The Montana MULE:
A Case Study In Interdisciplinary Capstone Design

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Overview

- In May of 2010, NASA conducted the first annual *Lunabotics Mining Competition* at the Kennedy Space Center.

- This event was put on by the NASA ESMD Higher Education Project with the intent to

"retain students in Science, Technology, Engineering and Math (STEM)"

- This report details the design process of the Montana MULE (Modular Unmanned Lunar Excavator) and the NASA Lunabotics competition. Further, it highlights the pedagogical impact of this project on the capstone curriculum in the MSU college of engineering.

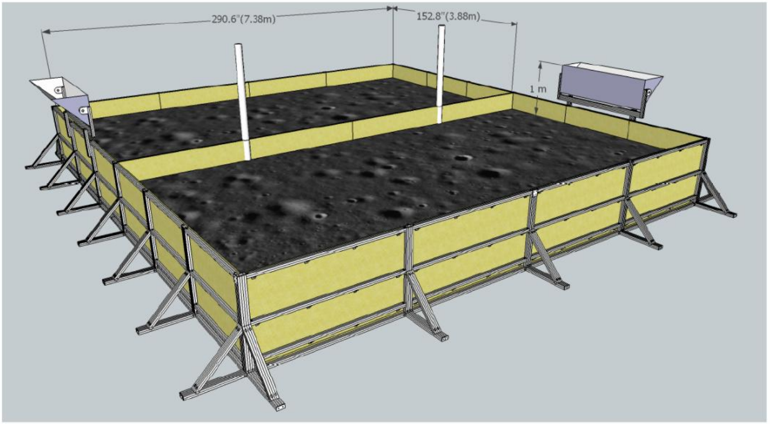
- The Montana MULE took **First Place** in the mining competition delivering 21.6kg of regolith simulant

  and

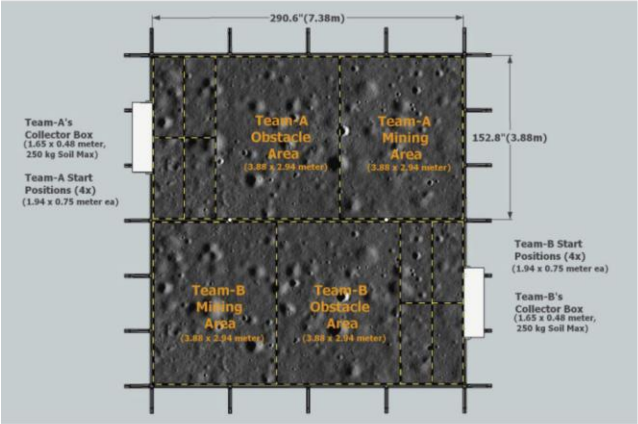
  won the ***Joe Kosmo Award for Excellence*** given to the team with the most overall competition points.

Competition Overview

- Students were to design a wireless-controlled robot to excavate lunar regolith simulant.
- The robot had 15 minutes to collect the regolith and deposit as much as possible into a collector.
- A minimum of 10kg of regolith needed to be deposited into the collector to qualify. The team with the most regolith deposited above 10kg wins.
- Limits were put on the size, mass, and technology.



Sandbox Diagram (side view)



Sandbox Diagram (top view)

Competition Overview

- What it really looked like…

The sandbox was housed in a ventilated tent.

(Chris Ching)

Tyvex suits and ventilation masks had to be worn inside the tent to prevent contact with the regolith

The robot was controlled form an isolated room with a camera feed

(Paul Dallapiazza, Steve Pemble, Ben Hogenson)


(Jack Ritter, Chris Ching, Jenny Hane)

Competition Overview

- NASA had a set of required and optional deliverables throughout the project.

  Required

  - Systems Engineering Paper (due 4/15/10)
  - Outreach Report (due 4/15/10)

  Optional

  - Slide Presentation (due 4/15/10)
  - Team Spirit Competition (at event)
  - Digital Video of Design Process (due 5/25/10)
  - Collaboration with a minority serving inst.
  - Forming a interdisciplinary team

- Each of these elements could be completed for points. These points were combined with points received from the mining competition to form an overall point total. The overall point leader received the ***Joe Kosmo Award for Excellence.***

Interdisciplinary Capstone Logistics

- MSU formed a team to participate in the competition. The design was completed as part of the students capstone.

