AC 2011-2444: A MULTIDISCIPLINARY SENIOR DESIGN PROJECT - REDSIGNED TO INCREASE INTERDISCIPLINARY INTERACTION

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A Multidisciplinary Senior Design Project – Redesigned to Increase Interdisciplinary Interaction

Abstract

An interdisciplinary team design experience has been conducted successfully for several years as part of the senior engineering laboratory effort at Western New England College. Recent modifications have been made to the project to increase the amount of interdisciplinary interaction during the project. For the past several years, students have designed, fabricated, and tested a solar-powered vehicle. This vehicle designed to transport two one-liter bottles of water uphill using wireless hobby-servos for steering control. During the current implementation of the project, multidisciplinary student teams are designing, fabricating, and testing a battery-powered electric vehicle. This vehicle's goal is also to transport water bottles uphill. In the new design, the vehicle has speed control and steering control via wireless hobby-servos. The new design requires mechanical, electrical, and computer engineering students to work together closely to design and package the electromechanical speed controls and sensing systems on the vehicle.

A major project objective of the course is to introduce the students to the design process typically associated with new product development. The approach is to have student teams develop an electric vehicle prototype that is optimized for speed while transporting payloads between two points up a sloped parking surface. The battery-powered electric vehicle must also be capable of completing a slalom course as quickly as possible. The effort requires multidisciplinary teamwork wherein mechanical, electrical, and computer engineers must work together to develop electromechanical speed control and steering systems, and a suspension system to stabilize the vehicle. The multidisciplinary design effort requires the parallel development of a performance prediction algorithm, the vehicle itself, and electrical and computer systems to gather data to validate the performance prediction.

Introduction

Multidisciplinary engineering teamwork has a long tradition of success at Western New England College. For well over 10 years, senior-level computer, electrical, and mechanical engineering students have been enrolled in a senior lab course where they design, fabricate, and test a vehicle prototype. The project has a very successful history of developing students' teamwork skills.[1,2] In the most recent implementation of the project, several changes were made to enhance the interactions between the engineering disciplines. The students enjoy the effort and learn a lot about real-world product design and development challenges including team dynamics.

The paper will present a brief background on the history of the project and discuss the recent changes in the project. This paper also briefly describes the details of the design experience, discusses efforts that were found to be both successful and unsuccessful, presents sample team prototype results, presents survey data to demonstrate the effectiveness of the project, and discusses student comments and feedback.

History of the Project

In the first few years of the project, mechanical engineering students as part of their senior lab, designed and built a solar-powered vehicle using 25-30W solar panels. The vehicles were started by removing a cardboard that covered the panel. The vehicles would then race against each other and the clock. A performance prediction model was used to determine the efficacy of the vehicle design. A few years later, with EC2000[3] approaching the faculty chose to integrate electrical and computer engineering students into the project. The main idea at that point was to attempt to form multidisciplinary teams. The teams were multidisciplinary but there was little interdisciplinary interaction. Around 6 years ago, in 2004, standardization of the design practices was implemented and multidisciplinary interaction increased slightly. In 2005, further improvements were made to the project that required more interdisciplinary design and testing effort.[4] While these changes were effective, the mechanical engineering faculty involved with the project deemed the required effort to be high for the 1 credit course. Subsequent survey data showed that the level of interdisciplinary interaction decreased after the additional requirements were not included. In 2010, another significant change was implemented. The project was changed from a solar-powered vehicle to a battery-powered electric vehicle with electromechanical speed control and steering, and a passive suspension.

Brief Project Description

Computer, electrical, and mechanical engineering students are enrolled in an interdisciplinary course during the fall of their senior year. The students are grouped into teams of 6 – 8 students with the objective of designing, building, testing, and racing an electric vehicle. Several constraints are specified for the design effort. The vehicle speed and steering has to be wirelessly controlled with RC hobby-servos, the vehicle components have to be machined and assembled at the college, and the total component budget has to be under $350. Each team is required to: conduct a product design feasibility study; conduct design brainstorming sessions; conduct conceptual design studies; design and fabricate a product prototype; develop a prototype prediction algorithm; design and fabricate an on-board computer to collect, store and analyze performance data; and use collected prototype data to analyze vehicle performance. Weekly meetings are conducted where each team gives a brief oral presentation describing both the work status with respect to their program schedule and the team-spending summary. During the weekly progress reports, faculty serve as the management team reviewing the technical aspects, design progress, and budget of each team during their presentation. During weekly lab meetings that are separated by discipline, faculty serve as technical advisors, helping the students with their designs. Often many extra hours are spent with the students beyond the regularly scheduled lab times.

