2006-2580: ENGAGING ECE STUDENTS IN THE PRACTICE OF ENGINEERING

Bruce Ferguson, Rose-Hulman Institute of Technology

Bruce A. Ferguson received the B.S., M.S., and the Ph. D. degree in electrical engineering from Purdue University, West Lafayette, Indiana in 1987, 1988, and 1992 respectively. He is currently an associate professor in the ECE department at Rose-Hulman Institute of Technology in Terre Haute, IN. His technical interests include communication systems and fiber optic systems, including his specialty of analog fiber optic links. He has previously worked with space and ground communication systems and photonics at TRW Space and Electronics (now NGST), and taught at The University of Portland in Oregon. Dr. Ferguson is a member Eta Kappa Nu, IEEE, and ASEE.

David Voltmer, Rose-Hulman Institute of Technology

David Voltmer is a Professor of Electrical and Computer Engineering at Rose-Hulman Institute of Technology. His interests include electromagnetics, microwave metrology, systems engineering, and entrepreneurial student classes and projects.

Engaging ECE Students in the Practice of Engineering

Abstract

The design sequence at Rose-Hulman Institute of Technology has a long tradition of educating students in the practice of engineering. A new course has been created to introduce students to the ECE design sequence. Engineering Practice, a 2-credit junior offering, has goals centered on learning and practicing team skills and applying the design process to a goal-based design project. The course is designed around two basic concepts: a fun Legos robotic project and in-class teamwork on the majority of assignments. The teams are given a scenario and Product Design Specification (PDS), or Requirements Specification, along with a project timeline. The project solution is presented in a competition at the end of the term, the results of which count for pride, but not for grade. Assessment of course objectives (and thus course grades) are through demonstrations of team communication skills and written assignments such as meeting minutes and agendas, project presentations in the form of a design review and test plan, and a team final report. The students are seen applying course-supplied techniques in their team process and design and test of their robotic solutions. The course is structured to allow for peer-reviewed writing assignments, professional development, and team skills coaching. The course also provides a convenient opportunity to discuss relevant professional issues such as professionalism, ethics, registration, and engineering societies. Student feedback on the course has been positive, and students carry enthusiasm into subsequent design sequence courses.

Introduction

Engineering is a practice and profession built upon a number of foundational blocks. An engineering student needs to prepare a strong mind, collect a number of tools for problem solving, and master a number of professional skills in a surprisingly short four-year degree program[1]. A program focusing solely on science and engineering is simply not capable of preparing today's students to be educated professionals in the engineering world.

At Rose-Hulman Institute of Technology (RHIT), we have added extra emphases to help our graduates excel after graduation, including a design sequence emphasizing professional practice in a design environment. This experience is grounded not only in an academic study of professional practice, but also in the industrial experience of the faculty and an entrepreneurial emphasis present at RHIT. An interesting validation of this idea may be found by looking at what some engineering employers expect of their candidates – the Boeing Corporation website[2] has a collection of criteria which closely match the content of the RHIT curriculum.

One particularly important part of engineering that is not stressed well in tradition science and engineering courses is the design process. While we often give "design problems", these are often just homework problems with only a slight degree of openness in the design variables, and often intended to be worked on in the same manner as the other homework problems. In the practice of engineering however, the process of design is applied to very open-ended problems by teams working in a rather open environment, quite dissimilar to the way most students have learned to work. It is therefore very unlikely that design problems or even projects in traditional classes can give students a chance to experience and practice design skills and teamwork as it

will be practiced after graduation. Rather, dedicated design courses would seem to be a better approach.

The design sequence for Electrical Engineering and Computer Engineering students at RHIT consists of a sequence of five courses (nearly 10% of program credit hours) in the final two years of the program. The sequence is designed to introduce students to the practice of engineering and then give them the chance to perform on a real-world team-based project for a client[3]. The courses are listed in Figure 1. The first two courses prepare students for "real-world" engineering by exposing them to the non-technical aspects of project engineering. The senior courses place the students in a team-based, client-sponsored design project experience. While some might consider some of this content "soft", we continue to receive feedback from alumni and employers that this sequence is an extremely valuable part of our curriculum.