- The Montana MULE team consisted of 8 students from 4 different departments

(Pemble, Dallapiazza, Ching, Hane, Hogenson, Harne, Ritter)

Ben Hogenson	(EE)
Jennifer Hane	(EE)
Phillip Karls	(EE)
Chris Ching	(CS)
Steve Pemble	(MET)
Craig Harne	(MET)
John Ritter	(ME)
Paul Dallapiazza	(ME)

- An Advisor from each department supervised their respective groups (ECE, CS, ME, MET)

Interdisciplinary Capstone Logistics

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- This was a 2 semester project. Coordinating the capstones between departments was a challenge.

Electrical Team

- ECE has a 1 semester capstone. 3 students designed the electrical system as their capstone.

- 2 students continued on the project during the 2nd semester. 1 student received undergraduate thesis credit for the effort. 1 student received a $750 undergraduate research fellowship from MSU for the effort.

(Karls, Hogenson, Hane)

Mechanical Team

- ME/MET has a 2 semester capstone. 2 ME and 2 MET students designed the mechanical system as their capstone.

- The ME/MET capstone matched the Lunabotics schedule the best.

(Pemble, Ritter, Dallapiazza, Harne)

Computer Team

- CS has a 1 semester, optional capstone for interdisciplinary minor students only. 1 CS student participated in this project as his capstone.

- The first semester the CS student did not receive credit. The second semester the student received 3 credits.

(Ching)

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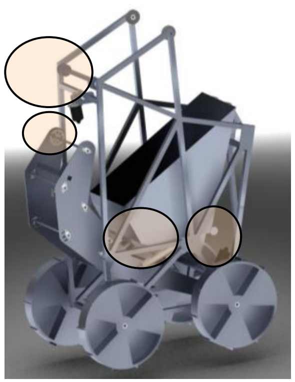
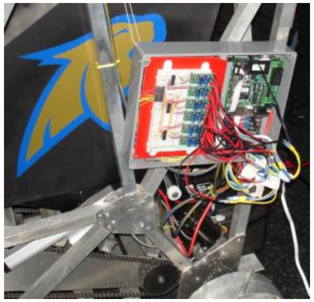
Design Process

- In September 2009, the entire team began with brainstorming conceptual designs and trading off requirements. All fabrication was completed at MSU

Electrical Team

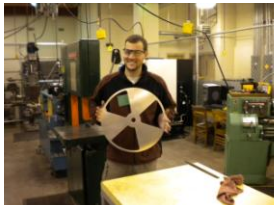
- Power Distribution, Motor Control





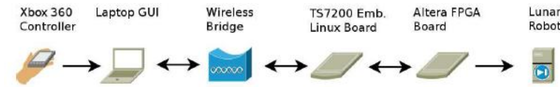
Mechanical System

- Locomotion, Digging, Dumping



Computer Team

- Wireless Networking, Control Algorithm.



Design Process

- **Testing**

  - The mechanical system was tested without the control electronics using a relay switch box. This allowed all of the mechanical systems to be verified. The testing was conducted in a volleyball course at MSU.

(Hogenson, Hane, Dallapiazza, Ritter, Pemble, Ching, Harne)

(Hogenson, Ching, Pemble, Dallapiazza, Ritter)

Outreach Events

- As part of the NASA requirements, an outreach report needed to be turned in. The team gave 5 outreach presentations and made a highlight video for use in student recruiting.

Event Ex – Presentation to 30 students from Mrs. Theide's 4th grade class from Morning Star Elementary School.

Competition Event

- In May of 2010, Dr. LaMeres and 6 students traveled to NASA's Kennedy Space Center to participate in the 1st annual Lunabotics Mining Competition.

  The students on the travel team were:

Ben Hogenson	(EE)
Jennifer Hane	(EE)
Chris Ching	(CS)
Steve Pemble	(MET)
John Ritter	(ME)
Paul Dallapiazza	(ME)

  Craig Harne and Phillip Karls could not attend due to already working in industry.

- The competition was held at the Astronaut Hall of Fame.

- **Local Support :** Prior to leaving for the competition, the University and local news picked up the story about a student team going to NASA for a robot competition.

