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Lessons Learned from Team-Teaching a PBL Robotics Course with Multi-Disciplinary Instructors and Students

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Abstract

A group of nine junior and senior level technology students were enrolled in a Design of Robotic Systems course in the fall of 2014. This class was co-taught by professors from the Mechanical Engineering Technology (MET), Electrical Engineering Technology (EET) and the Computer and Information Technology (CIT) programs at Purdue University.

The goal of this paper is to document the activities carried out during the semester the course was taught and present the lessons learned from teaching multidisciplinary students with the backgrounds in MET, EET and CIT.

The objective of the course was to provide a Project Based Learning (PBL) experience for the students. Students were tasked to specify, design, and develop prototype sub-systems for existing robots. During the semester, the students attended lectures and participated in laboratories that were heavily focused on hands-on activities relevant to design of these sub-systems. Interdisciplinary student teams were introduced early in the semester so that the requirements specification and design processes would have multiple views.

In the beginning of the semester, the course focused on topics related to team management, the design process and modeling and visualization of parts and systems. The second part of the course was centered on specific technical aspects for the design of robotic systems. These topics included: batteries, sensors and data acquisition, software control, actuator mechanisms, and propulsion. The course concluded with students focusing on the construction of the robotic sub-systems. The themes for these final lectures revolved around manufacturing techniques, reading and making electrical sketches, electric power conversion and design for robustness. References to the Systems Engineering Body of Knowledge (SEBoK) were made to show students how a systems engineering approach improves both the process and product, to motivate the students to have a broader perspective of the topics being taught in the class, and to serve as a bonding agent between the topics, the project, the students, and the faculty.

In addition to the narrative of the course, this paper also documents the assessment tools used and lessons learned during the process.

Background

In the fall semester of 2013 and spring semester of 2014, a group of students was led by a Purdue Electrical Engineering Technology (EET) faculty mentor to participate in a robotics football competition. This was organized as a Student's Robotics Club, and culminated in a National Football League (NFL) style combine. The combine consisted of individual skill events testing the robot players' speed, agility, strength and robustness, followed by a short scrimmage. To participate, it was necessary to design robots that would be able to play a robotic version of American Football. The club attracted students from multiple disciplines (EET, MET, CIT), and for many of the students, it was their first experience of working on an interdisciplinary project team. After weeks of requirements identification, idea generation, and brainstorming, it was decided to focus on the areas of form factor, propulsion, and control. The team was able to produce four working units that performed very well in the competition. Since none of the special players were built (i.e. passer, kicker, center), these units were nicknamed "basebots" and worked as linemen, linebackers, and rushers.

Figure 1- Robotic football team, first four players (2013-2014)

Encouraged by their success at the competition, and with support from the college administration, it was decided to offer a course focusing on the design of robotic systems that would cover the essential topics needed to design and build a full team of robotic football players. The Purdue EET faculty mentor invited colleagues from EET, MET and CIT to join him in the development of a one-semester course that would cover fundamental topics related to robotic design, construction and testing. These professors included skill sets in the power, electrical / mechanical and embedded systems areas, thus creating an interdisciplinary instruction team.

The goal of the course was to provide the students with a true multidisciplinary learning environment that would mimic the team environment an engineer creating a mechatronic project would experience. Additionally, the collaborators co-teaching the course wanted to provide a learning environment where all the students would learn from professors that were not necessarily in their major area of study.

Similar Undertakings

Many of the advantages of running a multidisciplinary design course were documented by Said El-Rahaiby and Tovar[1]. Their paper described the design and construction of the robots for a football competition by a student club. Using the multidisciplinary design optimization (MDO) strategy, tasks were divided among five teams from diverse, but related disciplines (e.g. structures and electronics). In their approach, each team had a leader that would interact with a system-level project coordinator. Their method allowed the system level coordinator to control the teams of disciplines, therefore assuring the end goal could be met.

Rios-Gutierrez and Alba-Flores[2] documented their experience with Electrical and Mechanical engineering students enrolled in one course. The biggest conclusion from their study was that students struggled to manage their time appropriately to finish the projects, but were able to complete them on time. In this case, the students were charged with creating a complete robotic system, not just a subsystem component that would interface to a base unit. They also highlighted the importance of using PBL as a tool to put the theoretical content of a class into a real life context.

