

2006-1190: ASSESSING INTERDISCIPLINARY ENGINEERING CAPSTONE PROJECT

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Assessing Interdisciplinary Engineering Capstone Project

Abstract

In industry, engineers from different disciplines and levels of expertise work together on projects. To prepare students for industry, professors from Electrical and Computer Engineering (ECE), Industrial and Manufacturing Engineering (IME), and Mechanical Engineering (ME) departments at Kettering University have combined their capstone classes to work on a common project.

Students are divided into teams composed of students from each of the ECE, IME, and ME departments. Every team works on their version of a project known as RoboBug. The team is responsible for the design, development, and manufacturing of a working robot in the shape of a bug capable of performing specified tasks. Students are given requirements for functionality and limitations such as weight, cost, and timeline for various activities of their work.

At the end of the term, each team is required to submit a final report and give a final presentation. Their presentation is assessed by faculty and invited guests on knowledge gained, coordination, team participation, and leadership skills.

Weekly and final evaluations by faculty, invited guests, and students are statistically analyzed to measure the effectiveness of this interdisciplinary engineering capstone project. This paper will discuss the assessment process and the results of these evaluations. In addition, the comments and observations made by the participants, along with the difficulties and successes will be presented.

Introduction

In an expanded effort towards engineering integration, it is imperative to integrate courses at many levels of education¹. To simulate an industrial setting and to prepare students for interdisciplinary careers, students from the various degree capstone classes are assigned to work together on a common project to develop a new product – RoboBug – for the Freshman Interdisciplinary Design and Manufacturing course, IME-100. IME-100 is an introductory course which exposes first year students to the activities and professional characteristics of each of the engineering disciplines offered at Kettering University. Via IME-100 freshmen are introduced to electromechanical principles through studying the mechanics and electronic control of these components. They discuss the nature of the product, the design principles and constraints used, the material selection, and the manufacturing processes. The IME-100 course includes IME laboratories where freshman students learn to perform basic manufacturing processes. These processes provide them the skills necessary to manufacture a RoboBug. The IME-100 course also has an ECE laboratory component where freshmen students build a circuit to be placed on a small robot. The robot is then used in the course to demonstrate system integration and simple programming in an effort to coordinate a walking motion.

To strengthen the relationship among the various degrees at Kettering University and to simulate a real world corporation, students are divided into teams of two students from each of the Electrical and Computer Engineering (ECE), Industrial and Manufacturing Engineering (IME), and Mechanical Engineering (ME) departments. Students maintain their own identity and expertise, but are required to communicate, collaborate, and work well with each other. Each team is responsible for the design, development, and fabrication of a working robot in the shape of a bug capable of performing specified tasks. Students are given requirements for functionality and limitations such as weight, cost, and timeline for various activities of their work.

Interdisciplinary Capstone Project Objectives

The objectives of the project are to work as teams with interdisciplinary students and to exercise innovation with new concepts in product and process development. The project assigned to obtain these objectives involves the design of a walking robot that could be used to fulfill the educational goals of the freshman IME -100 design laboratory, replacing the currently used RoboBug. A second-generation robot for the IME-100 class is being requested to address some deficiencies in the original RoboBug design.

The set goal for each team is to provide a functional robot that can be easily fabricated at a low cost following established design processes. In light of the interdisciplinary team environment, students were informed that the design of the mechanical mechanisms and the manufacturing processes for the robot play a critical role. Design is subject to realistic, competitive constraints such as a limited development budget and short development time.

Functional Specifications

Students were presented with expected functional specifications and were asked to realize them during the design process. Students were also notified that these specifications may be modified over the course of the term as the project evolves. These functional specifications are summarized in Table 1.

Assessment

An important part of the integration project is the assessment. The effectiveness of the project is measured by students' as well as professors' and guests' evaluations and comments. Students' progress at different stages and in various ways was observed and rated by professors and invited guests. The following assessment methods are used to evaluate students' performance, quality of work, and the functionality of products.