BOZEMAN DAILY CHRONICLE

THE BIG SKY

THURSDAY, MAY 27, 2010 — SECTION C — CITY DESK: 587-4491 OR E-MAIL: CITYDESK@DAILYCHRONICLE.COM

MSU student robot to dig 'moon dirt' in NASA contest

An MSU engineering student will remotely steer the 120-pound robot through a giant sandbox so it avoids craters and rocks then removes as much simulated moon dirt as possible in 15 minutes.

By EVELYN BOSWELL
MSU News Service

A Montana State University robot that sometimes had a spooky mind of its own is at the Kennedy Space Center to see if it can dig more moon dirt than any other student-built robot.

In a May 27-28 competition sponsored by NASA, an MSU engineering student will remotely steer the 120-pound robot through a giant sandbox so it avoids craters and rocks then removes as much simulated moon dirt as possible in 15 minutes.

The simulated dirt — officially called "regolith" — is different from the sand on a Florida beach or the outdoor volleyball court where the MSU students tested their robot in a May snowstorm. Since erosion doesn't occur on the moon like it does on Earth, the top layer will be like powdery glass that's extremely loose and super fine. The soil beneath will be small, sharp, jagged particles that can clump together. It's almost as hard as concrete.

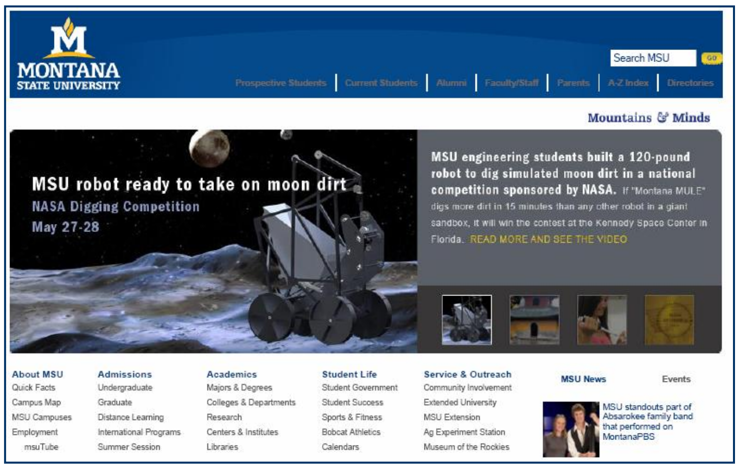
If MSU wins NASA's first Lunar Regolith Excavator Student Competition, it will receive $5,000 and the opportunity to return to the Kennedy Space Center to watch a launch. If MSU's robot, "Montana MULE," doesn't dig the most dirt and the MSU team doesn't dazzle with its spirit, robot design, video and project presentations — other contest categories — the students said they will still have gained valuable experience from the project that spanned two semesters.

Representing three departments and five majors in the College of Engineering, the team of eight students said the project taught them how to communicate their ideas across specialties — a skill they'll need when they become practicing engineers. They also worked together to design and build a robot that MSU faculty said is much more complex than senior capstone projects in past generations.

(More **Robot**, Page C2)

John Ritter observes "Montana MULE" to see what needs to be done before the robot competes in a national contest at the Kennedy Space Center. Six MSU students and a faculty adviser will be in Florida for the NASA competition.

MSU PHOTO BY KELLY GORHAM



MONTANA STATE UNIVERSITY

MSU News Service

MSU robot to dig "moon dirt" in national contest at Kennedy Space Center

May 21, 2010 -- By Evelyn Boswell, MSU News Service

BOZEMAN -- A Montana State University robot that sometimes had a spooky mind of its own is at the Kennedy Space Center to see if it can dig more moon dirt than any other student-built robot. (See the video.)

In a May 27-28 competition sponsored by NASA, an MSU engineering student will remotely steer the 120-pound robot through a giant sandbox so it avoids craters and rocks, then removes as much simulated moon dirt as possible in 15 minutes.

The simulated dirt -- officially called "regolith" -- is different from the sand on a Florida beach or the outdoor volleyball court where the MSU students tested their robot in a May snowstorm. Since erosion doesn't occur on the moon like it does on Earth, the top layer will be like powdery glass that's extremely loose and super fine. The soil beneath will be small, sharp, jagged particles that can clump together. They're almost as hard as concrete.

