AC 2008-2248: VERTICAL INTEGRATION PROJECT WITH FRESHMAN AND JUNIOR ENGINEERING STUDENTS

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Vertical integration project with freshman and junior engineering students

Freshman and junior engineering students participated in a final design project that was vertically integrated project during the Fall 2007 semester. Vertically integrated projects use teams that include students in the same discipline but different class years, e.g., freshman and junior engineering students. The projects were also horizontally integrated (students from different disciplines) since both Mechanical Engineering (ME) and Product Design and Manufacturing Engineering (PDM) students are required to take the junior class EGR 345 (Dynamic System Modeling and Control). The freshman students in EGR 101 (Introduction to Computer Design and Manufacturing) are also horizontally integrated because they have not formally selected their emphasis.

The project involved the design and build of robots to transfer ore (golf balls) from the mine to a container (bucket). The project was intended to emphasize project management and team skills to produce a complex engineering system from concept to completion. For each round, a combined team of freshman and juniors placed their robots on opposite sides of the playing field. Each team consisted of one junior team and eight to nine freshman teams but a maximum of six freshman teams could compete in a match. The freshman robots' goal was to feed golf balls to their junior team's robot in a designated transfer zone. The juniors' robot must then transport the balls to the bucket. The freshman robots could be controlled remotely using electrical connections, but the junior robot could not be controlled with any physical means.

A variety of scholars have investigated the use of vertical mentoring techniques. At Rose-Hulman senior level students were used as mentors who guided junior level students through a process of guided questioning [1]. This provided guidance for the juniors, and management experience for the seniors. A similar approach was used by Rowley when senior students were assigned as leaders of freshman teams [2]. Vertical project mentoring also occurs on an ad-hoc basis for extracurricular student project teams. For example the SAE Baja project team often includes students from multiple levels of the program.

Competitions [3] and integrated projects [4] have been assigned before and competitions like this have been held with freshman and junior students many times in the school using a tournament bracket. But each team is usually made up with either all freshman or all juniors. The novel aspect of this competition was that the junior teams had to develop partnerships and mentor their freshman teammates in order to be successful. For example, an outstanding junior team would not be successful if their freshman teams were unable to provide enough golf balls for the junior robot. Consequently, the juniors evaluated their freshman teams to decide which teams would compete. In some cases, less than six freshman teams were used to avoid getting in each others' way. These relationships had seven weeks to develop and resulted in freshman robots that were significantly better than in previous competitions. The experience also helped the freshman see the challenges that lay ahead of them when they reach their junior year.

Experiences of Freshman Students

EGR 101 includes a lecture and a lab. All the work for the competition is done in the lab during the last seven weeks of the semester, but the lecture provides the foundation with topics on Engineering Graphics, gears, springs, pneumatic cylinders, electric motors, and calculations for machining parameters, e.g., spindle speeds, feed rates, and power requirements. The design process shown in Figure 1 was used for the final project and two smaller projects that were assigned earlier in the semester. The project was introduced to the students via a letter from Dr. Sirkus who is a fictional character who communicates with the students via Blackboard®. Dr. Sirkus is actually one or more instructors who respond to questions via the discussion board in Blackboard® about the rules and made decisions about materials and techniques that may or may not be used. This approach avoids the problem of having one instructor approve a student's request when another instructor denies the same request, e.g., whether or not pneumatic cylinders may be used.

The final project began with the students being assigned to teams with two to three students. The teams were assigned based on the students' previous work in the lab, and the best students (based on current lab grades) were put on the first team, the next best students on the next team, etc., until all the teams were assigned. This approach avoids the problem of strong students carrying most of the load while the weaker students coast.

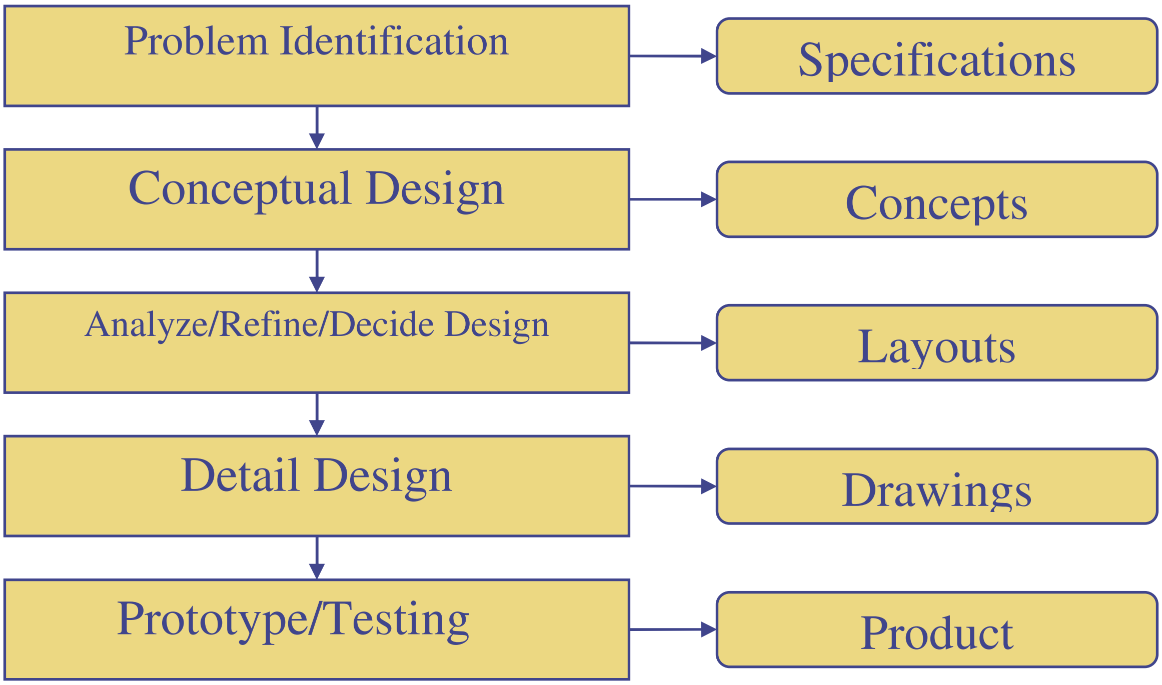

Figure 1. Schematic of the design process.