Weekly Assessment

Starting from the second week, each team was required to meet with the professors during an assigned time slot in order to review their project progress. Each team was required to submit a short written report of their work. Students were encouraged to add their current week's progress to their previous week's report instead of submitting a new report. This way, students can modify it and submit it as their final report instead of writing a new report. During the assigned time

The RoboBug is required to have a PIC-based control system that allows the RoboBug to demonstrate basic walking gaits in the forward and reverse directions and allows for both left and right turns. Furthermore, with an add-on sensor board, the functionality shall be enhanced to allow the RoboBug to autonomously navigate a simple (object avoidance) obstacle course.
The RoboBug will have a smooth walking motion (no rotating devices may be used in direct contact with the floor, e.g. wheels, tracks, etc.)
The RoboBug will utilize a minimum of four off-the-shelf actuators and sensors.
The RoboBug shall be powered by one of two interchangeable power sources, a) an external tether connected to a standard 110 Vrms outlet or b) a rechargeable Lithium-polymer battery pack. When operating on battery power, the RoboBug shall operate continuously for a least 15 minutes.
Printed circuit boards shall be used for the main electrical assemblies. A typical robot will have two board assemblies: 1) a main processor board and 2) an add-on/plug-in sensor board. All electrical connections, board-to-board, board-to-actuator, sensor-to-board, board-to-power supply, board-to-programmer, etc. shall be made with standard electrical connectors properly sized and rated for the application.
The RoboBug chassis, mechanisms, and electronics must be robustly designed to withstand frequent use in a freshman laboratory environment 4 times per week each academic term. The system must have high durability and operate reliably with a minimum amount of maintenance over a period of five years. (Low maintenance implies the design should require only ten minutes maintenance time per robot per four-week session).
All assemblies and parts must be held in place by standard mechanical connectors (screws, bolts, snap connectors, etc.)
The unit must be designed for easy service and inspection. It must also have a finished professional appearance, utilizing standard materials and processes.
Consideration must be given to the manufacturability and cost of the unit. The project shall have a low manufacturing cost within the constraints of an allowed budget.

Table 1. Functional Specifications of RoboBug

slots, both students and professors had an opportunity to discuss any problems or concerns. These weekly meetings were not only the partial basis of grading with respect to technical content as well as teamwork, but also provided a nurturing but structured and scrutinized environment for the students. In addition, these weekly meetings helped to insure progress towards the final objective and gave the professors awareness of how much time the students spent on their portion of the project.

Oral Presentation Assessment

At the end of the term, each team was given 12 minutes to give an oral presentation of their project. Also, they were given three minutes of time for questions and answers. Finally, they had a minute for transition – getting their audio visual materials ready. Students were evaluated based on their individual as well as team performance. Faculty and staff were asked to complete the Oral Presentation Form. At the team level, the form contained the following:

- How were the quality and use of audio visual materials? Were they clear, uncluttered, large font, easily read? Were the key concepts of design and fabrication explained well?

- Were their organization, planning, preparation, rehearsal, transition, and other materials pre-delivered to session chair on-time?
- Did they deliver in assigned time (not too long or too short ~ 2 minutes per team member)?

At the individual level, the Oral Presentation Form contained the following:

- How were the presenter's professional business attire, poise, body language, and eye contact?
- How were the presenter's presentation skills, language, vocabulary, grammar, articulation, rhythm, intonation, and voice projection?

The faculty and staff were asked to assess each of the above by assigning 0, 1, 2, or 3 points.