Successes and Failures

The vehicles competed in a 300 ft speed race and a 3-lap figure 8 race. Each team was allowed two attempts to complete each of the races. Of the Nine teams competing, five completed both races. Table 1 shows the race times and average speeds of the speed race. Since this was the first time the project required teams to incorporate suspensions and steering, the faculty involved with the course were satisfied with the race results. 100% of the vehicles completed the speed race while only 56% of the vehicles completed the figure 8 race. Combined steering and suspension design flaws were the main reason that 44% of the vehicles were unable to complete the figure 8. The primary design flaw in these vehicles was students choosing RC hobby-servo motors that did not have enough torque to turn the wheels sufficiently. Many teams needed to decrease the lever arms to compensate for undersized motors – thereby increasing the turning radius of their vehicles and making the figure 8 race more difficult to complete quickly. The second design flaw in the steering/suspension systems were inadequate fastening of components. A few of the vehicles experienced catastrophic failure when a wheel fell off – teaching the students a valuable lesson about cycle-fatigue. With regard to the servo motor torque problem, to be fair to the students, some of the teams realized that they had motors that did not have enough torque. These students wanted to purchase new motors but their groups did not have enough money remaining in their component budgets – another valuable lesson.

Table 1: Race Results

TEAM	Straightaway Time (seconds)	Straightaway Speed (mph)	Figure 8 Time (seconds)	Avg Time (seconds)	OVERALL RANK
1	21.16	9.67	41.06	35.94	1
2	24.84	8.23	DNF		
3	34.99	5.85	DNF		
4	53.56	3.82	DNF		
5	26.90	7.60	42.66	38.58	2
6	47.56	4.30	55.87	53.87	5
7	28.95	7.07	47.00	41.51	3
8	37.20	5.50	DNF		
9	31.31	6.53	62.81	50.33	4

One of the more successful aspects of the project was the integrated electromechanical speed control system. All nine teams successfully implemented a servo-controlled speed control system. All three disciplines of the teams needed to work together to implement the speed control system. The system was comprised of an RC hobby-servo motor that turned a potentiometer. The voltage from the potentiometer was the input to a differential amplifier on the electrical engineer's circuit board. The differential amplifier and subsequent current regulator circuit is shown in a block diagram in Figure 1. One of the inputs in the block diagram is an enable signal that comes from the computer engineer's circuit board. In order to calibrate the speed system to ensure that the vehicle can slow down to negotiate the turns in the figure 8 course, all three disciplines needed to be involved in the development and testing phases. Figure 2 shows the servo motor and potentiometer on one of the vehicles.