During the first week of the project, each team was required to submit a list of design constraints based on the rules of the competition, evidence of benchmarking of at least 3 different systems, including a morphological matrix with three concepts for each function (see matrix in Table 1). Isometric hand sketches of three robots using a concept from each function were also required, where a given concept could be used a maximum of two times. Each team wrote a business letter to Dr. Sirkus summarizing their interest in the competition and progress so far.

Table 1. Morphological matrix.

	Functions		
Concepts	**Move Robot**	**Transfer Ore**	**Release Mechanism**
1.	Four wheels with dual gearbox	Rotating arm	Motor-driven lever
2.	Three wheels with dual gearbox	Rolling on rails	Trip wire
3.	Tank treads	Pneumatic cylinder	Contact with junior robot

Design Matrix Example

Design Criteria	Weighting Factor			
Light Weight	0.25	6 / 1.50	7 / 1.75	2 / 4.50
Ease of Manufacture	0.40	8 / 3.20	5 / 2.00	2 / 0.80
Low Cost	0.35	8 / 2.80	6 / 2.10	3 / 1.05
Totals	**1.00**	**7.50**	**5.85**	**6.35**

Multiply weighting factors by rank

Figure 2. Decision matrix

Students made models of three of concepts using foam core, box cutters, and glue guns during the second week. Digital pictures, descriptions of each model, and a decision matrix for choosing the best concept were submitted along with solid models of each part of their design. A Decision matrix like the one shown in Figure 2 was used to select the best design. Process plans were required for the third week along with a Pro/E assembly file, G-codes to produce all parts with comments that identify which codes or lines were used to manufacture each feature of the part. A process plan was required for every part unless the part was purchased and no additional operations were necessary. For example, a process plan was required if a 6 *ft* piece of PVC pipe was purchased and then cut to 1 *ft*.

The process plans included the following items, and an example is shown in Figure 3.

1. The size of the stock material required to make the part. Three dimensions are required to specify the size.
2. The type of material required.
3. The machines used to manufacture the part.
4. Any fixturing required.
5. Any finishing operations required.

Process Plan

Part Name ______________________ Part Number ____________

Stock Material and Size________________________

Op. #	Machine and file name	Work Holding Device	Part Location and Orientation(Sketch)	Tool (Size and Material)	Speeds and Feeds	Description of Operation
10						
20						
30						
40						

Figure 3. Process plan worksheet

For the fourth week, dimensioned and toleranced prints were required for all parts that were manufactured or modified. All parts (purchased and fabricated) were also due along with a Pro/E assembly file with a bill of materials (BOM) with index balloons. The assembled machines were evaluated in the fifth week and robots were tested and tweaked during the sixth week. A final report was due and presentations were given during the last week. The competition was held on the last Saturday before final exams.

Experiences of Junior Students

The catalog description for EGR 345 (Dynamic System Modeling and Control) shown below.

> An introduction to mathematical modeling of mechanical, thermal, fluid, and electrical systems. Topics include equation formulation, Laplace transform methods, transfer functions, system response and stability, Fourier methods, frequency response, feed back control, control actions, block diagram, state variable formulation, and computer simulation. Emphasis mechanical systems.

After comparing the topics in EGR 101 and 345, it is clear that the capabilities of these two sets of students are quite different. EGR 101 is a first-year freshman course whereas EGR 345 is both very mathematical and applied. However, both the freshman and junior students were charged with some similar tasks. Both courses required the fabrication of robots that were capable of moving and transferring golf balls using motors, gears, and wheels. The difference was that the freshmen used switches to control their robots and the juniors used programs for autonomous control or wireless technology to control the robots.

Table 2 shows the mass and budget for the 1st place EGR 345 robot and Table 3 shows the mass and budget for their EGR 101 teams. Note that the total cost for the EGR 345 was around $220, but the costs for the EGR 101 teams were $18 to $33.

Table 2. Mass/budget for EGR 345 Team 1 (1st Place)

Description	Qty.	Unit Price ($)	Unit Weight (lbs)	Supplier	Price ($)	Mass (kg)
Micro Servo	1	18.00	0.016875	Cobble Stone	18.00	0.00767
Standard Servo	1	10.90	0.07	Acroname	10.90	0.03182
SingleLine Detector	1	14.95	0.2	Acroname	14.95	0.09091
Sharp Detectors	3	12.18	0.04	Digikey	36.54	0.05455
Wheels	2	3.50	0.05	Acroname	7.00	0.04545
Parallax Continuous Rotation Servo	2	13.00	0.125	Acroname	26.00	0.11364
1/8” Polycarbonate	-	-	-	Total Plastics	15.00	0.22727
Aluminum Angle	-	-	-	Ace Hardware	3.75	0.22727
Aluminum Screen	-	-	-	Ace Hardware	2.95	0.00568
Aluminum Stock	-	-	-	GVSU	2.56	0.10909
ATMega32	1	35.00	0.25	EMSYDE	35.00	0.03636
Printed Circuit Board	1	30.00	0.01	Sunstone Circuits: PCB Express	30.00	0.00455
AA Batteries	4	0.50	0.055	Meijer	2.00	0.1
9V Battery	1	1.5	0.1	Meijer	1.50	0.04545
AA Battery Holder	1	1.79	0.05	Meijer	1.79	0.02273
LED's	3	1.485	Negligible	Radio Shack	4.46	0
Toggles	2	2.99	0.01	Radio Shack	5.98	0.00909
Wires, Fasteners, Misc.	-	-	-	-	-	0.0584
Total					**218.37**	**1.1899**