Course	Description
ECE 361 – Engineering Practice (Junior – 2 credit)	Creativity, project design specifications, team roles, effective conduct of team meetings, written and oral communication skills, ethics and professionalism, completion of team project(s).
ECE 362 – Principles of Design (Junior – 4 credit)	System engineering, team project involving conception, design specifications, conceptual design, scheduling, project management, business plan, market survey, and budgeting that culminates in a written proposal and oral presentation requesting funds for development of a product.
ECE 460 – Engineering Design I (Senior – 4 credit)	The third in a sequence of formal design courses that emphasizes completion of a client-driven project using the design process. Student teams carry a project from inception to completion to satisfy the need of a client. Integral laboratory.
ECE 461 – Engineering Design II (Senior – 6 credit)	Continuation of the design project from ECE 460. Offered over two terms; no credit will be granted for the first term alone. Six credits will be granted after completion of the second term. Integral laboratory.

Figure 1 Course descriptions for design sequence courses at RHIT.

Course Overview

Engineering Practice (ECE 361) is the first course in the RHIT ECE design sequence. The winter quarter of the 2006 academic year (Dec 2005 – Feb 2006) marks the sixth offering of this junior level course, and the course continues to be met with good student evaluations and feedback from instructors in subsequent design sequence courses. The course has become stable enough that we feel we could report on its impact and give some indication of its value to the students and the program.

The objectives of the course are focused on the application of basic team and project skills to the successful completion of a team design project. These objectives are listed in Figure 2 (from the departmental course specification) to provide a framework for the discussion of the course structure. These objectives were translated into two major course constructs. The first was the course project. The second was the set of assignments for grading in the course.

Objectives
After successfully completing this course the student should be able to:

1. Identify blocks to creativity and apply that knowledge to overcome stumbling blocks,
2. Conduct and participate in team meetings and prepare agendas, minutes, and memos,
3. Make team decisions to solve open-ended problems,
4. Organize and manage a project toward successful milestone completions,
5. Present their work both orally and in writing,
6. Demonstrate an understanding of ethical behavior in the profession of engineering and practice this behavior throughout the course, and
7. Prepare and carry out a personal Professional Development Plan.

Figure 2 Objectives for ECE 361 from departmental course specification.

There were several ground rules guiding the design of the course. First, the course is a 2 credit course (technical courses are 4 credit), meeting twice a week for two-hour sessions. Since the work is predominately team-based, time is a serious issue. Since scheduling a meeting for three-to-four student teams these days is more challenging than it might seem, we decided to provide time in class for most work to be completed. This also allows for the individuals and teams to be monitored as they apply the techniques presented in class. Second, while there are individual assignments, the work is almost entirely based on team activities. This allows the student to become immersed in the team culture in a lower risk (2 credit) class before the more serious senior design project team experience of the senior year (10 credit). Finally, the project must not be such that there is a heavy time burden for the students or the faculty/staff. We chose Lego™ Mindstorms™ because of its reputation for flexibility and ease of use, and have found that they provide an excellent environment for design process education.

The course has a strong team emphasis, from the fact that the students sit with their teams in class each day, to the strong team nature of the assignments, to the obvious team focus of design. All work is performed as a team, and the students quickly identify equally as a team member and as an individual in the course. After the first few classes, the students naturally enter the room and group into teams before the bell. This requires some room accommodations, where possible, to allow for group meeting rather than face-forward seating.

This course is offered in the fall and winter terms for junior students, preceding *Principles of Design* (ECE 362), which is offered in the winter and spring terms. The material covered in class, and the assignments, are coordinated with the content of ECE 362 to reinforce learning and appreciation of the design process.

Lecture Material and Assignments

The *Engineering Practice* course has content which is meant to educate the student in the process of design, teamwork, and engineering practice as well as practicing these topics in the project. Much of this content is "front-end loaded" in the term, leaving the remainder of the class meetings available for team project work. The term covers ten weeks, with two two-hour sessions meeting per week.

