AC 2011-531: THE MONTANA MULE: A CASE STUDY IN INTERDISCIPLINARY CAPSTONE DESIGN

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Abstract

In May of 2010, NASA held the 1st annual Lunabotics Mining Competition at the Kennedy Space Center in Florida. In this competition, 22 teams from across the nation built remote-controlled, robotic excavators to mine lunar regolith simulant. The winner of the competition was the team who could successfully deposit the most regolith into a collector in 15 minutes. The goal of this competition was to encourage multidisciplinary capstone design projects. Of the 22 teams that participated in the competition, the "Montana MULE" from Montana State University (MSU) was the only robot to successfully mine the qualifying weight of 10kg and ultimately deposited 22.6kg to take first place at the competition. The interdisciplinary capstone team that was assembled at MSU consisted of 8 students and 5 faculty advisors from 4 different departments and represented the largest multidisciplinary project ever attempted in the College of Engineering. This paper will present an overview of the multidisciplinary capstone project and detail the challenges of administering such a large capstone team. These include coordination of schedules, deliverables, and student supervision. The assessment strategy will also be presented and the challenges will be discussed. Recommendations and lessons-learned will also be presented in order to assist faculty at other institutions in implementing similar multidisciplinary projects.

1. Competition Rules

NASA initiated this competition in order to stress the fundamentals of systems engineering and to expose students to working in interdisciplinary teams. The rules of the competition were posted approximately 10 months before the May 2010 competition date. The competition field consisted of a 7.38m x 7.76m box that was filled with regolith simulant and divided into two 7.38m x 3.88m regions for simultaneous mining by two teams. At one end of each field, there was a collector box that was connected to a scale to weigh the amount of regolith deposited during the competition. The top of the collector was located 1m above the surface of the regolith. The fields were divided into an *obstacle area* and a *mining area*. At the beginning of the competition, the robot was placed near the collector box and had to move through the obstacle area while avoiding craters and boulders to get to the mining area. Once in the mining area, the robot was allowed to collect as much regolith as desired. The robot had to carry the regolith back through the obstacle area and deposit into the collector. Each robot was given 15 minutes to compete and could make as many trips to the mining area as it could during the competition time. Figure 1 shows the graphical depiction of the competition field that was provided in the rule book [1]. The physical competition field was located inside of a tent in order to minimize the distribution and inhalation of regolith. Each person entering the tent needed to wear protective clothing and a ventilation mask. Figure 2 shows the actual competition field.

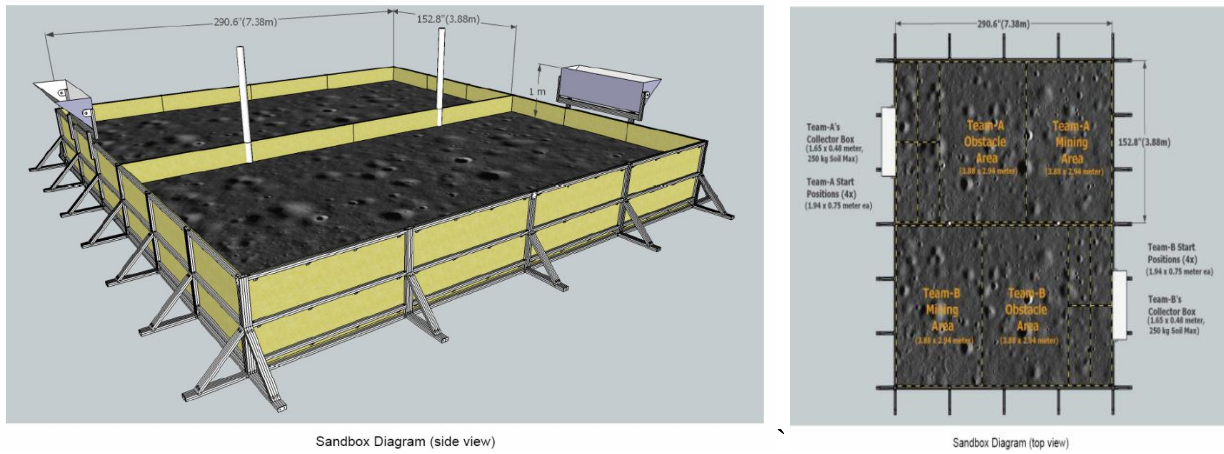

Figure 1. Competition field “sandbox” depicted in the rule book [1].

Figure 2. Photo of the actual competition field “sandbox” housed in a ventilation tent.