Table 3. Mass/budget for EGR 101 Teams (1st Place)

Team Names	Lab Section	Qty	Material	Total Cost ($)	Weight (grams)	Balls/min
Chris Simon	905	2	Wheels	$1.99	420	0
Tyler Schlientz		1	Dowel	$0.00		
		4"	PVC	$0.42		
		1	Tamiya 70168 Double Gearbox	$8.95		
		1	Tamiya 70093 3-Speed Crank-Axel Gearbox	$6.50		
		1	Base (Scrap Plastic)	$0.00		
		1	Boom (Scrap Plastic)	$0.00		
		1"	Slider	$0.10		
Total				**$17.96**		
Ryan Bozio	901	1	Double Gearbox	$8.95	700	7.5
Andrew Cieslinski		1	3-Speed Crank Axle Gearbox	$6.50		
Justin Pattermann		2	Tires and Wheels	$5.50		
		1	Base (Plastic)	$0.50		
		1	Box (Plastic)	$0.25		
		15	Nuts	$3.00		
		1	Hinge and Screws	$2.11		
		1	Steel L-Bracket and Separator	$0.25		
		1	Aluminum Support Rod	$1.18		
Total				**$28.24**		
Dan Sowa	905	1	Scrap Plastic	$0.00	465	9.5
Matt Dixon		1	Tamiya 70168 Double Gearbox	$5.95		
Bretton Wainright		1	Tamiya 70093 3-Speed Gearbox	$4.50		
		2	Tamiya 70145 Tire Set	$7.25		
		2	Ball Caster	$5.00		
		1	Ladder-Chain & Sprocket Set	$7.00		
		1	2 Part Epoxy	$0.00		
		1	Wire & Connectors	$0.00		
Total				**$29.70**		

Table 3. Mass/budget for EGR 101 Teams (1st Place) - continued

Phil Dial	901	1	Tire Set	$6.50	560	7.5
Scott Sarver		1	Gear Box	$8.95		
Jacob Morris		1	2pk DPDT Switch	$1.49		
		1	1.5-3V DC Motor	$2.99		
		15"	0.25-20 Threaded Rod	$1.36		
		2	6-32 StoveBolt	$1.98		
		4	6-32 Nuts	$0.76		
		4	.25-20 Nuts	$0.80		
		8	.25-20 Washers	$1.20		
		1	Door Hinge	$1.99		
		36"	Fishing Line	$0.00		
Total				$28.02		
Derek Bross	901	2	Tires and Wheels	$6.00	315	7
Kevin Vermeer		1	Double Gearbox	$8.95		
		1	18" Aluminum Arrow	$1.50		
		1	Pipe Extension	$2.14		
		6	Screws	$0.98		
		6	Nuts	$0.98		
Total				$20.55		
Josh Bowen	901	2	Tamiya #70111 sports tire set	$5.85	880	7.5
Karl Kaluzny		1	Double Gear Box #70168	$8.95		
Jordan Smith		1	3-speed crank-axle gearbox #70093	$6.50		
		1	Dowel	$0.25		
		6	¼′ Hex Nuts	$0.56		
		2	¼′ Carriage Bolts	$0.18		
Total				$22.29		
Brian Coté	901	1	Screws	$2.19	715	7.5
Tyler Devoogd		1	Bracket	$0.15		
Ryan Mattox		1	Pulley	$0.90		
		1	Twin Motor Gear Box	$11.25		
		1	Single Gear Box	$8.50		
		1	Tire Set	$7.25		
		1	2" PVC Cup	$0.40		
		36"	Fishing Line	$0.10		
		1	Plastic	$2.00		
		12"	Wire	$0.25		
Total				$32.99		
Total				$179.75	4055	
Average						6

Figures 4, 5, and 6 show the architecture and state diagrams and the wiring schematic, respectively for the 1st place EGR 345 robot. A picture of this robot on a scale is shown in Figure 7. As described in the rules of the competition in Appendix A, teams received one bonus points for each 100 *g* under 4 *kg* and each \$10 under \$300 for all equipment (EGR 345 and 101 teams) combined. Figures 7 – 11 show five of the six EGR 345 robots and Figure 12 shows the competition field.