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The eight team members are Christopher Ching of Belgrade, Ben Hogenson and Phillip Karls from Billings, Steve Pemble of Colstrip, Craig Harne of Cutbank, Paul Dallapiazza from Florence, Jennifer Hane of Fort Shaw and John Ritter of Idaho Falls, Idaho. Their faculty advisers are Brock LaMeres in the Department of Electrical and Computer Engineering, Hunter Lloyd in the Department of Computer Science and Robb Larson in the Department of Mechanical and Industrial Engineering.

John Ritter observes "Montana MULE" to see what needs to be done before the robot competes in a national contest at the Kennedy Space Center. Six MSU students and a faculty adviser will be in Florida for the NASA competition. (MSU photo by Jackson Harris). Click here to see a video of Montana Mule in action and its history.

Representing three departments and five majors in the College of Engineering, the students said the project taught them how to communicate their ideas across specialties -- a skill they'll need when they become practicing engineers. They also worked together to design and build a robot that MSU faculty said is much more complex than senior capstone projects in past generations.

The robot that stands about five feet tall is mostly recycled aluminum, rolls on four wheels and incorporates several systems instead of just one. The students run it by using wireless technology and the controls for an X Box 360 computer game. The wireless technology talks to the robot's electronics system. The electronics system turns a motor on and off. The motor turns a chain that moves small buckets below the level of the wheels. The buckets -- moving as though they were the seats on a Ferris wheel -- dig the soil, take it along for the ride and dump it into the robot's hopper.

NASA said the purpose of the regolith competition is to retain students in science, technology, engineering and math. The contest may also result in innovative ideas and solutions that could be applied to actual NASA excavations.

NASA gave students some general guidelines for their robot. Besides weight, height, power and communication constraints,

MSU team digs into 'moon dirt' in contest

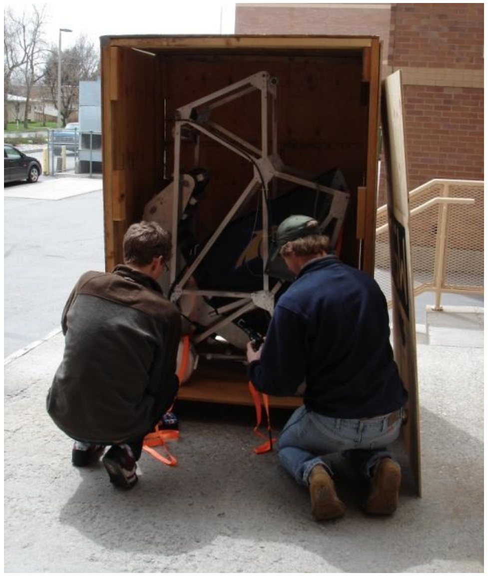
By EVELYN BOSWELL
MSU News Service

Competition Event

- **Shipping**

  - 22 teams from across the nation participated in the mining competition.

  - MSU traveled the furthest distance. The robot was shipped to the Kennedy Space Center the week prior to the event.



(Ben Hogenson and Steve Pemble fasten down the MULE in a custom crate)

(Jenny Hane, Steve Pemble, and Ben Hogenson stand by the sealed crate)

(The MULE and its crate weight for the shipping truck to arrive on the MSU loading dock)

- **Practice Day**

  - Each team was given a trial run in the sandbox prior to the official competition days.

  - Very few robots moved. The MULE was one of them.

(Jenny Hane and Ben Hogenson try to get the motor controller electronics turned on)

(Steve Pemble, Ben Hogenson, and Paul Dallapiazza lift the MULE into the sandbox for its practice run)

(Chris Ching comes into the sandbox from the control room trying to figure out why it didn't move)

Competition Event

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- **<u>Competition Day #1</u>**

  - The MULE was called late in the afternoon for its competition run. No team had dumped any regolith and very few robots even moved.

  - The MULE moved, the buckets spun, and the hopper could dump

  BUT…..

  a broken wire prevented the digging head from actuating and getting the buckets into the regolith.

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Competition Event

- **Competition Day #2**

  - All wires were checked and the MULE made its 2nd competition attempt.