Winter 05-06

Day	Date	Topic	Project Milestone	Individual Assignment	given	due	Team Assignment	given	due	Day
1	30-Nov	Engineering Design		skills assessment	I1	I1				1
2	2-Dec	Team Skills - Meetings	Team Assignments; Receive Kit				Team Memo; Kit Inventory Memo	T1, T2	T1	2
3	7-Dec	Team Skills - Communications		minutes (cpr), project notebook	I2				T2	3
4	9-Dec	Technology Familiarization	Technology Familiarization				Tribot Project			4
5	14-Dec	Design Process / Creativity	Receive PDS			I2	Project Functions Memo	T3		5
6	16-Dec	Team Skills - Brainstorming							T3	6
7	4-Jan	Conceptual Design					Conceptual Capture Report (informal)	T4		7
8	6-Jan	Subsystem Identification		Presentations (cpr)	I3					8
9	11-Jan	Project Work Day	Conceptual Capture Report						T4	9
10	13-Jan	Design Review prep				I3	Design Review	T5		10
11	18-Jan	Design Reviews	Design Review						T5	11
12	20-Jan	Testing and Evaluation					Test Plan	T6		12
13	25-Jan	Professionalism	Design Freeze	Professional Development Plan	I4					13
14	27-Jan	Project Work Day								14
15	1-Feb	Project Demonstration	Dry Run				Dry Run	T7	T7	15
16	3-Feb	Project Work Day	Test Plan						T6	16
17	8-Feb	Final Report Guidelines		executive summary (cpr)	I5	I4	Final Report	T8		17
18	10-Feb	Project Work Day								18
19	15-Feb	Class Competition	Competition			I5				19
20	17-Feb	Team Presentation Guidelines	Final Report				Final Presentation	T9	T8	20
21	TBA	Final Presentations	Final Presentation						T9	21

	Individual Assignments		Team Assignments
I1	Skills assessment	T1	Team Memo
I2	Minutes (cpr)	T2	Kit Inventory Memo
I3	Presentations (cpr)	T3	Project Functions Memo
I4	Professional Dvlpmnt Plan	T4	Conceptual Capture Report
I5	executive summary (cpr)	T5	Design Review
		T6	Test Plan
		T7	Dry Run
		T8	Final Report
		T9	Final Presentation

Figure 3 Class schedule for winter 2005-06 term.

The term starts with team skills, discussing what elements constitute a team, what teamwork involves, and presenting and mastering the sorts of skills a good team member must possess. It is important to find ways to get the information across while keeping the students engaged, so the engineering education community should exchange ideas about what works. A great video about meetings that the students highly regard is "Meetings, Bloody Meetings"[4], which does an excellent job of presenting the basics of preparing for and conducting meetings. As with most material in this course, a formal process is presented and practiced in homework, and then the students are allowed to tailor the process to a more appropriate form for this project and their team. Throughout the term, students issue meeting minutes via email, record information in lab notebooks, issue meeting agendas, update websites, and engage in other practices to keep their

teammates informed and collect information useful for future assignments such as the final report.

After team skills, a discussion of the design process is presented which is closely integrated with the project (see Figure 4). Of course, the "design process" is a nebulous thing, and each author will present a slightly different version. This particular version is meant to capture major ideas and integrate them with the project and objectives of this course. As the course progresses, assignments correlate with the elements of this process and move the students towards successful completion of the design project, practicing the skills we intend to present as part of the course curriculum. For example, major project milestones in the course include a conceptual capture event, in which the team captures on paper their design concept, a design review, a test plan, and a dry run. Each of these milestones is a part of the presented design process, so the student has a structure in mind to guide their work.

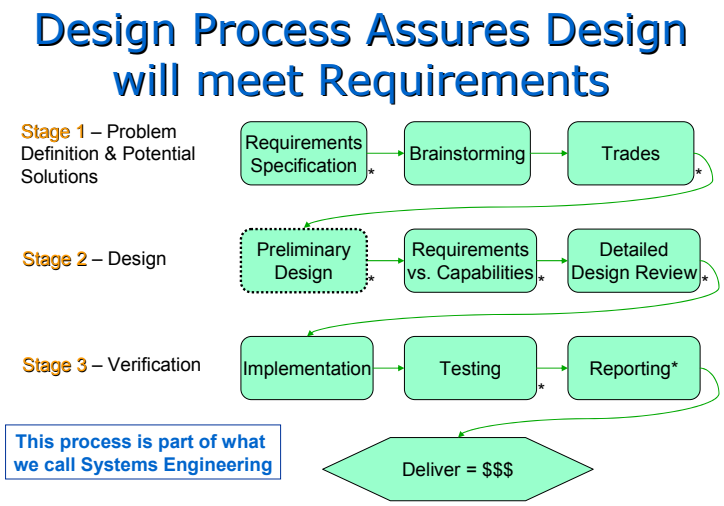

Figure 4 Design process applied to course project.