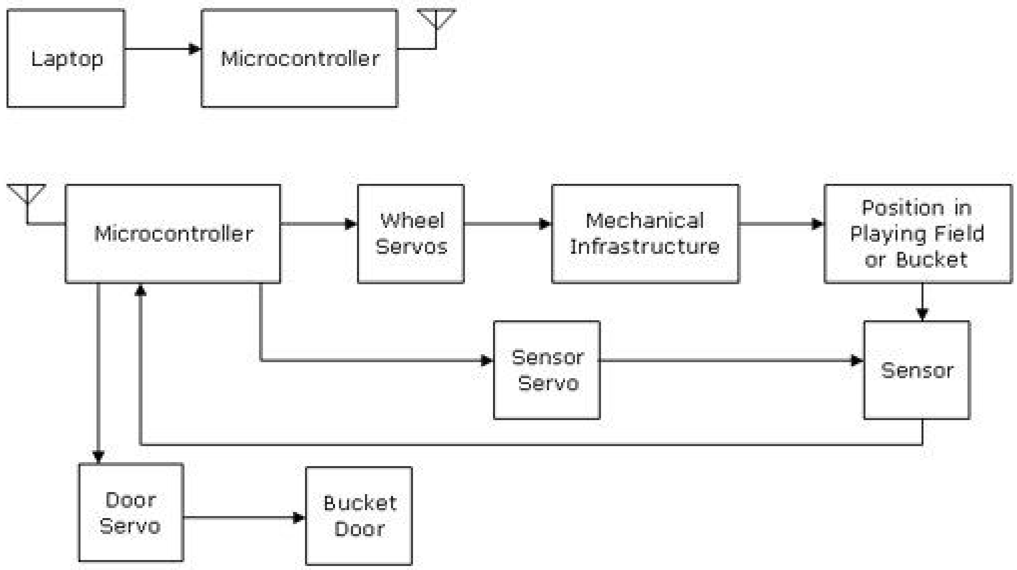

Figure 4. Architecture diagram

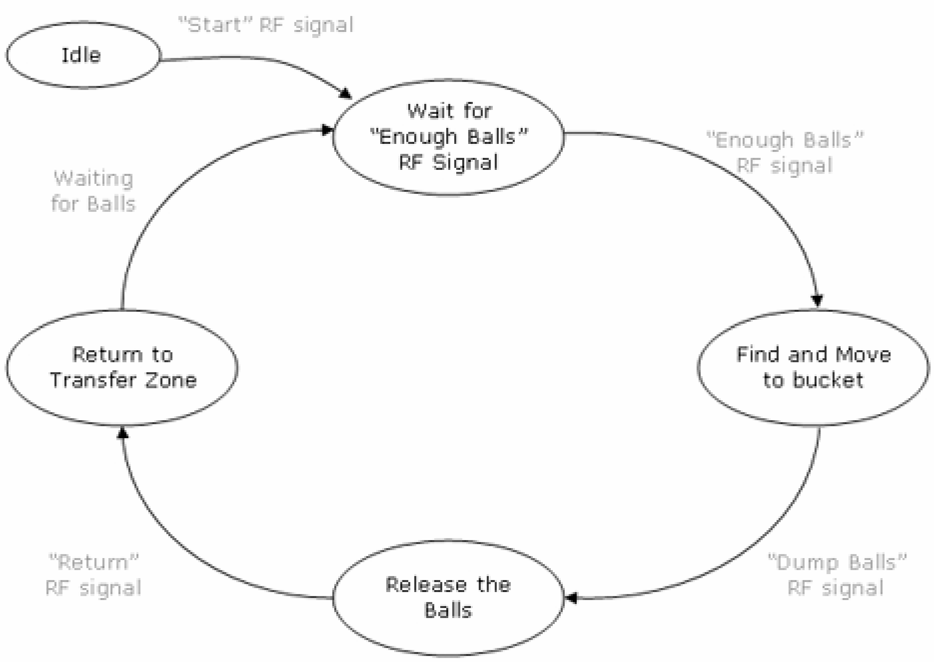

Figure 5. State diagram

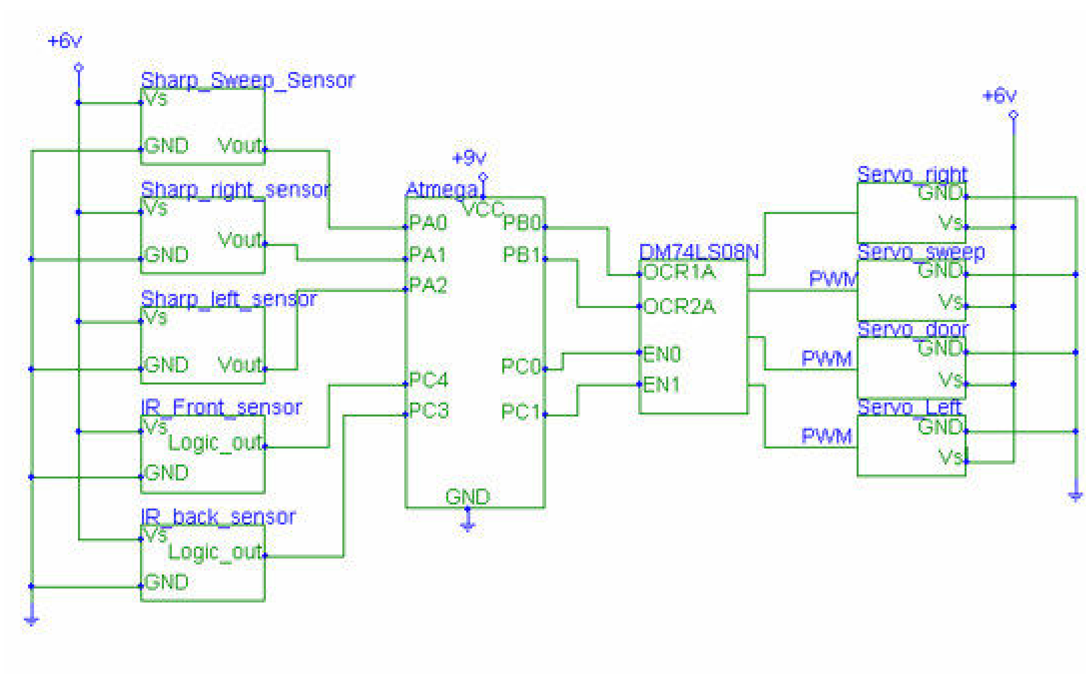

Figure 6. Wiring schematic

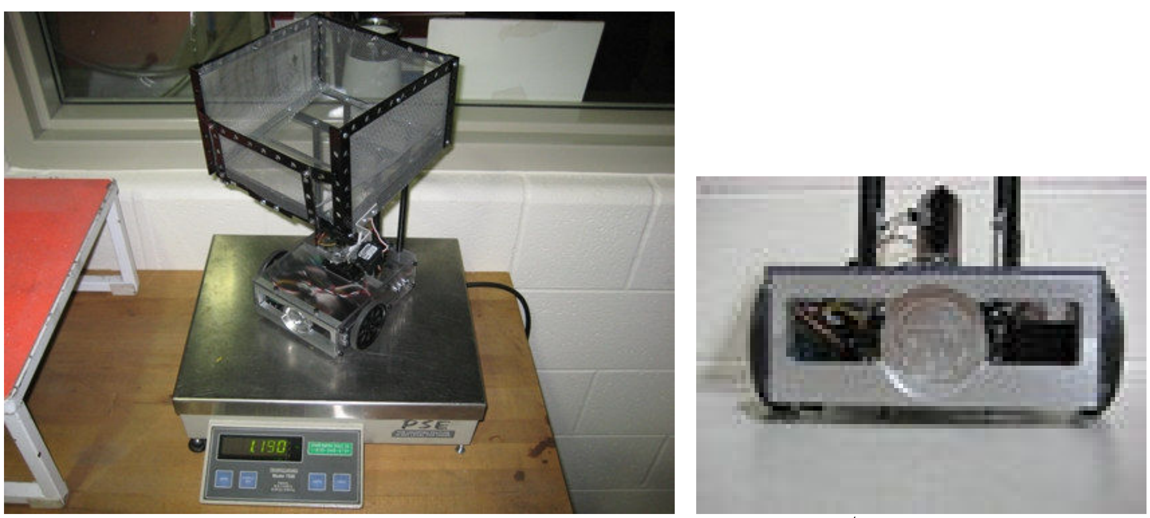

Figure 7. EGR 345 robot on scale and wireless controller – Team #1 (1st place)


Figure 8. EGR 345 robot with EGR 101 robots – Team #2 (2nd Place)