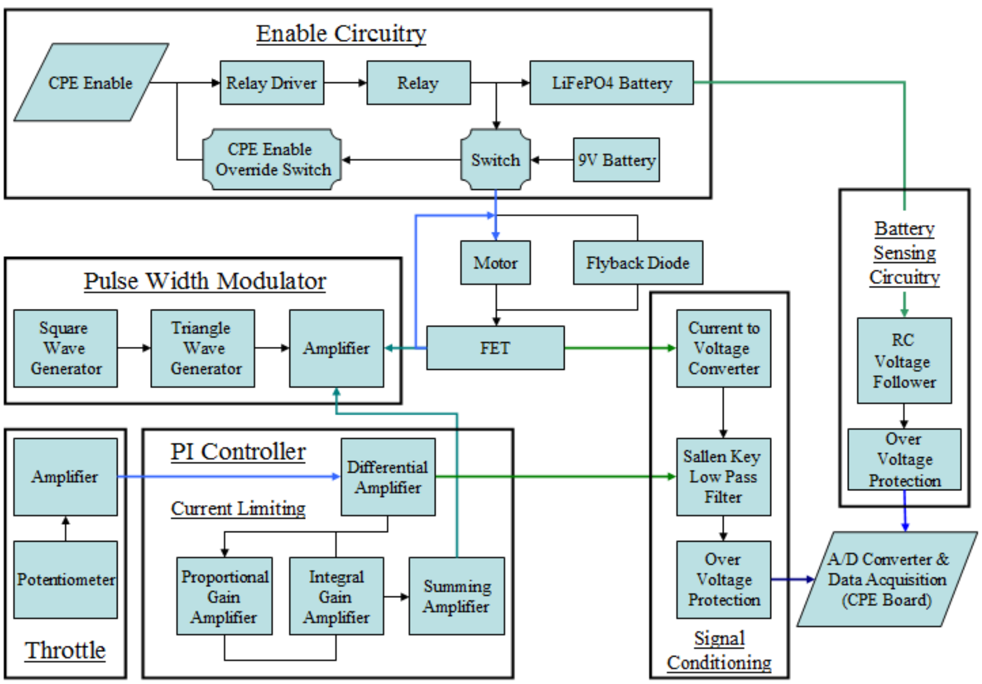

Figure 1: Electrical System Block Diagram showing the current regulator, the system inputs, and the signal conditioning circuits.

Figure 2: The leads connecting the potentiometer connect to the EE board to control the motor speed. (Top) The C-clamp bolted to the frame holds the potentiometer in a direct connection with the set screws and servo motor T-connection so that it has a 1:1 coupling. (Bottom)

Sample Team Prototypes

Shown in Figures 3 – 6 are some of the vehicles built by the teams. The photographs show a wide variety of design choices for the frames, wheel sizes, steering and suspension designs, and payload placement. Some of the teams improvised and added Scotch Tape® to the surface of the front wheels to reduce the friction thereby allowing the undersized servo motors to turn the wheels.

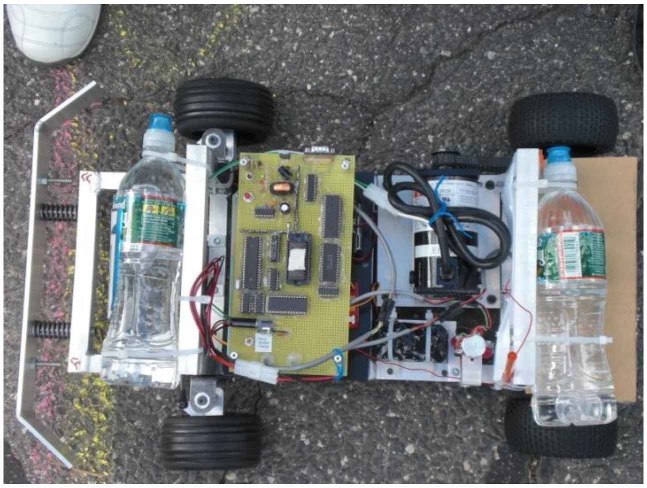

Figure 3: Top view of vehicle showing water bottle payload, potentiometer speed control input, protection bumper, computer engineer's circuit board, motor-belt drive, and wiring harnesses.

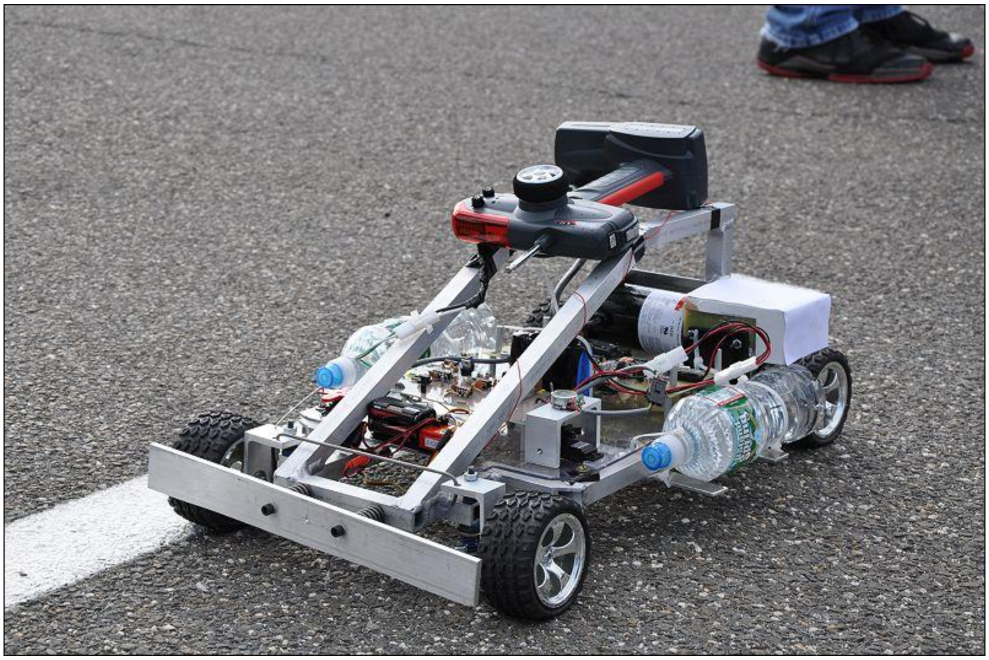

Figure 4: Vehicle prototype showing servo controller resting on top and a bumper that has clearly been tested.

