autonomy was not a goal of the 2012 year's team, primarily because there was only one electrical engineer on the team. In the future, with more electrical engineering majors working on the Lunabot, full autonomy is anticipated. In the fall, the team created all of the communication flow diagrams and some of the software.

The mechanical engineers fully modeled the Lunabot in SolidWorks, in which they also performed finite element analysis to support their load calculations. The approximate size and weight of the design were also obtained through the computer model of the Lunabot. Potential problems and material needs were determined from these models and calculations, allowing risk analysis to be performed. The full model and an example FEA are shown in Figures 3 and 4 below. Two additional design reviews occurred during the fall semester to continue to develop and refine the design.

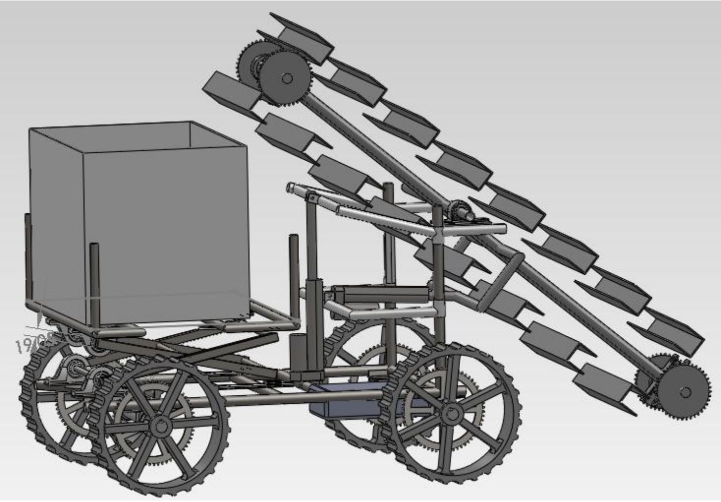

Figure 3: Fully developed 3-D model

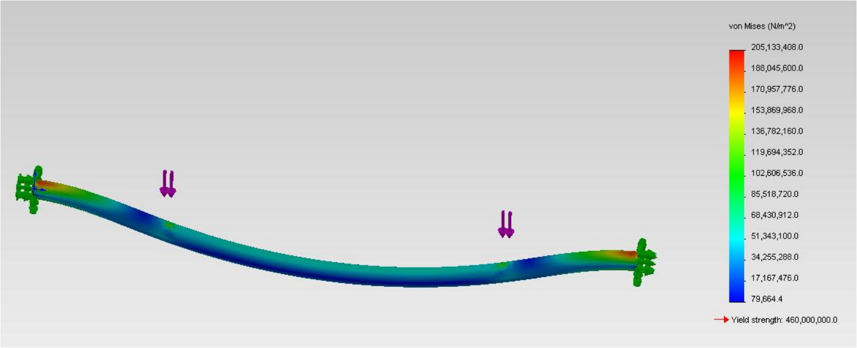

Figure 4: FEA of lower frame cross beam

Throughout both semesters, the team was involved in fundraising, outreach among local schools, and team development. The Arkansas Space Consortium awarded the team several grants, including both team and individual scholarships. Members of the team, including not only the five seniors, but also several underclassmen, travelled to Kansas, Texas, and various locations in Arkansas to present to elementary through high school students, encouraging them to study STEM fields. Since the 2012 Lunabot was not operational until April, as part of the presentation the team demonstrated and allowed the students to drive the 2011 Lunabot. The five seniors also participated in monthly team dinners and other team development activities, in addition to their weekly meetings with an engineering faculty mentor.

Early testing of the systems began at the end of the fall semester and the beginning of the spring semester as parts and materials were being ordered. A simple test of the excavation system was performed to analyze the motor performance and the paddle design. The ejection system was also tested to determine the manner in which the BP-1 would leave the storage bin. These tests can be seen in Figure 5. As many parts and materials as possible were ordered before the end of the fall semester.

(a) (b)

Figure 5: Testing rigs (a) excavation system and (b) storage/ejection system

In the spring of 2012, the team constructed the Lunabot. Partnering with a local machine shop, the mechanical engineers used various tools, equipment, and machinery to manufacture the physical structure of the Lunabot. Several juniors and freshmen were involved in the work of fabricating and assembling the parts. The electrical engineer created a “flat robot” to test all of the motors, actuators, sensors, and routers before they were connected to the mechanical equipment, as seen in Figure 6. Freshmen were able to help with the wiring and the organization of the electrical equipment in the housing.