Major team assignments include a design capture report, design review, test plan, and a final report, which are all based on the elements of the design process presented in class. Each of these assignments is based upon work required to prepare the design solution for the competition, so there really is no "busy-work" involved. Some of the assignments are less formal, such as the conceptual capture report, which consists of a page of text and a collection of attached sketches. In this report, the students present their design/competition strategy, their design solution, and the concept of operations for their design solution. The project final report is more formal, but is relatively easy to prepare if the students have done a good job of maintaining minutes and lab notebooks throughout the term. In the final report, the team presents the final status of their design, prior to the competition. This is a sort of "sell-off" report to the client, intended to give results of testing, design capabilities versus requirements, and proposals for improvement.

In addition, individual assignments practice writing skills using the Calibrated Peer Review (CPR) process[5] and engage the students in a process of professional development. The CPR tool is used in other courses at RHIT, particularly in the follow-on design sequence course ECE 362.

All of the assignments, then, give the students the opportunity to practice and receive feedback on their writing and presentation style and skills.

The final presentation in the course, which is given in lieu of a final exam, is an opportunity for the students to discuss the performance of their design at the competition. We ask that they give an overview of their design and comment on their success and failure with regard to two main considerations. First, they must express how the course content on teamwork and design process has impacted their design and its success. Second, they must analyze their design's performance at the contest in terms of a design process success or failure. (In other words, the may not simply say that the cause of failure was that their sensor did not read the guide strip properly, but they must indicate that they failed to design or implement their testing procedures properly). This allows the students to include "lessons learned" – which is another required component of their final presentations. Finally, the students are asked to suggest a project for the next term, which can be quite interesting.

The team and individual assignments form the basis for 90% of the student's grade in the course. The final 10% of the grade is reserved for "instructor evaluation", and can account for such subjective factors as asymmetries in team performance or class participation. RHIT has a published attendance policy impacting course grades, and since teamwork requires attendance this policy is adhered to in this course. The instructor evaluation term could also be used to cover attendance in some instances.

The Design Project

Each term a new project is selected, assuring both maximum interest and minimum "reuse" of ideas. The project is an open-ended design problem with several possible solutions. There are several requirements applied to the problem, and these are listed in Figure 5. The most important consideration is that the project be goal based, not machine based (for example, not "design a car…") in order to allow for maximum creativity and best use of the design methodology presented in class. It is also important that there be a good chance of overall success, and multiple levels of success.

Student Constraints	Other Constraints
Able to be completed in time frame consistent with 2 credit course using predominantly in-class work	Goal based – not design based (i.e. project should be to accomplish a task, not build a widget)
Able to be completed with background of student just entering Junior year (e.g. programming experience)	Able to be accomplished using only components available in Legos™ Mindstorms™ kit, with 1 additional motor
Appropriate difficulty/work level for team of 3-4 students	Minimal impact to departmental technicians and resources (e.g. constructing competition surface)

Figure 5 List of constraints placed upon course project.

The project is presented as much like a real-world problem as possible. A “client” presents a problem and scenario and asked for designs to solve the problem subject to stated constraints. The instructors present the students with a timeline with milestones since the students have limited exposure to project management at this point in their education. The timeline is presented using a Gantt chart organized by major tasks and milestones, and the importance of adhering to this schedule is stressed. Reflections on previous competitions indicate that “schedule slip”, specifically testing in advance of the competition, is the major cause of failure at the competition. (Of course this is given as advice to the students several times…)

The projects offered thus far have been a barcode based calculator robot, triathlon, mission to Mars, soccer shootout, medicine delivery robot, and a package delivery system (winter 2005-06). The package delivery project is performed on the competition surface shown in Figure 6. A scenario has been developed and a competition will be held. Each team is asked to deliver critical components to three locations for a fee, as if running a robotic mail service. There are three types of items to be delivered. The first is normal equipment, to be delivered by regular delivery methods. The second type is required quickly, and so must be delivered within a time limit (1 minute). The third type is a delicate piece of equipment, and so must be handled with extreme caution (shake/tilt sensor). As each of these pieces contributes to a manufacturing process which is a whole, failing to deliver all three is a failure of the contract, and the team will loose its bonus and future with the client. The white lines on the surface are guide strips for navigation. The packages are picked up from the loading docked and delivered to specified intersections (red dots). The dispatch tower transmits infrared signals carrying specific delivery instructions for each of the packages. There are, of course, several constraints placed upon their design. While the project seems straightforward, the problem of integration and test is one most students will find challenging.