Project Specifications Assessment

The students' RoboBug design was also assessed based on whether or not:

- The RoboBug utilized off-the-shelf actuators and sensors and if a minimum of four actuators (servo motors) were used?
- Printed circuit boards were used for the main electrical assemblies? [The RoboBug shall have two board assemblies: 1) a main processor board and 2) an add-on/plug-in sensor board.]
- All electrical connections, board-to-board, board-to-actuator, sensor-to-board, board-to-power supply, board-to-programmer, etc. were made with standard electrical connectors properly sized and rated for the application?
- The robot chassis, mechanisms, and electronics were robustly designed to withstand frequent use in a freshman laboratory environment four times per week each academic term? Also, if the system has high durability and operates reliably with a minimum amount of maintenance over a period of five years? [Low maintenance implies that the robot should require only 10 minutes maintenance time per four-week session.]
- All assemblies and parts are held in place by standard mechanical connectors (screws, bolts, snap connectors, etc., i.e., no duct tape and zip ties allowed!)?
- The unit is designed for easy service and inspection as well as having a finished professional appearance, utilizing standard materials and processes?
- Consideration was given to the manufacturability and cost of the unit within the constraints of the required specifications?

The faculty and staff were asked to value each of the above by assigning 0, 1, 2, or 3 points each.

Project Functionality Assessment

Students were required to demonstrate basic functional specifications of their project. Faculty specifically examined the following basic functionality of each team's newly manufactured RoboBug and evaluated them by assigning 1, 2, 3, 4, or 5 points each:

- Does the walking robot design have a PIC-based control system that allows the robot to demonstrate basic walking gaits in the forward and reverse directions and allows for both left and right turns?
- Does the robot have a smooth walking motion (no rotating devices may be used in direct contact with the floor, e.g. wheels, tracks, etc.)?
- Can the RoboBug be powered by one of two interchangeable power sources (a. an external tether connected to a standard 110 Vrms outlet or b. a rechargeable Lithium-polymer battery pack)? And when operating on battery power, can the RoboBug operate continuously for a least 15 minutes?

Final Report Assessment

Each team was required to submit a final report. The final reports were assessed based on following areas:

1. Design process – such as:
 - Did students follow the design process to achieve the preset attributes?
 - Were students able to brainstorm and think creatively to achieve alternate design solutions?
2. Simulation – such as:
 - Did students identify the proper simulations needed for their design?
 - Did students successfully perform the simulation needed for their design?
3. Project planning and management – such as:
 - Were students able to use project planning tools to plan tasks and timing?
 - Were students able to coordinate design activities and successfully implement their plan?
4. Achieving product attributes – such as
 - Were students able to achieve the conceptualized product attributes?
 - Did the final design meet the preset criteria and engineering targets?
5. Analyzing process – such as

- Did students conduct time studies for each procedure and prepare a process report for underclassmen?
- Did students develop a high volume production plan and refine the project to minimize costs?

The faculty evaluated the above by assigning 0, 1, 2, or 3 points each.

Student Evaluation

Students were given two sets of questionnaires. The first one contained 12 questions which were related to special qualities – team participation and assignment completion. The other one had 10 questions which were designed to collect students’ statement-perceptions of an interdisciplinary engineering capstone project. Each student was asked to respond to each of the questions in terms of whether they completely agree (CA), somewhat agree (SA), somewhat disagree (SD), completely disagree (CD), or not applicable (NA)¹. Questions were deliberately designed in a way that, in some of them positive, and in others, negative answers are desired. These kinds of questions appear to increase the likelihood of students answering the questions after reading and understanding them instead of categorically responding to all or most of the questions, for example, CA. By the time students are qualified to register for their capstone class, they have an extensive experience being a team member of their own discipline. Therefore, they can compare different aspects of team activities when a team is composed of their own discipline verses combined disciplines. Consequently, most of the questions were intentionally designed to assess the integration aspects of the project. The following 13 questions are selected from the aforementioned sets of questionnaires.

- Q1. I felt freer to do out-of-the box thinking because some of the students were from other disciplines.
- Q2. I felt uncomfortable negotiating a group consensus because my group included students from other disciplines.
- Q3. I felt the students from my discipline were more supportive than students from other disciplines.
- Q4. I think the team defined the problem effectively even though it was more difficult because of all the different perspectives from each discipline.
- Q5. I think the team collected/provided relevant data even though it was more difficult because the teammates were from different disciplines.
- Q6. I think the team generated solutions effectively even though it was more difficult because the teammates were from different disciplines.
- Q7. I found the team activities to be more worthwhile because we had students from different disciplines on the teams.