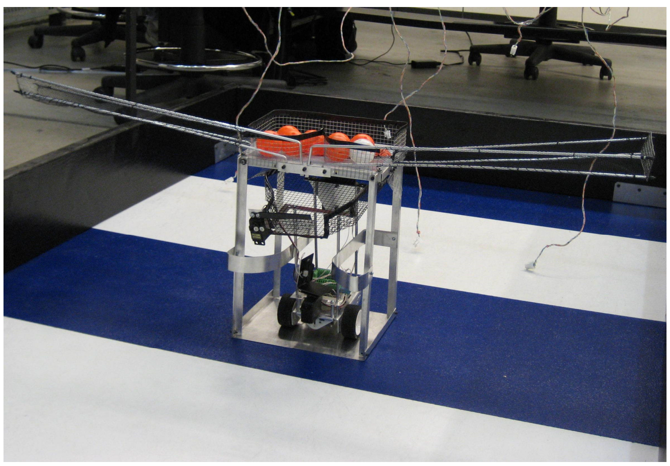
Figure 9. EGR 345 robot – Team #3

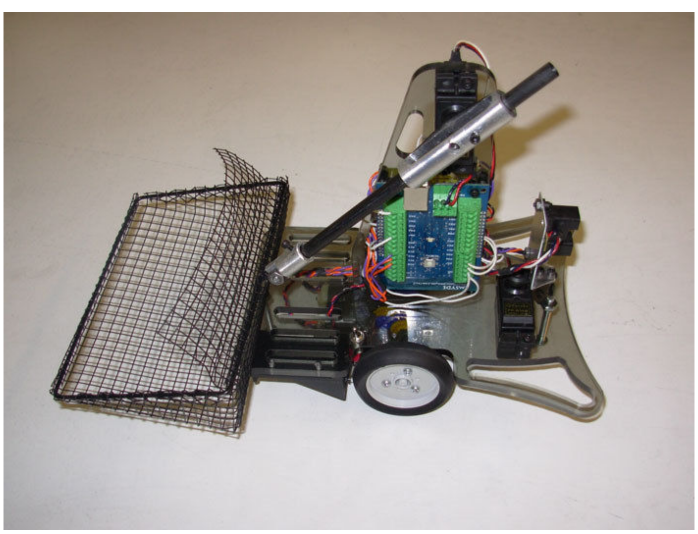
Figure 10. EGR 345 robot - Team #4

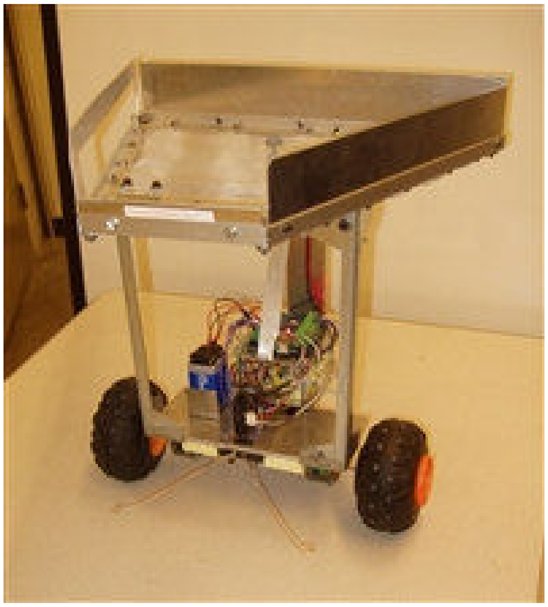

Figure 11. EGR 345 robot - Team #6

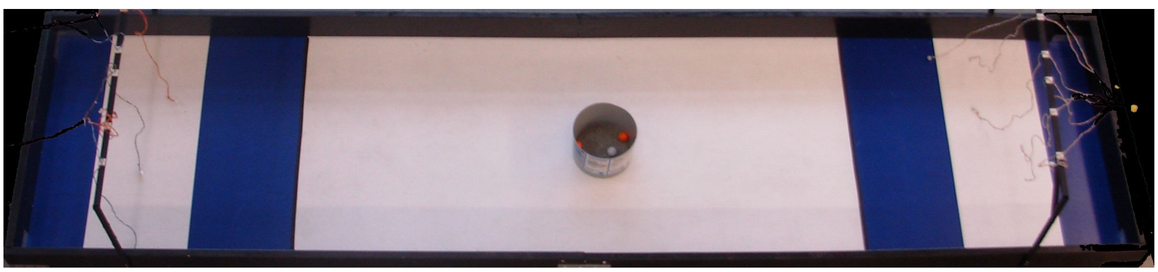

Figure 12. Competition field

Competition Results

The winning team described the results in the following way. "In the culminating event for this project, robot teams battled head to head in a single elimination tournament. The result of this was Team 1 winning overall, with a high score of 86 points, scored solely on the basis of the number of balls in the bucket." See Figure 13 below.

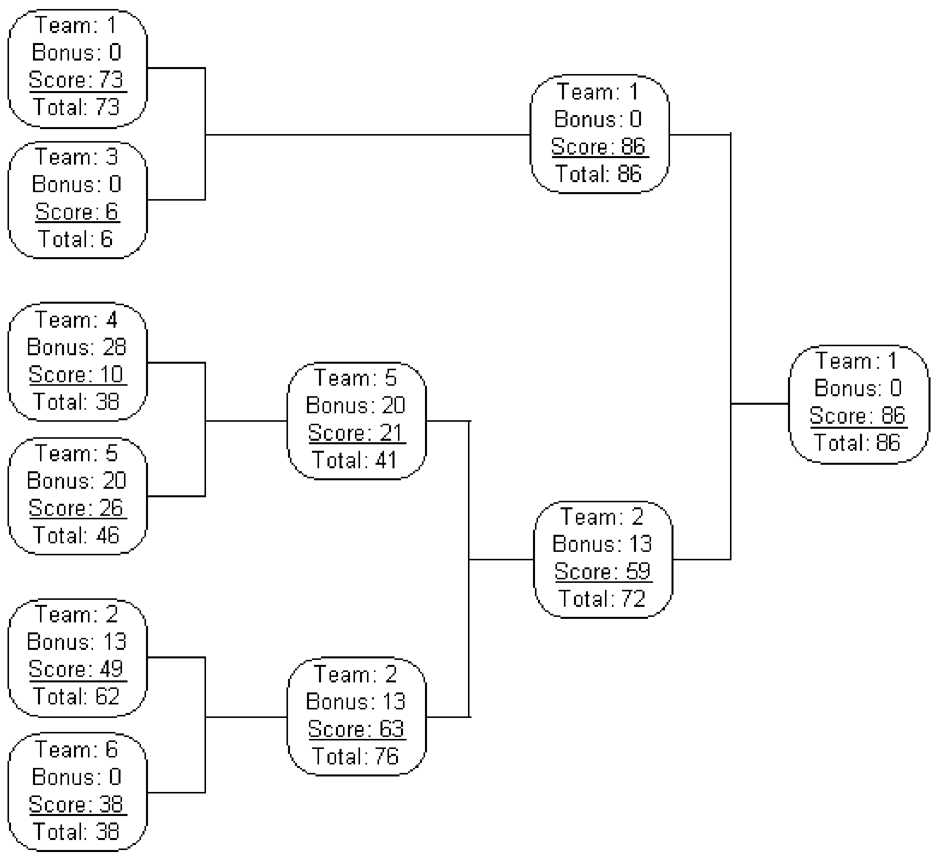

Figure 13. Tournament bracket

Discussion

Partnering freshman teams with a team of juniors worked well for the most part. There were some logistical issues, but the juniors made an effort to schedule meetings that were convenient and they also visited the freshman labs to discuss design, manufacturing, and competition strategies. The rules were rather brief and there was a lot of discussion about the proper interpretation of the rules. Dr. Sirkus responded to over 120 questions, and there would have been many repeat questions without the Blackboard® discussion board.

The designs and fabrication by the freshmen continue to improve each year, but the quality of this semester's projects were very good. It is likely that the mentoring of the freshmen by the juniors had a lot to do with the performance of the freshmen. The juniors' experience and familiarity with more complex project work helped them provide direction for the EGR 101 teams. Teams 1 and 2 were significantly better than the other four teams because they used real time, i.e., wireless control. The autonomously controlled robots took much longer to collect golf balls from their freshman teams and to deposit them in the bucket. This lead to frustration for some freshmen because their grade depended on the success of their team. These students felt that their grade should have depended on the how well they transferred the golf balls to their EGR 345 robot and not how well their junior team performed. This may be one disadvantage to the partnering approach to these competitions, but it was outweighed by the experience of working with juniors and learning to work as a team with people with better or different skills. In the future, alternative grading rubrics may be used to address this issue. It was also a good experience learning first hand that just like in sports, a business or engineering team wins as a team or loses as a team.