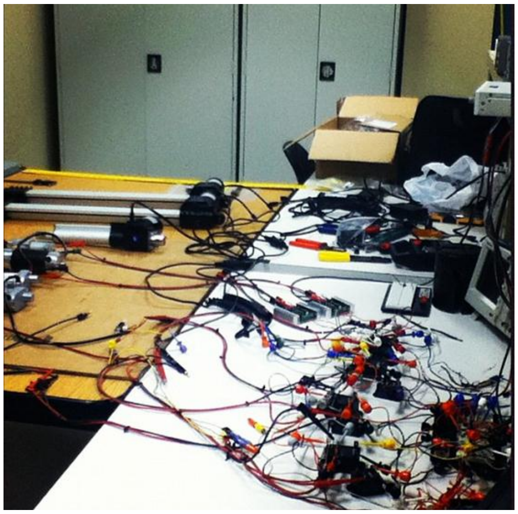

Figure 6: The “flat robot” used to test all of the electrical equipment

Completing the assembly of the various components early, allowed the team to alter components and have slight design adjustments which the integration of the systems required. Figures 7 and 8 show the team working on building the robot and beginning the integration the electrical and mechanical components. The various stages of assembly were each milestones proving what was designed well and revealing the areas that needed to be improved. As of the writing of this paper, system level robot testing is in progress.

Figure 7: Welding the frame

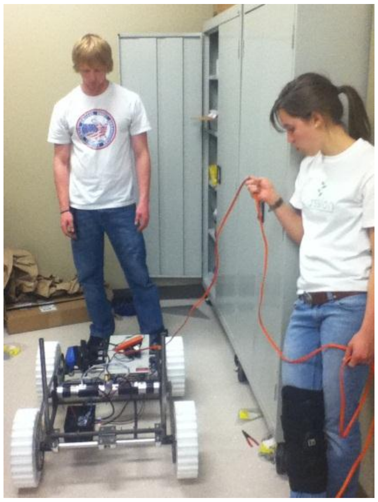

Figure 8: Integrating the mobility frame and motors

The end of the semester involves several presentations of the completed Lunabot, including the design, construction, and testing components. Figure 1, at the beginning of the paper shows the final Lunabot used for the completion. The team that is going to the Kennedy Space Center in May 2012 consists of the five senior engineers, and three junior engineers.

Best Practices

From our university experiences, there have been several best practices of the competition that we will continue to implement for our teams and recommend for other teams attending the competition. These include team size, structure, and formation.

Teams of five students are optimal. This team size allows for collaboration, brainstorming, and appropriate work allocation, but is small enough to allow each of the team members to have a voice and an active role in the designing, building, and testing of the Lunabot. A team of five also can include several disciplines and skill sets.

As a senior design project, the Lunabot team is given a time structure as well as a team structure. Since applications for the competition are due in the fall and the competition is in May, the two semester sequence corresponds well. It encourages students to spend the first semester brainstorming, talking to industry professionals individually and at design reviews, and designing the Lunabot. The second semester can then be devoted to building, testing, and perfecting the design. The senior design course structure aligns with the NASA requirements, especially with the final NASA deadlines for the systems paper and video, which are due in late April. Having the project be part of a class encourages the students to stay on top of the project by requiring weekly team updates and various other written and oral progress reports. The team structure used by JBU also proves to work well. Since the Lunabot competition is a senior design project, the team is required to meet regularly with a faculty sponsor, which encourages accountability and allows a time for questions, mentoring, and suggestions. The team is compromised of both mechanical and electrical engineers, which creates a division of labor and also the opportunity for interdisciplinary growth and collaboration. One of the team members is selected, by the professors, as the team lead and systems engineer. This provides a structure in which the team can function with clearly defined roles and it ensures that all of the various aspects of the project are completed.

The formation of the team has already been mentioned, but it will be summarized again, as it is an important aspect of a quality team. During the spring semester juniors have the opportunity to apply to attend the Lunabot competition with the senior team. This gives juniors the opportunity to see the competition, the arena, and various other teams' designs before they begin their senior design project. With the insight and experience gained from this opportunity, the team the next year has the advantage of first hand information about the competition. The following fall, the rest of the team members are selected based on their application, their skill, and the professors' discretion. This multidisciplinary team is formed of five students who are highly motivated but have varying levels of experience and skills so that they all have the opportunity to be challenged.

Student Learning Outcomes

While design competitions are fun for the student participants and can create good publicity for the university, especially if the university does well in the competition, the primary goal of the project should be effective student learning. This learning goal is especially important when the competition is used for course such as engineering senior design. In order to measure the student learning achieved through participation in the NASA Lunabotics mining competition, we present here two assessments of the student learning achieved through this project. The first is a direct assessment of student learning from JBU. The second is an indirect survey of faculty and student participants in the 2011 competition.