Figure 5: The monster truck vehicle prototype. Tape was used to reduce friction and allow the steering servo to turn the wheels.

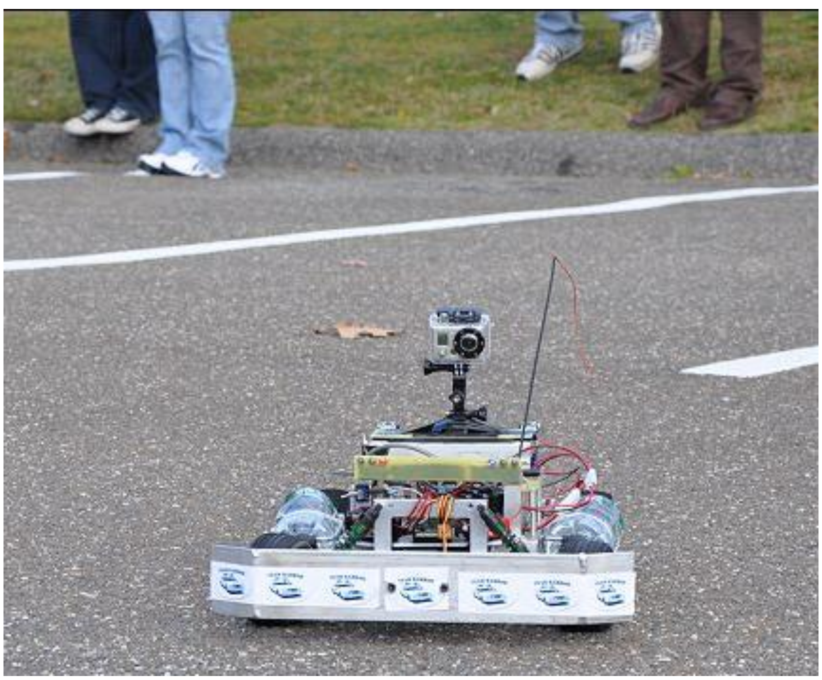

Figure 6: Vehicle prototype with a camera mounted for "youtube" style video capture.

Survey Data

Researchers have indicated that on-line surveys are effective tools to obtain data and to provide feedback to students more efficiently than paper-pencil methods[5]. Since the survey given to the students in this course was used to provide only summative feedback to the faculty, it was decided that a paper-pencil method would be used. The survey assessment was performed after the students' final presentations were delivered. Students were informed that the surveys would not be used to as input to their individual grades and that the data would be used for both ABET assessment of their ability to function on multidisciplinary teams[3] and for publication in peer reviewed paper(s). Figure 7 shows the survey that was used to assess the level of interdisciplinary interaction within the multidisciplinary teams. Several of the questions ask the students to report their knowledge of the interactions between the other disciplines. For example, "Implementation of the speed control required all CPE's and EE's to work together", when answered by a mechanical engineer, the question required the mechanical engineer to report his/her knowledge of the level of interaction between the computer and electrical engineer.

The questions were scored on a 5-point Likert scale with strongly agree, 5, and strongly disagree, 1. There was also opportunity to report "don't know". The survey participants were 60 engineering seniors – 23 computer engineering students, 10 electrical engineering students, and 27 mechanical engineering students. Five students did not participate, four of them were mechanical engineering students and one was an electrical engineering student. The averages, medians, standard deviations, number of "Don't Know" responses, source of "Don't Know" responses, and percentage of "Don't Know" responses are shown in Table 2. The reason for the focus on the Don't Know responses will be discussed shortly.