Survey

The end-of semester survey for the EGR 101 students is shown in Appendix B. The questions are paraphrased in the paragraph and the results are summarized in parentheses.

The survey asked questions about how much each freshmen spent of their own money on the project (most spent less than $30), was the qualification process fair 90% said yes), was the tournament fair (74% said yes), did the rules allow both freshmen and juniors to contribute 77% said yes), did you like partnering with the juniors (83% said yes), do you plan to continue in the engineering program (85% said yes), and if not why (most students leaving the program didn't like the work, workload or rigor of the course(s)? An attrition of 15% is significant, but in recent years it has been decreasing as the university attracts stronger students.

Conclusion

Freshman students worked along side juniors in a seven-week project that included benchmarking, brainstorming, concept development, prototyping, solid modeling, CNC machining, machine testing, and a final competition. Each of the six junior teams mentored eight to nine freshman teams, and the result was a significant transfer of knowledge and skills for the freshman. The juniors also had the opportunity to sharpen their leadership skills because they had to manage their freshman teams to be successful in the final project.

These activities can be considered multidisciplinary because both Mechanical and Product Design and Manufacturing Engineering students are required to take the junior course. The project also includes vertical integration with freshmen and junior students. Horizontal integration was also involved since the freshmen course included students pursuing degrees in Computer, Mechanical, Electrical and Product Design and Manufacturing Engineering.

Overall the final project was a success and resulted in some quality design and builds, although there were some winners and not so happy losers in the final competition.

References

1. G. Livesay, Rogge, R., "Vertical Mentoring: Closing the Loop in Design", *ASEE 2006 Annual Meeting*, Chicago, Il, June 2006.
2. B.A. Rowley, "BME senior design and freshman engineering", *ASEE 2005 Annual Meeting*, June 2005.
3. J. Oliva and W.K. Waldron Jr., "Virtual Design Competitions in a Computer Aided Engineering Course," *Proceedings of 2004 ASEE/NCS Conference*, Western Michigan University, Kalamazoo, Michigan (2004).
4. W. Waldron, P. Chaphalkar, S. Choudhuri, J. Farris, "Teaching Design and Manufacture of Mechanical Systems," 2007 ASEE National Conference and Exposition, Honolulu, Hawaii, June 24-27, 2007.

5. APPENDIX A – Contest Rules - Fall 2007

● EGR 101 and EGR 345 Project - Spectacular Robotic Mining (Fall 2007) - Last Revised October 9, 2007

NOTE: This version is not final and subject to major changes

●OVERVIEW

The project is intended to emphasize proper project management and team skills to produce a complex engineering system from concept to completion.

The combined teams from EGR 101 and EGR 345 will place their apparatus on opposite sides of the playing field. Each team will consist of up to 6 EGR 101 teams who will feed ore (practice golf balls) to an EGR 345 robot in a designated transfer zone. The EGR 345 robot will then transport the ore to a central depository (a bucket). The EGR 101 robots can be controlled remotely using electrical connections (i.e., wires, switches, etc.). The EGR 345 robot must be self contained, and cannot be controlled with any physical means. The teams will compete head to head over a 5 minute period to deposite the most ore in the bucket.

The competition for EGR 101 and EGR 345 students will be held Saturday December 1st, 2007.

●RULES

1. The geometry of the playing field is shown in Figure 1. The endzone is where EGR 101 robots must start, and where balls can be reloaded. The transfer zone is where the EGR 345 robots and other related components must start, and where balls can be transferred from EGR 101 robots. The bucket will be placed in the middle of the field approximately at the center, but it will be free to move during the competition. The walls will be approximately 7 1/2" tall. The floor will be concrete, with black electrical tape lines for the boundaries of the zones.

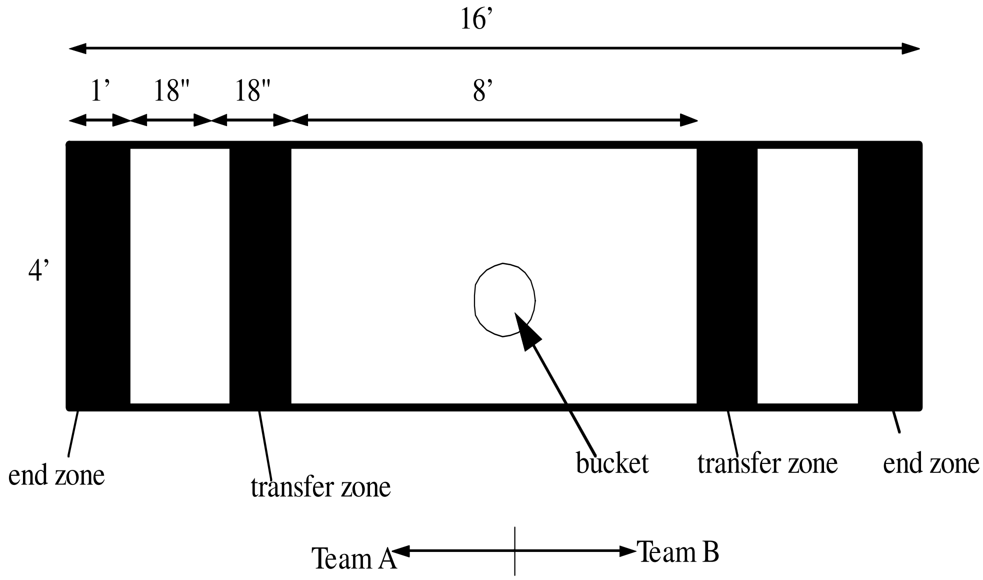

Figure 1 - Playing Field

2. At the start of the competition all of the robots must be in their resplective zones. EGR 101 robots are not permitted to travel beyond the front of the transfer zone. EGR 345 robots must not travel any further back than the back of the transfer zone. Robots may not enter the zones of the opposing teams.