- Q8. I was more comfortable working on group projects when all the team members were from my discipline instead of from multiple disciplines.
- Q9. It was difficult to listen to team members from other disciplines.
- Q10. It was easier to encourage and praise team members from my own discipline and harder to encourage and praise team members from other disciplines.
- Q11. It was easier to explain/help someone from my own discipline than someone from another discipline.
- Q12. I felt more encouraged by teammates from my own discipline than I did from teammates of other disciplines.
- Q13. Because we have had students from other disciplines my team-working skills improved

The students' responses were converted to percentages and summarized as shown below:

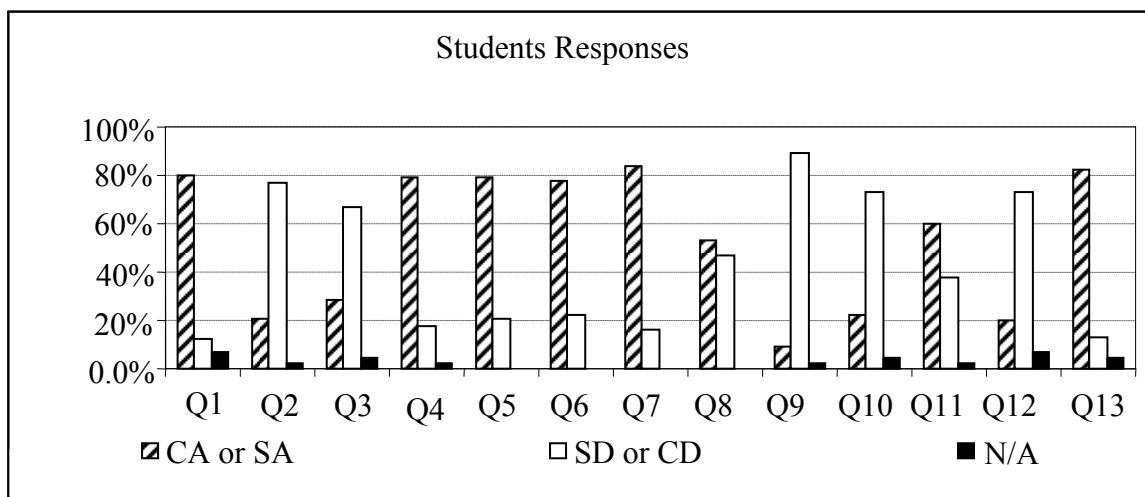


Figure 1. Student responses to 13 selected evaluation questions

The above figure shows that higher percentages of students valued the interdisciplinary engineering project and, most importantly, they welcomed the experience. For example, a high majority of students believed that their team-working skills improved because of this interdisciplinary concept.

The responses to the same questions which were collected in the previous term are compared with the current term. The following two figures show improvements on almost every aspect of the project. Figure 2 and 3 indicate that the percentage of agreeable responses to positive desired questions increased while the percentage of disagreeable responses to negative desired questions decreased. This is mainly due to the fact that improved and more proper steps and communications were used prior to start of the project for the second term.