Analysis of the averages, medians, and standard deviations show that there was a considerable agreement by the students that the multidisciplinary teams functioned well from an interdisciplinary perspective. Questions 3, 17, and 20 point in a positive direction with an average of the respondents Agreeing that the teams brainstormed in the beginning of the project, that All disciplines worked together to test the vehicle, and that their group worked well as a team. Several validity questions were asked where low-valued responses indicated that the teams functioned well. Questions 7, 12, 18, and 19 were designed with low scores indicating good teamwork and/or good participation by all members. Responses for questions 12, 18, and 19 indicated that students believed that their teams worked well together. The average and median for responses on question 7 indicate, however, that on average students were neutral when indicating that their team had a non-participating member or members. When examined on a team-by-team basis, the results for question 7 are more illustrative. Table 3 shows that there were two teams that had an excellent level of participation from all team members, while four teams had mixed reports, and three teams reported a member or members who did not participate much.

Table 2: Survey questions with average, median, standard deviation shown, number of Don't Know responses, and source of Don't Know responses. N = 60.

	Question	Mean	Med.	Std. Dev	Don't Know	DK Src	% DK
3	All disciplines worked together in initial brainstorming meetings	4.2	4.0	0.9	0		
4	Most of the frame of the vehicle was assembled at the time of the mid-semester review	4.4	5.0	0.7	3	CPE	13.0
5	Our team tested the vehicle on the pavement enough before the race day to find and correct problems	3.9	4.0	1.2	0		
6	We were able to gather good data on race day	3.0	3.0	1.3	2	ME	7.4
7	Our team had a member or members who did not participate/contribute very much	2.8	3.0	1.4	1	CPE	4.3
8	Implementation of the speed control required all disciplines to work together	3.9	4.0	0.9	1	ME	3.7
9	Implementation of the speed control required ME's and EE's to work together	4.4	4.0	0.6	3	CPE	13.0
10	Implementation of the speed control required ME's and CPE's to work together	3.2	3.0	1.2	2	EE	20.0
11	Implementation of the speed control required all CPE's and EE's to work together	3.8	4.0	1.1	9	ME	33.3
12	Our team was dysfunctional	1.9	1.5	1.1	0		
13	All disciplines worked together to integrate the vehicle systems	4.0	4.0	0.8	0		
14	EE's and ME's worked together to test the vehicle or parts of the vehicle	4.3	4.0	0.8	3	CPE	13.0
15	CPE's and ME's worked together to test the vehicle or parts of the vehicle	3.9	4.0	1.1	2	EE	20.0
16	CPE's and EE's worked together to test the vehicle or parts of the vehicle	4.3	5.0	0.8	11	ME	40.7
17	All disciplines worked together to test the vehicle	4.2	4.0	0.9	0		
18	I wish my group would have worked better as a team.	2.5	2.0	1.3	1	ME	3.7
19	The vehicle would have performed better if we had better teamwork	2.5	2.0	1.3	0		
20	Our group worked well as a team	4.1	4.0	0.8	0		

Table 3: Non-participating team member(s) average score by team

Team	1	2	3	4	5	6	7	8	9
Q7 Avg.	1.17	2.83	2.71	3.83	3.50	3.00	1.63	4.00	2.71

There were two sets of questions designed to determine whether the multidisciplinary teams functioned with a high-level of interdisciplinary interaction and, if so, show the effectiveness of the project. The first set of questions was questions 8 – 11. Here, students were asked to rate all disciplines and sets of two disciplines with regard to their levels of interaction while implementing the speed control system. The response to question 8, taken alone, would seem to indicate that on average, the students agreed that all disciplines worked together while implementing the speed control. However, the responses to question 10 indicate that students believed that the mechanical and computer engineers did not need to work together on the speed control system. This is likely to be true since many of the electrical engineers built a switch into their circuits to obviate the need for the computer engineers' circuit board's enable signal. Many of the students were clever enough to work around the need to have all three disciplines included in the testing phase for the speed control. Responses to questions 9 and 11 indicate that students believed: 1) electrical and computer engineering students worked together and, 2) electrical and mechanical engineering students worked together while implementing the speed control system. Again, this is likely true because the electrical engineers' control circuit was the crucial piece for the speed control system – needing interaction with the servo motor – potentiometer input and interaction with the enable signal from the computer engineer's circuit board.

The second set of questions designed to determine the level of interdisciplinary interaction within the multidisciplinary teams, was questions 13 – 16. Here, the questions focused on system integration. Again, the questions started with a query about all disciplines working together and followed with questions about sets of disciplines working together. For all 4 of these questions, the average student response indicated that students agreed that all disciplines and that sets of disciplines worked together to test the vehicle. Taken alone, this too would indicate that the project successfully achieved the goal of a high-level of interdisciplinary interaction within the multidisciplinary teams.