Maxwell and Meedem[3] reported in their article the perceptions of students who participated in a 1999 robotics competition. One of the students reported enjoying learning to work in a team. The student also reflected on the importance of performing independent research for finding ideas that could be implemented in their projects. However, the most notable of the student's comments was his understanding of his own learning process, and how the experience of building robots helped him understand that learning a specific technical topic serves a higher purpose and that the learning experience should be inter-connected.

The motivation for putting together the multi-disciplinary robotics course was precisely to help the students take ownership of their learning process. The intent was to use a PBL approach throughout the semester to provide the students with the motivating environment to stimulate the learning process.

Published literature on the positive effects of PBL in the classroom seem to indicate that an engaging project would increase the motivation of the learner[4,5] and help with 21st century skills[6] that are typically not assessed in traditional engineering or engineering technology curricula.

The faculty at Purdue wanted to leverage the context and success of the robotic football team to boost the learning experience of the students taking the course. Some of those students were actual members of the first group that participated in the robotic football competition. Both the students and the advisor for the team realized that learning the concepts and techniques taught in mechatronics programs would allow them to develop better robots.

The combination of robotics and PBL seemed appealing to the teaching team. However, there were questions regarding how the course would be assessed and whether the students would be engaged and willing to work with peers from other disciplines.

Planning the Course

One of the problems that may arise with teaching an interdisciplinary class is simply the course numbering system. There are sometimes restrictions and special permissions that are required so that a course can be included in a program of study. This is where the use of variable title / variable topic (e.g. 399) courses can be very useful. Since all three departments had a variable title course that was meant for one-off, project, or experimental delivery, three separate sections could be co-listed at the same place and time, but with three different instructors. Thus students from all three disciplines could take a course that counted automatically in the major, with each instructor having responsibility for recording the grades of the students in their own programs. The on-line course management system had the capability of combining the sections into a single section seen by the students.

Permission was also required of the three different curricular committees. This included a presentation of the general and specific course objectives, a syllabus, and assessments. Because of the appreciation of interdisciplinary instruction and PBL, this was approved with minimal delay. Planning for the scope and sequence of the course could then commence. In a group meeting, the instructors jointly developed the topics list. These topics were mostly related to the learning needs and theoretical shortcomings of the initial robotics team. Then, the faculty team developed individual content along with a corresponding assessment metric. Content sharing was done using standard email.

The semester consisted of 16 weeks of lecture and laboratory, with a 17th week for final exams. It was decided that the first 13 weeks would be devoted to two lecture sessions per week with a laboratory exercise related to the lecture topic of that week. Finals week (Week 17) would be used for project presentation and demonstration. The topics included in the course are shown in Table 1.

Table 1- Course Outline and Topics

Week	Lecture Topics	Lab Exercise
1	Introduction, Systems and System Components, Sketching	Component sketching, Brainstorming session
2	Teamwork, Project Methodologies, Project Management	Project work breakdown structure (WBS) using Microsoft Project
3	Problem Definition, Requirements Definition and Specification, Subsystem Interfacing	Requirements and specification documentation
4	CAD Modeling	CAD Tutorial
5	Battery Technology, Specification, and Safety	Battery measurement
6	Sensors and Data Acquisition	Dynamometer testing
7	Software Control	Real-time software
8	Software Coding environment	Coding for control of hardware
9	Design of Motion Systems	Robot arm dynamics

10	Electric Motors and Drives	Electric motor measurement techniques
11	Design of Propulsion and Mechanical Transmission Systems	Mechanical specification of propulsion components
12	Electric Power Conversion and Electrical Schematic Generation	Reverse engineering schematic drawing of an existing system
13	Fabrication Techniques, Design for Robustness	Begin Project
14	Project Work	
15	Project Work	
16	Project Work	
17 (Finals Week)	Presentation and Demonstration	

Although this course would not be part of an ABET assessment review, attention was paid to ABET student outcomes. Even though ET and IT accreditation are guided by different commissions (ETAC and CAC respectively), many of the outcomes are quite similar[7, 8]. These include problem solving, design, teamwork, communication, and project management. Course planning incorporated the development of these skills along with the requisite technical topics needed for the project.