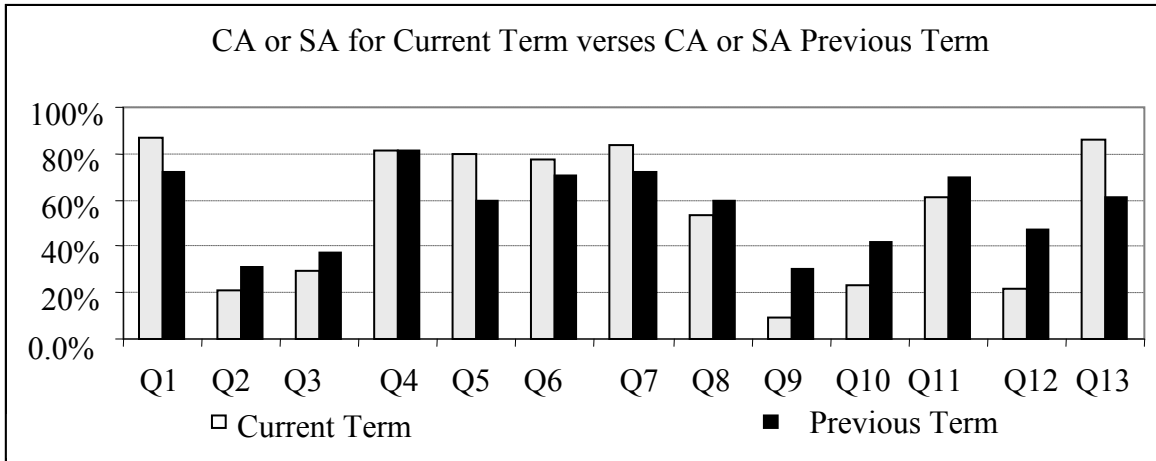


Figure 2. Comparison of agreeable student responses over 2 terms

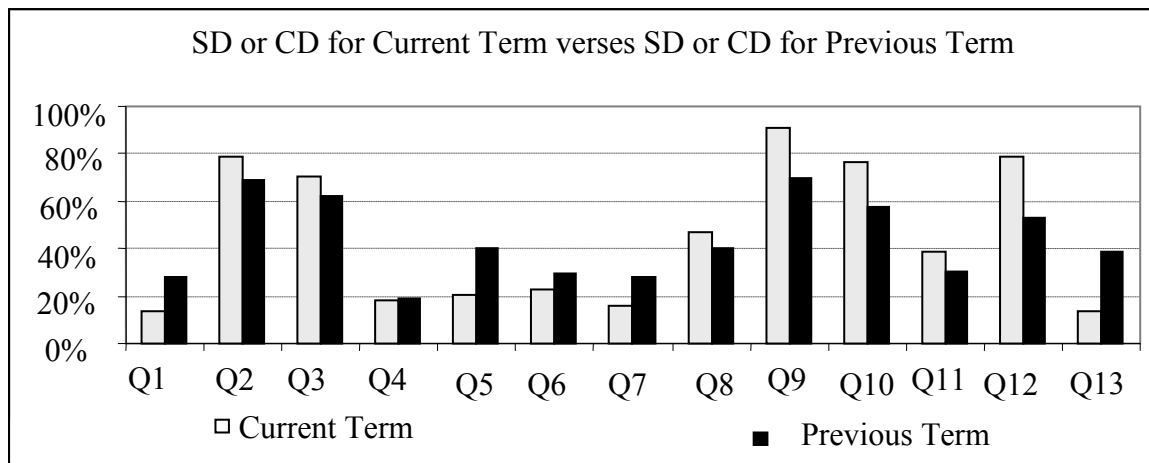


Figure 3. Comparison of disagreeable student responses over 2 terms

Comments and Observations

The overall comments and observations of faculty and guests indicated that there were true team dynamics and students were enthusiastic about their project. They also agreed that students gave them an impression that having to work under time constraints, communicating and working with engineers from different disciplines would greatly benefit their engineering careers. During the final oral presentation, every individual student presented his/herself well, however it was observed that the Industrial Engineering students showed a higher level of professionalizing in their presentation styles and their business attire. It was also observed that the ECE and ME students were more concerned with the presentation of the technical aspects of the project rather than, for example, the presentation style. In addition, it was observed that there was a problem with the way the various disciplines viewed the project objectives. For instance, the ECE students' objectives were clearly focused on designing and building a functioning robotic bug. Whereas, the ME students' placed more emphasis on following a prescribed process for design with less emphasis placed on building a functioning system. The professors were also satisfied with the level of engineering synthesis each group incorporated into their project design, data

collection and analysis, experimental design, and conclusions. However, the consensus was that due to Kettering University 11-week term, students had to work at a fast pace to finish their team project.