However, as mentioned previously, there were many "Don't Know" responses. Shown in the right three columns of Table 2, are the number of Don't Know responses, the disciplines responding, and the percentage from the discipline responding with Don't Know. Interestingly, for each question where students responded with Don't Know, only one discipline responded this way. When the data is viewed with respect to which discipline indicated Don't Know, a clear pattern emerges. For the responses with a high percentage of Don't Know responses, the disciplines are responding to knowledge about the other two disciplines. For example, 33% and 40.7% of the mechanical engineers responded that they didn't know what the level of interaction between the computer and electrical engineers was with regard to speed control implementation and vehicle testing. Also, 13% of computer engineering students and 20% of electrical engineering students indicated that they didn't know the level of interaction between the complement peer disciplines. These are alarmingly high response rates for students not knowing the level of interaction between their peers. Further investigation of the underlying causes is warranted but is not within the scope of this work – obviously, there is room for improvement.

Student Comments and Feedback

Shown below are a few of the open response questions given with the summative survey. The discipline of the responder is in parenthesis after the response. It is not surprising that common themes of working together, better communication, more meetings are prevalent. Also, many students responded that they liked the project but that it was an extremely large amount of work for the credit allotted.

What would improve your teamwork?

- More tasks that need interdisciplinary work (EE)
- more working together (CPE)
- more formal group meetings (CPE)
- communicate between disciplines (EE)
- work together on each design rather than assigning 1 person to subsystem (ME)
- everyone participating (CPE)
- More communication with CPE's (ME)

What tasks in the project required your team to work together across disciplines?

- Car design and placement of the boards and battery (EE)
- Anything involving integration, frame setup/layout, throttle control, board mounting, speed calculations, code involving voltage, current & speed calculations (EE)
- Throttle control & beam break. Also outline of placement of boards (ME)
- Speed control, final testing, layout design (ME)
- Final Testing (CPE)
- Testing, trouble shooting (CPE)
- Potentiometer, beam break, board layout (ME)

What made your team succeed?

- Cooperation within disciplines (ME - 1st place team)
- Teamwork, fun, determination (ME)
- Working together (CPE)

Other comments:

- Fun was had, many lessons were learned (ME)
- No need for roll cage or water bottles (ME)
- Plan on components breaking before the race (CPE)

Future Improvements

The next time the course is delivered, several improvements can be implemented. First, the groups need to be smaller. For this project, groups should not exceed six students. In a perfect world with even distributions, two students per discipline would comprise a well balanced group. Second, formative evaluation with feedback using a system such as

CATME[6] would be helpful in informing and helping students with their intra-group dynamics. Third, increasing the budget to allow students to purchase new components after they discover inadequacies would help students achieve better results. Fourth, requiring groups to meet during a formal time that is block scheduled would allow teams to meet more regularly and increase the level of communication. And finally, faculty should develop a requirements document that describes what each discipline is responsible for and what designing and testing will be required that involves interdisciplinary interaction. This document would help students see the bigger picture and understand what the other disciplines are doing and how the disciplines need to interact.

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[6] https://engineering.purdue.edu/CATME/research.html (accessed January 3, 2011)

Appendix

Electric Vehicle Project – Interdisciplinary Teamwork Evaluation

Name: ____________________________ Date: ______________________

My group number/letter: ________________ My major is: EE ME CPE (circle one)

	Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Don't Know
3	All disciplines worked together in initial brainstorming meetings						
4	Most of the frame of the vehicle was assembled at the time of the mid-semester review						
5	Our team tested the vehicle on the pavement enough before the race day to find and correct problems						
6	We were able to gather good data on race day						
7	Our team had a member or members who did not participate/contribute very much						
8	Implementation of the speed control required all disciplines to work together						
9	Implementation of the speed control required ME's and EE's to work together						
10	Implementation of the speed control required ME's and CPE's to work together						
11	Implementation of the speed control required all CPE's and EE's to work together						
12	Our team was dysfunctional						
13	All disciplines worked together to integrate the vehicle systems						
14	EE's and ME's worked together to test the vehicle or parts of the vehicle						
15	CPE's and ME's worked together to test the vehicle or parts of the vehicle						
16	CPE's and EE's worked together to test the vehicle or parts of the vehicle						
17	All disciplines worked together to test the vehicle						
18	I wish my group would have worked better as a team.						
19	The vehicle would have performed better if we had better teamwork						
20	Our group worked well as a team						

Figure 7: Summative survey given to students after their final team presentations.