Rules were given regarding the size and mass of the robot. The physical size of any robot needed to fit within a volume of W=1.5m x L=0.75m x H=2m. This size corresponded to a wheelchair elevator that was used to transport robots in the staging area. The mass of each robot could not exceed 80kg. Prior to competing, each robot was weighed and was not allowed to compete until it met the 80kg max weight requirement.

Rules were given regarding technology with the spirit that any technology that could not be used in a lunar environment could not be used in the competition. This limited the use combustion engines unless a fully self contained airflow system was implemented. Every team in the competition choose to use electric motors and batteries to power their robot.

An 802.11 wireless network connection was used to control each robot remotely. Each robot was given a fixed IP address and communicated with a wireless access point located inside the competition tent. This access point was hardwired to a control room physically located out of site of the tent. Cameras were used to show images of the competition field in the control room. The two teams controlling the robots were located in separate control rooms that were isolated from the competition area. A maximum data rate of 5Mb/s was set on the communication link, between the control room and the robot. The following figure shows the inside of the control room during the competition.

Figure 3. Inside of the control room during a competition (MSU students John Ritter, Chris Ching, and Jennifer Hane).

In addition to the technical rules, all teams competing had to turn in a systems engineering paper, and an outreach report. Optional items could also be turned in including a presentation about the design process and a video showing the design progression. Each of these elements of the competition earned points toward an overall team score that was combined with the results of the mining competition. One award was given to the team that mined the most overall amount of regolith above a 10kg qualifying weight and another award was given to the team with the most overall competition points. This second award was titled the *Joe Kosmo Award for Excellence*. Awards were also given for each of systems engineering paper, outreach, and presentation items.

2. Capstone Make up at MSU

This design project was accomplished over two semesters (Fall-09 and Spring-10). The team was made up of 8 students from departments spanning Computer Science (CS), Electrical Engineering (EE), Mechanical Engineering (ME), and Mechanical Engineering Technology (MET). Five faculty advisors participated in the project.

The ME/MET department has a two semester capstone sequence with each semester counting for 2-credits. Two ME and two MET students participated in the project. This structure fit very well with the Lunabotics schedule. The EE department offers a one semester capstone worth 3-credits. This structure was not as optimal. Three EE students participated on the project as part of their capstone during the fall semester. One of the EE students graduated in December and was not able to continue working. Another EE student continued on the project to get credits toward an honors thesis that had a research requirement. The final EE student continued on the project after receiving an undergraduate scholars program fellowship from MSU that aims at engaging students in hands-on research. The CS department has a two semester capstone in which the first semester earns 0-credits and is intended to be used for project selection. The second semester earns 4-credits and is for implementation. This sequence was also sub-optimal due to the credits being earned not reflecting the amount of work at each stage of the project.

3. Design Approach

Each of the departmental teams were responsible for a sub-system of the final robot. These subsystems corresponded to the deliverables for their respective department's capstone requirements. The three main sub-systems were:

A) Mechanical System (Propulsion, Digging, Dumping)

B) Electrical System (Propulsion, Power Delivery Motor control electronics)

C) Control System (Wireless interface, Control application)

The teams worked together to come up with an entire design on paper. This design drove the number of motors, amount of power required, and type of control electronics that were going to be used. This set the specifications for each of the sub-system designs.