Delivering the Course

The course started with the three professors meeting with the students and describing the objectives of the course. Specific goals were to develop three subsystems that would fit onto the basebots developed previously by the robotics club. These subsystems would add additional functionality to the basebots to create a:

- Center, whose task was to deliver the football to either a quarterback or a running back
- Quarterback, whose task was to throw a forward pass to another robot up to 20 feet away, and
- Kicker, whose task was to be able to propel a ball over a goal at a distance of at least 30 feet

It was also stated that teams would be used to create these subsystems, and that the students must group themselves so that each team would have multiple disciplines represented.

In the second week, the students were able to create three evenly distributed teams. The teams then divided up the three projects. This was done quite quickly by the students themselves. This then led into the course lecture and laboratory exercise on development methodologies and project management, including production of Gantt Charts for the semester. In the third week, each team worked through requirements elicitation, analysis, and specification. A distinction was made between functional or service requirements and other requirements such as decision and realization constraints[9]. This included using the robotic football rulebook for constraints and the combine objectives for functional requirements. An example of each would be a height or weight requirement being a constraint while a passing distance requirement being functional. Having a project plan and a set of requirements early in the semester aided the teams in their development efforts.

As the semester progressed, all the presenting instructors took their turns presenting material and guiding the laboratory experiences. One of the EET professors was present for all meetings of the course, which meant that there were often two, sometimes three professors present. This meant that while one was presenting, another could be watching and recording student reaction. Laboratory experiences were handled in the same way, with one instructor guiding the lab while a second was assisting. Overall, laboratory exercises were credited with 30% of the final score.

As each new topic was introduced, care was taken to connect the topic to the overall course project objective. Block diagrams were sometimes used to describe how the subsystem was integrated to the whole system or how mechanical, electrical, and computer components worked together to create a system. Among these core topics were CAD, batteries, sensors and data acquisition, real-time C programming, actuators, and electric motors.

The prime directive to each team was that they must have a working mechanism by the end of the semester, and then make a team presentation and demonstration. A major constraint was that the mechanisms needed to be constructed from available or easily obtainable material. After the final lecture topics of fabrication techniques and design for robustness, actual construction was begun. This started like a scene from "Apollo 13", where a long table of available parts was presented to the students along with the charge to implement their designs.

Although there were many worries that the plan had not given enough time for actual fabrication, all teams were able to successfully demonstrate a working design. This could be attributed to the early planning and designing that each team had to do. Presentations and demonstrations were done during finals week, with all instructors using the same assessment rubric originally developed for senior project courses.

Results and Observations

Having two instructors in the classroom for much of the instruction facilitated a unique qualitative assessment of student engagement. It was noted that during the lecture and laboratory portion of the course, some of the students tended to "tune-out" when the topics were outside their field of interest. The common topic of robotics seemed to be appealing to all of the students, but it was found that students with more "hands-on" aptitudes tended to enjoy the class more. However, it was also observed that most of the laboratory experiences and the course project were still engaging to all the students taking the course.

In retrospect, considering these observations and the individual performance of the students, it was speculated that those students that tended to "tune-out" had a harder time connecting the technical content from the lectures with the projects and laboratory assignments. This was particularly evident during the evaluation of some of the laboratory reports, where the students that performed poorly reported not understanding what was asked of them and how to utilize the data collected during the exercise to produce meaningful results. As an example, one instructor explained in a lecture the concepts of electric power and mechanical power and how they could be measured to specify the ratings of an electric motor. That same day during the laboratory, all the students were asked to measure the input and output power of an electric motor using a Prony brake. The instructors helped them obtain the data and created a template to estimate the power input, power output and to calculate the efficiency of the motor under various operating conditions. Surprisingly, upon finalizing the laboratory exercise, a portion of the students returned their reports with estimations of the power that were several orders of magnitude off the nominal motor values.