Students were also encouraged to write-in any additional remarks. Only a few students made written comments and they were basically in three distinguished areas. Students were pleased with the course by making comments such as:

“Good stuff, real good stuff”

“Learning experience – cope with problems out of your specialty or control. It was actually more comfortable working with different majors for a change, real life situations were faced. Good investment for my education and future jobs.”

Some students were concerned or uncertain about the role of Industrial Engineering in the project. This was partially due to the common wrong culture that “Mechanical Engineering can take an Industrial Engineering role without any problem” and partially due to the nature of the project that did not require the same amount of work from industrial engineering as it did from electrical engineering or mechanical engineering. Some of the students’ comments were as follows:

“Still unsure how IE’s fit into this project.”

“Industrial Engineering Role not quite understood or defined.”

“The nature of the project made it difficult for the IE members to contribute significantly.”

“It was difficult as an IE because we were not assigned work from our discipline to be done. Therefore, the group viewed us as people to make charts and presentations “pretty.” It made us look incompetent because we did nothing that showed our skill level – this project was very demeaning to IE’s.”

“IE’s felt somewhat irrelevant at times; difficult to contribute as much to the group & sometimes other disciplines couldn’t understand/accept that we have two capstone projects.”

It was clear from the start that the amount of work that was going to be required from industrial engineering for the RoboBug would be less than from electrical or mechanical engineering. Therefore, industrial engineering students were assigned to work on an additional project with a local company. The participating faculty decided that it is necessary to come up with a solution for preventing such a concern in the future.

There were some concerns and comments that the participating faculty decided to take appropriate actions on before offering any interdisciplinary engineering capstone projects in the future. Some of the students’ comments were as follows:

“Combine all three of your syllabi into one. It was confusing to figure out who had what requirements.”

“It was difficult that each discipline had different milestones and grading.”

“Have allotted time slots for the groups to work in the lab together.”

“Organization needs to have cohesion. Professors should discuss overlapping discipline milestones and grading should be equal among all disciplines.”

“The structure should be explained better in the beginning of the course.”

Conclusion

In an effort to enhance the capstone experience of Kettering University, an integration of classes from three different departments was implemented. To evaluate and improve integration effort, an assessment and evaluation methods were developed. In these methods the effectiveness of the integration is measured by the evaluations and comments of students as well as professors and guests. Students' progress at different stages and in various ways was observed and rated by professors and invited guests. The thrust of the assessment methods was to evaluate students' performance, quality of work, and the functionality of products. The assessments and comments showed that a high percentage of the students believed that their team-working skills improved because of this interdisciplinary concept. Some students, however, were concerned or uncertain about the role of some of the other disciplines. There were some concerns and comments regarding organization, cohesion, having different syllabi, requirements, milestones, grading scales for each discipline, and having common time for work on the project. Although majority of these issues were addressed – for example, a common time slot was put aside by the involved departments for each group to meet with the professors and the time line and milestones were given at the beginning of the project – the participating faculty sincerely valued the comments and considered them as *“lessons learned.”* Meetings are suggested to discuss what actions are necessary to improve the weakness of the project. In particular, further development of a common syllabus for the three disciplines that clarifies uniform project objectives, milestones, and grading has been identified as a priority. Also, it is clear that continuous communication and more efforts are needed to achieve seamless integration. Furthermore, because the results from previous term to current term were improved (refer to figure 2 and 3) and because proper action will be taken to overcome the weaknesses, the authors are optimistic that the future interdisciplinary engineering capstone projects will have much better results.

References

1. L. King, M. El-Sayed, M. Sanders, J. El-Sayed, “Job Readiness through Multidisciplinary Integrated Systems Capstone Courses,” Proceedings, 2005 American Society for Engineering Education Annual Conference & Exposition, Portland, OR, June 2005.