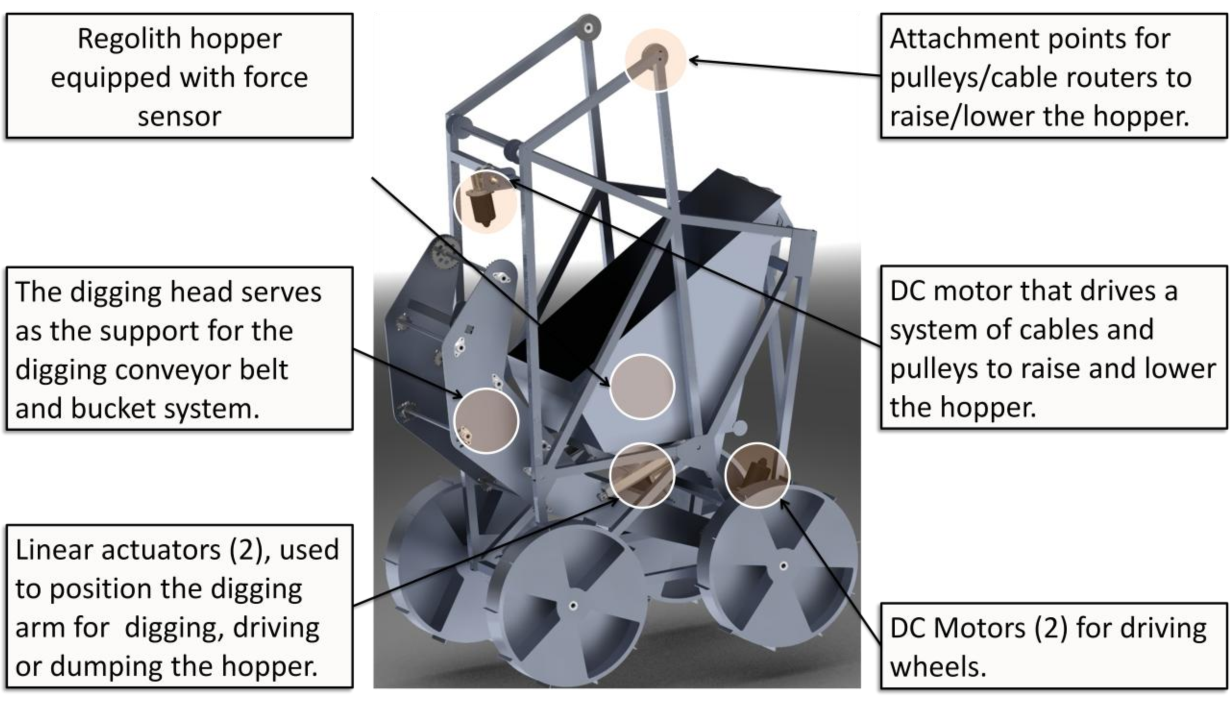

Figure 3. Excavator design decided upon prior to prototyping and fabrication.

The electrical team prototyped their system on the lab bench. The control system was prototyped using a single motor also on the lab bench. The following figure shows the prototype of the electrical and control system.

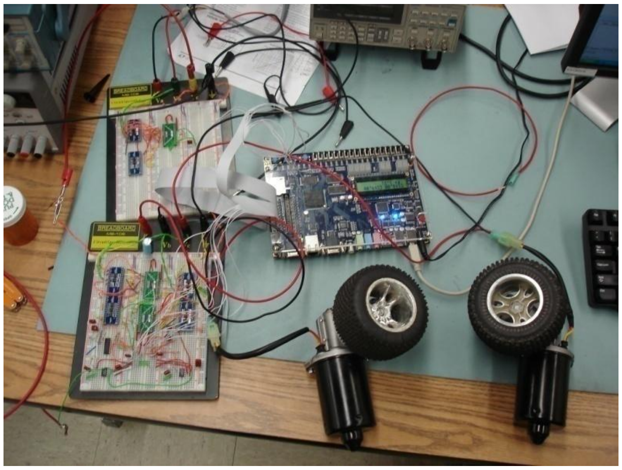

Figure 4. Electrical and control prototype.

In the spring (semester 2), the mechanical team began fabrication. All of the sheet metal and tubing was cut and assembled at MSU.

Figure 5. Fabrication.

The final design was assembled and testing toward the end of the spring semester. The following figures show the assembled robot and field testing.

Figure 6. Assembled robot.

Figure 7. Field testing of the robot.

4. Competition Event

The robot was shipped to the Kennedy Space Center two weeks prior to the competition. The competition was held at the Astronaut Hall of Fame. A staging area was located in the main museum area in which all of the 22 competing teams setup their robot.

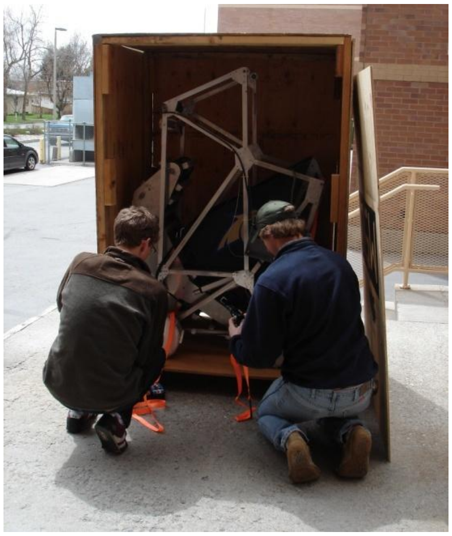

Figure 8. Shipping of the robot to NASA (left: loading at MSU, right: unloading at NASA).

Figure 9. Competition at the NASA Astronaut Hall of Fame.