  - Still, no other team had put any regolith in the collector….

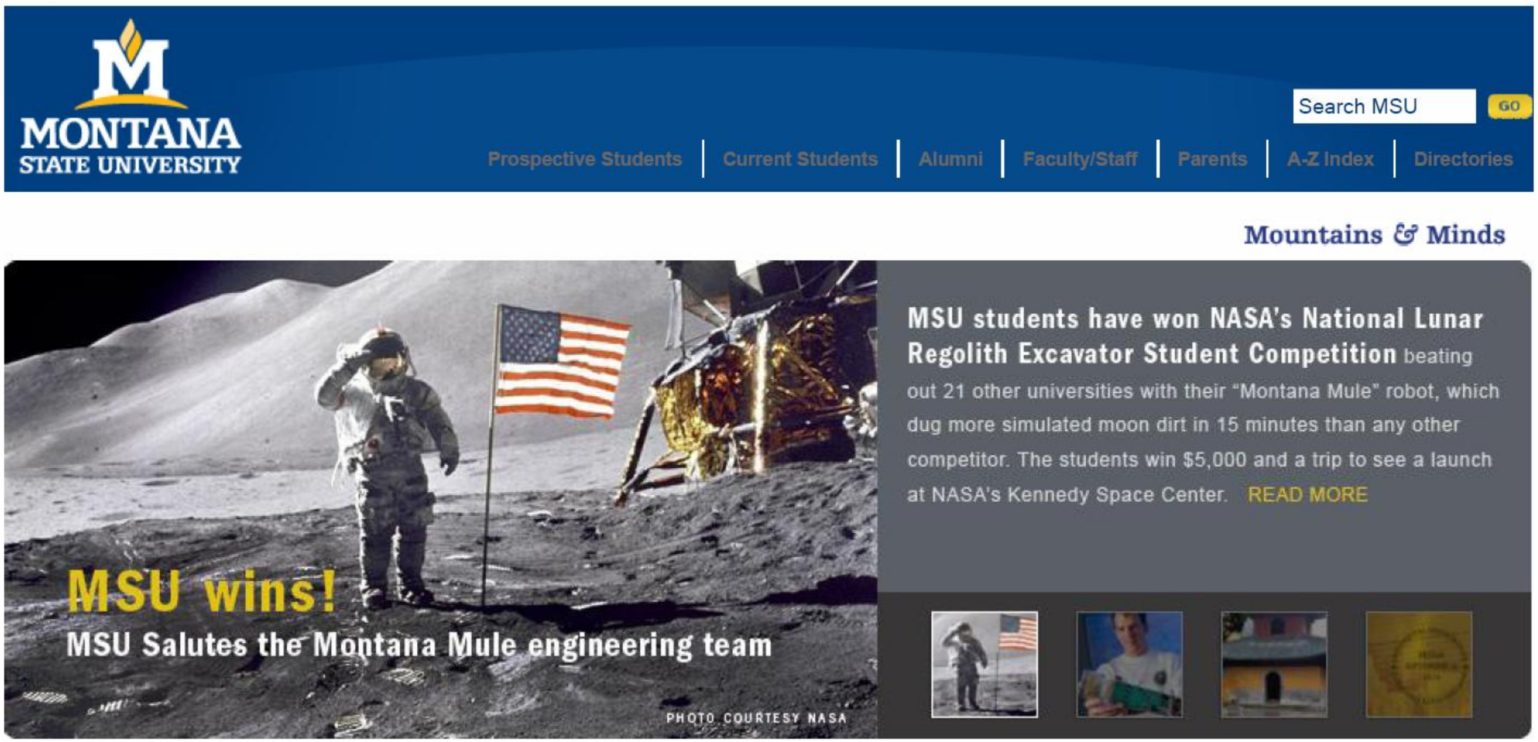
- It was loaded……………………….It moved………………………………….It dug…………

- **Competition Day #2**

- It dumped……………………………………………**21.6kg !!!!!!!!**

Competition Event

- In the end, no other team was able to dump the required 10kg of regolith.