An article written by Kay[10] suggested that the robotics curriculum content of the course should be focused on the topics that are interesting to the student, as an example she presented a list of topics that would be suited to fit better the skills of a specific major, but not those of the other two majors. Kay's argument for tailored curriculum content stemmed from her frustration in trying to find a robotics textbook that would cover specific topics relative to robotics for undergraduates in her major area of study. However, this argument is insufficient to justify a program major specific robotics course simply because it would intensify the disconnection between the disciplines. Robotics is a multi-disciplinary field that requires broad understanding of technical material in mechanics, electrical and programming arts.

A midterm exam worth 15% of the final grade was given covering the lecture and laboratory topics that had been completed by that time. It consisted of three sections, one from each of the disciplines written by the professor from that discipline. It was interesting to note that despite the differences in student majors, the class average for each section of the exam was nearly identical to the overall average, as shown in Table 2.

Table 2- Midterm Exam Grade Distribution by Topic

MIDTERM EXAM	Average Grades by Topic			Overall Grade
Exam Section	CIT	MET	EET	
Grade	76%	76%	74%	75%

The pictures in Figure 2 below portray the three sub-systems designed by the students as part of their course project. All three sub-systems were functional and were tested for reliability and accuracy in meeting the project specifications defined by the competition and also the students design objectives.

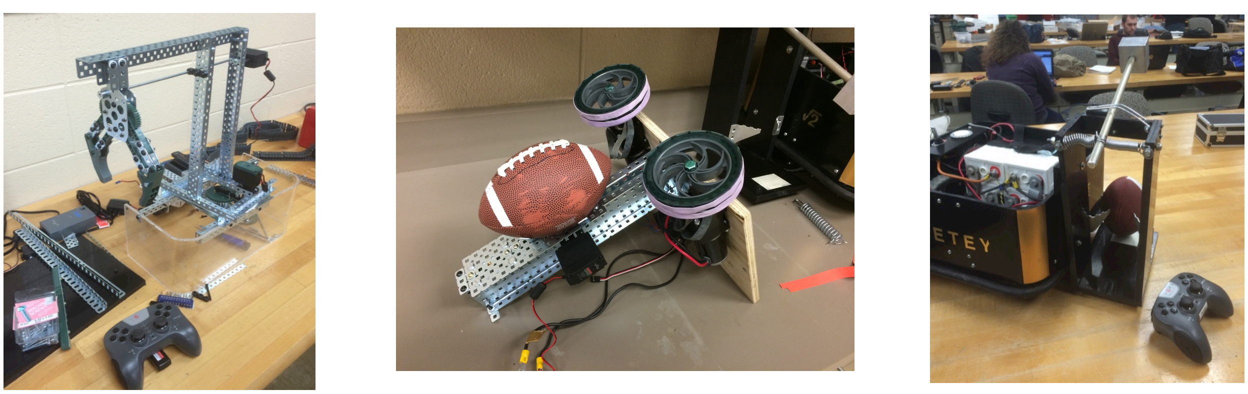

Figure 2- Add on subsystems for the center, quarterback, and kicker

Conclusions

The approach of co-teaching a multi-disciplinary course with instructors of diverse backgrounds was a pleasant teaching experience. All the instructors involved in the planning, delivering and evaluation of the course have a "hands-on" teaching style for their own courses. It appeared that having a similar teaching style was beneficial for conducting the course because it facilitated agreeing with the learning objectives for the class, and also motivated the instructors to learn from each other's technical content. The benefit to the students was twofold: First, they were exposed to topics that would not be covered in their majors, but are essential to the robotics field. Second, students learned and practiced non-technical skills that are important for their careers including: critical thinking, teamwork, project planning and management, oral and written communication and creativity. Lastly, it appeared from this experience that the three credit hour structure used for delivering this course was appropriate for delivering the technical content and for laboratory practice. It also seemed that giving the students three weeks to put together their subsystems was sufficient time to build, and test their assemblies. It is worth mentioning they had been given a fixed number of tools and materials to use and that a large portion of the laboratory time was devoted to planning the project.

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