The original competition was intended to have one practice day and one competition day. After the competition day, only one team deposited anything into the collector and it was below the 10kg qualifying weight. It was decided that a 2nd competition day was to be added. On the second day, 6 teams were able to deposit regolith into the collector. Only MSU was able to meet the qualifying weight of 10kg and ended up with a total of 22.6kg of mined regolith.

Figure 10. MSU robot competing on the final day and the 22.6kg reading on the collector scale.

MSU won first place in the mining competition and also won the Joe Kosmo Award for Excellence for accumulating the most overall competition points.

5. Lessons Learned

This project was one of the largest inter-disciplinary capstone projects ever attempted in the College of Engineering at MSU. This project had a major impact on the education of the 8 participating students and the 5 faculty involved. From a faculty perspective, this project represented one of the most logistically challenging efforts many of us had undertaken. The following list some of the key take-always from this experience.

5.1 Challenge: Different Capstone Structures Across Different Departments

While it is widely accepted that having students work on interdisciplinary design teams will better prepare them for the workforce, it is a logistical challenge when trying to administer a cross-departmental project in academia. First, the different capstone structures create a situation where the team members are not being *compensated* at equal levels throughout the project. In our project, the ME/MET students had a capstone sequence that aligned well with the Lunabotics schedule. However, the EE's were pressed to deliver the majority of their work in the first semester due to having only a 1-semester capstone. The CS student did not receive any credit during the first semester but was pressed to support the EE's for their delivery. The uneven distribution of credits and different deliverables caused a difficult situation that required students to put in additional effort without getting the appropriate credit.

Second, getting students to continue on the project after their capstone has ended presented a challenge. For a time-intensive project such as this, it is impractical to try to accomplish it with volunteers. We found that each student working on the project needed to be receiving something for their work. In most cases, this was credit but we did have one situation were a student receive a cash fellowship to continue.

5.2 Recommendation: Synchronizing the Capstone Sequences.

Due in large part to this project, the MSU EE department decided to change its 1-semester capstone to match the ME/MET capstone sequence. The EE department is now using a 2-semesters capstone sequence with 2-credits being assigned each semester that matches the ME/MET departments. This curriculum change will support more inter-disciplinary projects. This should also synchronize the deliverables so that the project team is working on the same schedule. We have agreed cross-departmentally to use the following design flow. This 2-semester design process is based on some of the key components from Systems Engineering.

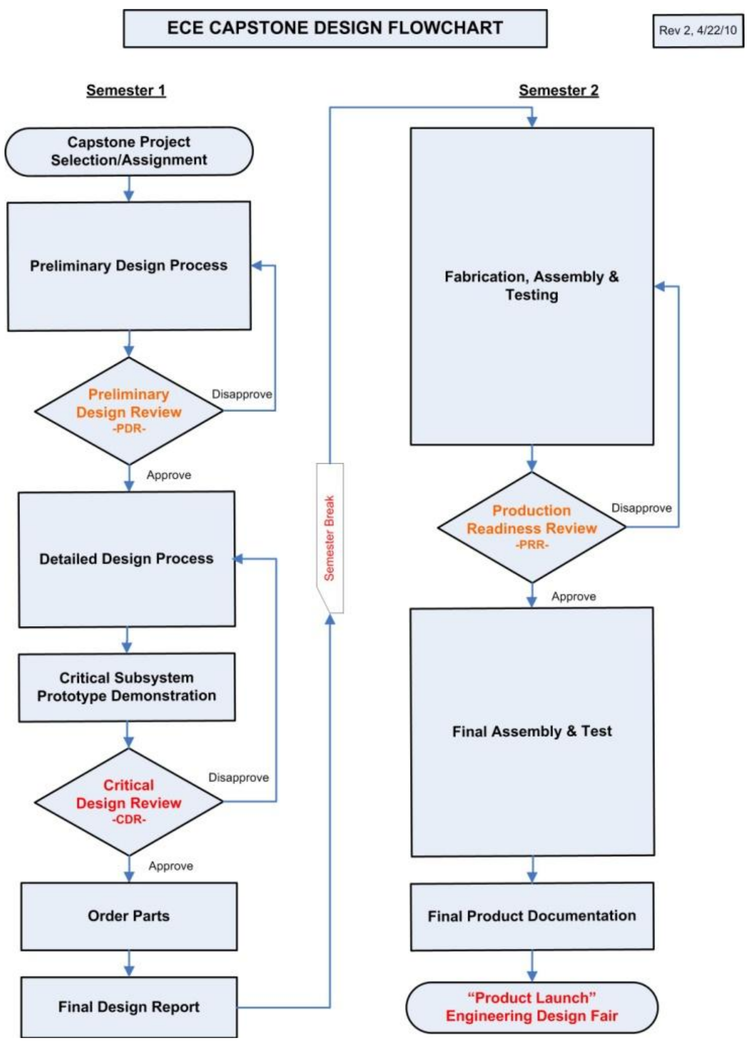

Figure 11. 2-Semester Design Process for Interdisciplinary Capstones.