3. The EGR 101 robots may not be touched when outside the endzone, including the loading of balls. A tether consisting of wires may be used to control the robots. It is recommended that motors be used to drive the robots.

4. The EGR 345 robots must be self contained. Once the competition starts the robots must not be attached by any tethers for control or power delivery. Wireless communication is permitted if using the CC2500 RF modems.

5. Teams will be awarded bonus ore for the following criteria,
+1 for each 100g under 4kg for all equipment combined
+1 for each $10 under $300 for all equipment combined
+1 for (Others to be considered)

6. Teams or individual robots will be disqualified for the following reasons.
- Causing major damage to the playing field or opponents robots.
- Entries are deemed unsafe
- Unprofessional construction including duct tape, card board, etc.
- Failure to setup during the 2 minute setup time.

7. The EGR 101 robots can carry one ball between the endzone and the transfer zone. The balls may be loaded by hand when the EGR 101 robot is complete inside the endzone. The ball can be transferred to the EGR 345 robot when it is completely inside the transfer zone.

8. Balls and other obstructions will not be removed from the field.

9. The competition will be 5 minutes long and there will be an unlimited number of balls available for each team. Teams will have 2 minutes to setup.

10. The bucket will be approximately 12" in diameter, 8" tall, and may have a slight taper. The center part of the field, between the transfer zones, may be lightly lubricated. The bucket can move anywhere between the transfer zones. If a team moves the bucket into any zones they will be disqualified. The bucket cannot be captured, or held, in any way that prevents the opposing team from depositing balls.

11. The ore (practice golf balls) are approximately 1.5 +/- 0.1 inches in diameter. The Balls that will be provided are similar to 'Top Flite 24 Practice Golf Balls' purchased from Target for $3.99. (model # 59016-White).

13. EGR 101 Components that may be purchased include those listed below. Exceptions are permitted only when approved by Dr. Sirkus on the Blackboard website.

- Tamiya brand gearboxes
- Wheels and tires
- Fasteners (nuts, bolts, threaded rod, etc.)
- Electrical components (Motors, switches, etc.)
- Pneumatic components (Cylinders, fittings, etc.)

Prohibited materials are listed below. Using these will result in immediate disqualification unless approved on Blackboard by Dr. Sirkus.

- Cardboard
- Paper
- Tape of any form (duct, electrical, masking, etc.)
- Refuse materials (bevarage containers, paper towel tubes, etc.)

14. EGR 345 teams are expected to use professional construction techniques and materials. This rule is somewhat subjective, and if there is any doubt teams are to ask for clarity.

APPENDIX B – End of semester survey - Fall 2007

Assessment Statistics: End of Project Survey

The statistics are calculated based only on the attempts being used in the grading option (Last attempt, First attempt, Lowest Score, Highest Score, or Average of Scores). If Average of Scores is the grading option, then all attempts are included in the statistics.

Name	End of Project Survey
Attempts	84 (Total of 91 attempts for this assessment)
Instructions	Please answer the questions below honestly and completely.

Question 1 Multiple Choice

How much money do you estimate you individually spent on this project out-of-pocket? (Please do not include expenses that your team mates paid for.)

Answers	**Percent Answered**
0 to $10	27.381%
$10 to $20	50%
$20 to $30	11.905%
$30 to $40	5.952%
$40 to $50	2.381%
$50 to $60	0%
$60 to $70	0%
more than $70	2.381%
Unanswered	0%

Question 2 Multiple Choice

Do you think that the qualification process for the EGR-101 robots was fair?

Answers	**Percent Answered**
Yes	90.476%
No	9.524%
Unanswered	0%

Question 3 Multiple Choice

Do you think that the tournament itself on Saturday was run fairly?

Answers	**Percent Answered**
Yes	73.81%
No	26.19%

Unanswered	0%

Question 4 Multiple Choice

Do you think that the rules were structured in a way that allowed the EGR-101 and EGR-345 students to contribute to the success of your team?

Answers	**Percent Answered**
Yes	77.381%
No	21.429%
Unanswered	1.19%

Question 5 Multiple Choice

Do you think that partnering with the EGR 345 students enhanced the Final Design Project and Competition?

Answers	**Percent Answered**
Yes	83.333%
No	15.476%
	1.19%
	0%
Unanswered	0%

Question 6 Multiple Choice

Do you plan to continue in the GVSU engineering program after this semester?

Answers	**Percent Answered**
Yes	84.524%
No	15.476%
Unanswered	0%

Question 7 Essay

If you answered "No" to the previous question, why do you plan to leave the GVSU engineering program? Please give as complete and as specific of an answer as possible. (If you answered "Yes" above, you can leave this answer blank.)

Unanswered Responses

61

Given Answers

With the countless hours of hard work I invested into the engineering program and the grades i am going to recieve, i have realized that i am not suited to be an engineer.

Actually the robot design project helped in my decision to stay in engineering.