MSU News Service Article
May 29, 2010

Competition Event

BOZEMAN DAILY CHRONICLE

THE BIG SKY

Saturday, May 29, 2010

SECTION C

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MSU robot moon-digger wins NASA competition

By MICHAEL BECKER
Chronicle Staff Writer

The 120-pound, 5-foot-tall robot was designed last fall by eight students from three MSU engineering departments. It was built and tested on campus over the past year.

A robot moon-digger designed by Montana State University engineering students bested 21 other robots in a competition at Kennedy Space Center on Friday, earning the student team $5,000 and an invitation to a NASA rocket launch.

The Lunar Regolith Excavator Student Competition was held at the Astronaut Hall of Fame in Florida on Thursday and Friday and featured teams from universities around the country.

The goal: to see which student-designed and built, remote-controlled robot could pick up the most simulated moon dust.

The MSU robot, dubbed Montana MULE, picked up about 22 kilograms of dust — roughly 45 pounds. The MSU robot was the only one at the competition to meet NASA's 10-kilogram minimum, said the team's faculty adviser, MSU professor Brock LaMeres.

"They're freaking out. It's incredible," he said. "We went third, so we'd been sitting here for I don't know how long, six hours, waiting while other teams went."

The 120-pound, 5-foot-tall robot was designed last fall by eight students from three MSU engineering departments. It was built and tested on campus over the past year.

The students will split the $5,000 prize and will get V.I.P. seating at a future NASA launch, LaMeres said.

The competition was intended as part of an effort to keep university students around the country enrolled in science, engineering and mathematics courses, according to its website. NASA also hopes that the students will come up with innovative ideas that could be used on future moon missions.

Michael Becker can be reached at 582-2657 or becker@dailychronicle.com.

MONTANA STATE UNIVERSITY

MSU News Service

MSU robot digs most "moon dirt," wins NASA contest at Kennedy Space Center

May 28, 2010 -- By Evelyn Boswell, MSU News Service

BOZEMAN -- A Montana State University student-built robot won a national contest at the Kennedy Space Center Friday by digging the most simulated moon dirt in 15 minutes.

Defeating robots from 21 other colleges and universities, Montana MULE removed 21.6 kilograms of regolith from a giant sandbox. That was far above the 10 kilograms required to qualify in the contest and far ahead of the nearest competitor in NASA's first Lunar Regolith Excavator Student Competition.

A robot from Auburn University dug 6.6 kilograms. The University of Southern Indiana's robot dug 2.4 kilograms. Montana MULE was the only robot that met and surpassed the minimum requirement, beating out other, larger universities such as Virginia Tech, Iowa State University and the University of North Carolina-Charlotte.

Some of the MSU team members who designed and built Montana MULE test their robot at MSU before heading to the Kennedy Space Center. From left are Chris Ching, Steve Pemble, Paul Dallapiazza and John Ritter. (MSU photo by Jackson Harris).

The victory gives the MSU students $5,000, the chance to return to the Kennedy Space Center for a launch, and plenty of thrills. Additionally, the team won the Joe Kosmo Award for their combined work in engineering, outreach and presentation.

"I'm supposing my parents won't have much problem with how many video games I played as a kid," Chris Ching said by telephone from Florida.

Ching from Belgrade, an MSU senior in computer science, remotely steered Montana MULE to victory by using the controls of an X Box 360 computer game and wireless technology. Ching sat inside a building that was isolated from the arena, so he controlled Montana MULE by watching the robot on a screen. Helping him watch were teammates Jennifer Hane of Fort Shaw and John Ritter of Idaho Falls, Idaho. Ching said the screen refreshed at a low rate, which meant there were lags between what he was doing and seeing.

"It was pretty nerve-wracking," Ching said.

Loud cheers and applause interrupted a NASA talk show Friday morning when the 120-pound MSU robot became the first robot in the contest to dig more than 10 kilograms of simulated moon dirt. The competition began Thursday, but no robots were able to dig 10 kilograms the first day. A few teams were disqualified. As a result, NASA gave the remaining teams three hours to fine-tune their robots, then started the competition over on Friday.

Brock LaMeres, faculty adviser for the MSU team, said a loose wire was the reason Montana MULE wasn't digging on Thursday. Ching could move the robot across the dirt and into the mining area, but he couldn't lower the bucket into the dirt. The students fixed the wire, taped down all their wires and recharged the battery that night. LaMeres said he believes the robot finally did so well because the students incorporated the right combination of systems into their robot. They probably had three or four alternatives to choose from for each system, but they apparently chose the best combination, he said.