Each year at JBU the work of senior design students is assessed by external judges at a senior design poster session. This poster session provides an opportunity for the external judges, members of JBU's engineering advisory board (EAB), to interview the seniors on various aspects of the student's project. The judges then rate the student achievement of several well defined performance criteria. This process gives the program high quality assessment of student achievement even if the number of students involved is small[14].

The table below shows the performance criteria used at the JBU senior design poster session and their linkage to the ABET outcomes. JBU has participated in the lunabotics competition the last two years. During that time, there have been nine seniors who participated in the lunabotics competition and twenty four other senior design students who have industry sponsored projects. The judges at the JBU poster session have ranked the achievement of the lunabotics students equal to the students involved in other projects. We should note that while this measurement is externally valid, it may suffer from low inter-rater reliability.

ABET Outcome a	an ability to apply knowledge of mathematics, science, and engineering
a.1	Student has a satisfactory knowledge level of mathematics, science and engineering for their stage of their college career.
a.2	Student identifies relevant engineering principles in an open ended problem.
a.3	Student appropriately and correctly applies knowledge of mathematics, science and engineering to solve problems.
ABET Outcome c	an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
c.1	Student develops realistic design criteria from an open – ended problem statement.
c.2	Student conceives of solutions to an open – ended problem.
c.3	Student technically analyzes possible solutions to show that they should meet design criteria.
c.4	Student successfully implements design solution and solves problems which arise in manufacture / integration.
c.5	Student judges quality of prototype or product through testing against established design criteria.
c.6	Student selects and performs appropriate monitoring and modification of project schedule during design process.
ABET Outcome g	an ability to communicate effectively
g.1	Student uses appropriate visual aids and presentation techniques to engage audience (e.g. maintains eye contact, modulates voice, does not use distracting gestures).
g.2	Student identifies and selects appropriate material to include in oral and written presentations depending on analysis of audience and purpose.
g.3	Student creates effective graphics for a variety of audiences and purposes using appropriate graphical conventions (e.g. formats, captions, titles, axes, legends etc.).

We also measured student learning indirectly through a survey of 2011 student and faculty participants of the lunabotics competition. These individuals were asked “How well did the lunabot mining project enable learning and / or demonstration of the following ABET program outcomes?” and then gave the choices “Very Well,” “Better Than Average,” “Below Average,” “Significantly Below Average.” We then grouped the responses by institution and averaged the results across institutions. We note that while the results in the table below include student self – reported data, we separated out responses from students and from faculty supervisors. There was no difference between the ratings of the students and faculty. Both are overly pleased with the learning in their project.

	ABET Outcome	Average Rating of Student Achievement by Survey Participating Schools (Out of 4.0 with 4.0 meaning "Very Well"
a	an ability to apply knowledge of mathematics, science, and engineering	3.9
b	an ability to design and conduct experiments, as well as to analyze and interpret data	3.4
c	an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	3.9
d	an ability to function on multidisciplinary teams	3.9
e	an ability to identify, formulate, and solve engineering problems	3.9
f	an understanding of professional and ethical responsibility	3.5
g	an ability to communicate effectively	3.8
h	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	3.3
i	a recognition of the need for, and an ability to engage in life-long learning	3.5
j	a knowledge of contemporary issues	3.4
k	an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	3.7

The results in the table above are indirect and taken from a small data set so one should not get too excited about the positive results. It does seem that students in this competition achieve reasonable learning in outcomes a, c, d and e which are most directly related to engineering design and problem solving. The competition project does not seem to have as much ability to help students learn and demonstrate outcomes h and j related to broad contemporary issues.

These results are not surprising. The participants in the NASA Lunabotics mining competition find the competition project to be an excellent learning environment. However, when direct measures of student learning are taken, those results show that there is no difference between the learning in this project and industry sponsored projects. It does seem that we can at least conclude that the student learning through this project is no worse than industry sponsored projects.

Conclusion

The Lunabotics Mining Competition, sponsored by NASA, is a challenging and well organized competition for undergraduate students. Funded by the educational division of NASA, it is a good fit for senior design courses. Our university has benefited from using this competition as one of the projects in which seniors participate. The three years that we participated have given us insight into several practices that make up a quality team of students, including the size, structure, and formation of the team. As the student learning outcomes show, the Lunabot project is a comparable project to industry based projects.

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