5.3 Challenge: Schedule Coordination

Weekly team meetings are critical in all design projects but especially in an academic environment where distractions are abundant. While coordinating different schedules is always a challenge, there is an inherent difficulty in coordinating schedules between departments. Within a department, students of a certain level (i.e., junior, senior) tend to have schedules that match due to taking a majority of the same courses. There are deterministic free times that can be used for project meeting times. When trying to match these free times across departments, it becomes very difficult simply due to the different curriculums and class meeting times that different departments have.

5.4 Recommendation: After-hour, Student Only Meetings

While faculty can rarely attend after-hour meetings, students are most often available during this time. We implemented a brief (30-minute) full team meeting each week in which the requirement was that at least one representative from each department was present. These representatives were responsible for conveying team announcements back to their discipline teams. We instituted an after hour (6pm+) meeting that all the students could attend where the faculty were not present. Eliminating the requirement of faculty being present allowed the meeting to be held in the evening when all of the students could attend. It also allowed the students to interact on a peer level without the faculty being a distraction.

5.5 Challenge: Conflicting Deliverables

One of the major challenges faced in this project was the different deliverable requirements from the different departments and the different schedule that these deliverables were on. Since the departmental deliverables were tied to the students grade, they always took precedence over moving the project forward. Excessive deliverables in the capstone courses have become a problem at our school due to the capstone course being a *catch-all* for ABET outcomes. Since this course blends everything the students have learned together into a single course, it is ripe for collecting assessment data on a large range of ABET outcome. This leads to requiring a large amount of deliverables in order to document and assess the outcomes. These deliverables can often be in addition to the actual design process and present a distraction to progress. This is especially true when the deliverables are tied to a grade because students will always work on a graded item first. In this project, we continually lost momentum when a discipline sub-group had to stop working on the overall project and focus on a class deliverable.

5.6 Recommendation: Common Deliverables

We feel that if interdisciplinary capstones are going to be successful, the deliverable requirement needs to be at a team level. This means that if a design document is requirement, it is turned in by the entire team and not by individual sub-groups. This puts a burden on the faculty to define and bound the deliverable, but it emphasizes that the project is being completed by a team in all aspects. This also puts a burden on the faculty to extract their ABET outcome data from a larger, interdisciplinary design documents, but this seems feasible. We suggest using the design flow chart presented for a unified set of deliverables. A single design document is created chapter by chapter throughout the project by the entire team. This paper can be thought of as the final "systems engineering paper". The design reviews also present an opportunity to collect assessment data in an oral fashion.

5.7 Challenge: Faculty Support

Being an advisor for an interdisciplinary project can be more work than a traditional capstone project if serving the role as the overall project mentor. However, the distinction between a traditional capstone and an interdisciplinary capstone is rarely made due to the participation of an advisor from each department. This presents a challenge when trying to recruit faculty to serve as advisors.

5.8 Recommendation: Faculty Support

Our team has conducted an informal poll on how faculty are *compensated* at other universities for serving as advisors on large capstone projects. It was found that most faculty serve as advisors as part of the "service" portion of their contracts. While this borders on volunteerism due to the typically small fractions that service contributes to a faculty contract (~5-10%), serving as a faculty advisor can be considered part of their contract assignment.

Another technique that has been seen is that serving as an advisor counts toward a faculty's teaching load. For example, advising a n number of capstone projects each year is equivalent to teaching one class.

Defining capstone projects that are part of existing research contracts are a common way to fund design projects. This approach allows students to design something that is a deliverable of a research project. The funded research project typically is already funding the faculty in some manner (i.e., summer salary) so there is mutual benefit to both the students and advisor.

6. Summary

This paper presented a case study on an interdisciplinary capstone project that designed an excavation robot that participated in the 2010 NASA Lunabotics Mining Competition. An overview of the competition rules, design process, and competition activity were presented. Lessons learned were given that the faculty participating on this project gained through this experience.

7. Acknowledgements

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Bibliography

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