Montana MULE had wheels, for example, instead of moving like a Caterpillar as some other robots did. It also had a bucket-digging system and a hopper. The robot itself contained a computer system.

Ching and LaMeres said MSU also benefitted from some extra practice time. Since MSU still had a few minutes left in its 15-minute allotment on Thursday, Ching used the time to practice running the robot through the course and give the audience a show. He got Montana MULE to do a doughnut. He got it to dodge rocks and craters. He turned it so people could see the MSU Bobcat on its side.

MSU students win NASA moon dirt-digging contest

What did this Cost?

- **What did this experience cost?**

Materials & Supplies	**$4,200**
- Mechanical System ($1,650)	
- Electrical System ($2,050)	
- Computer System (used existing HW)	
- Printing & Media ($500)	
Travel	**$8,900**
- Airfare ($4,200)	
- Motel ($2,050)	
- Rental Car ($600)	
- Per Diems & Miscellaneous ($2,050)	
Shipping	**$2,100**
Faculty Support	**$11,300**
- salary + fringe benefits	
Total	**$26,500**

Lessons Learned (#1)

- **Challenges with Different Capstone Deliverables**

  - Everyone agrees an interdisciplinary design experience is greatly beneficial to students.

  - But rarely do departments have common capstone structures

  - Competition projects often have an additional set of deliverables

- **Recommendations?**

  - Can departments agree on a common set of deliverables for interdisciplinary projects?

  - Can departments come up with an interdisciplinary capstone track?

  - Can the academic deliverables be matched to the competitions deliverables for these types of projects?

Lessons Learned (#2)

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- **Challenges with Schedule Coordination**

  - There is an inherent schedule conflict with students from different departments trying to coordinate times to meet.

  - Interdepartmental schedules have evolved to avoid time conflicts as much as possible, but this becomes impractical when considering multiple departments.

- **Recommendations?**

  - After hour meetings?

  - Student-only meetings?

  - There is great value in a full team meeting with respect to accountability. Can faculty attend afterhours meetings?

Lessons Learned (#3)

- **Faculty Support**

  - Interdisciplinary projects take more effort from the faculty.

  - There is greater coordination and one or two faculty often need to take the role of "prime advisor"

  - Competitions put an even greater strain on the faculty and can approach a time commitment similar to a full research project.

  - Faculty advisors for capstones are often volunteers (or volun-told) and receive no "credit" for their effort.

  - Burning out faculty leads to a sustainability of larger, high impact projects.

- **Recommendations?**

  - Can faculty receive "credit" for their effort in the form of summer support or additional compensation?

  - Can faculty receive "credit" for their effort in the form of teaching assignment credit?

Lessons Learned (#4)

- **Fund Raising**

  - Interdisciplinary projects tend to cost more than traditional mono-department projects.

  - Competition projects can cost considerably more when travel is considered ($20k+)

  - Should faculty spend time fund raising?

- **Recommendations?**

  - Can institutional support be committed to long term?

  - Can foundations be used to form interdisciplinary capstone endowments?

Lessons Learned (#5)

- **Sustainability**

  - Large, Interdisciplinary projects (particularly competition designs) tend to start off strong. Perhaps due to the “new car smell”?

  - These projects can dwindle in subsequent years due to faculty burn-out and lack of continuing funds.

- **Recommendations?**

  - Without some type of institutional support, it is unlikely to sustain these types of projects.

  - Can university funds be targeted at strategic projects that are high impact?

  - Each successfully, large interdisciplinary project (particularly competition designs) tend to have a primary advisor that drives the success. These prime advisors need to be compensated in some manner in order to keep them engaged.

Conclusion

- Each student on the Montana MULE team said more than once that this was the single most valuable experience they had during their time at MSU.
- Being able to apply what they've learned in the class room to a real design project is what capstones are meant for. An interdisciplinary design project forces the students to communicate across departmental boundaries.
- The NASA event allows the students to feel the pressure of competition.
- It also allows the students to see students at other universities did and gain confidence that their education has prepared them for successfully careers.

Go Cats!!!

Go MULE!!!