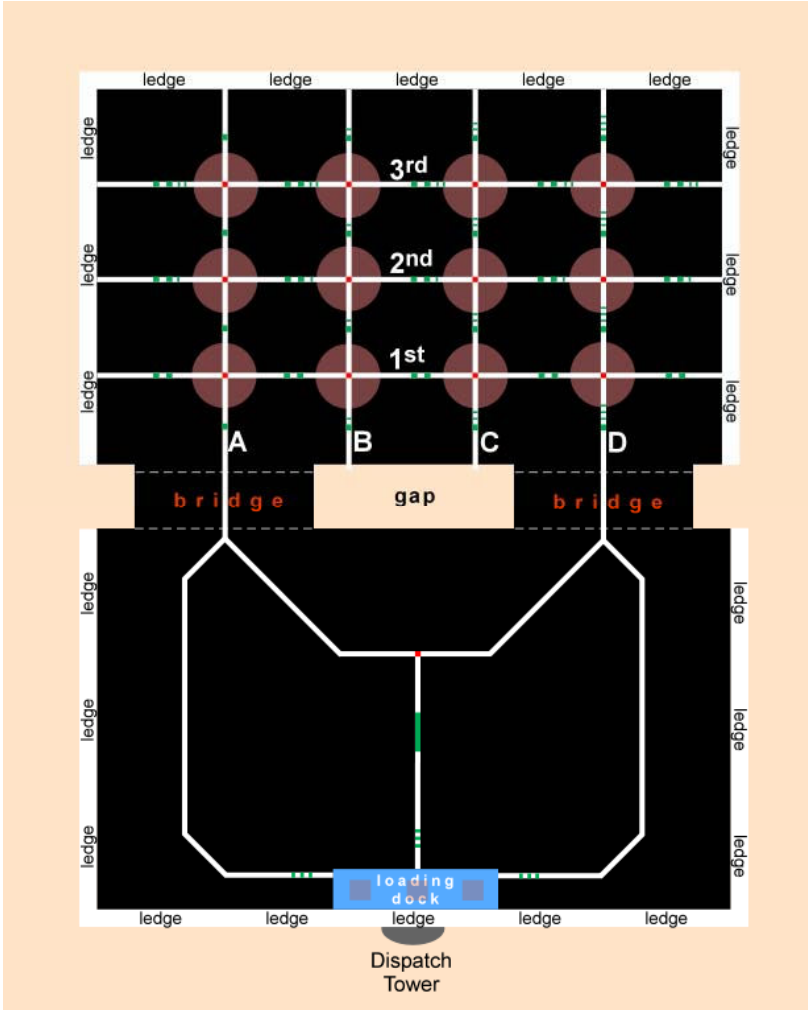

Figure 6 Competition surface for package delivery project.

Results and assessments

While no formal assessment process has been applied to this course, several qualitative results have been noticed through the various measures normally used to gauge course performance. Course evaluations and feedback from faculty teaching the follow-on courses are the primary indicators discussed here. The reader is also referred to Figure 2 when reading this section, as measuring student performance against these course objectives is another success metric.

There are two questions on the student evaluations which ask the students to evaluate the quality of the class. These questions ask the students to respond to statements using a Likert Scale measurement tool. The first statement is "Overall, my learning experience has been:" The second statement is "Overall, how would you rate this course? (Set aside your feelings about the professor.)" Each of the statements is followed by the following scale "Excellent, Above Average, Average, Below Average, Poor", with point totals assigned as 5, 4, 3, 2, and 1

respectively. Over the previous five offerings of Engineering Practice, the average response of the 101 responses recorded was 3.77 for the first statement and 3.65 for the second. This indicates that the students perceive some value in the course and are learning some new material. (Each term, the comments are reviewed for trends that can be used to improve the course.) A review of the written comments reveals some of the reasons for a lower than desired response.

In the first two terms of the course's existence, there were some definite wrinkles to work out regarding presentation, assignments, and the text. Generally, the students reacted very negatively to anything resembling busy-work, so it was clear that all assignments needed to be carefully coupled either to the project or to something of value to the students (such as our required professional development plan, describing what the student will do professionally during their time at RHIT). The required text was not a popular part of the course, even though the faculty considered it as containing useful material. It was discovered that a better approach was to create a collection of original and referenced materials into a course notes format, and to present this in presentation format (this was implemented in the fifth offering). The student comments have been used to greatly improve the course over the past few terms. Some students remain confused about whether the point of the course was learning or working on the project, so some work in organization still needs to be done.

There was a general trend in the comments expressing the usefulness of teaching team skills, and practicing them in the project. Working with people other than friends, the feeling of having "accomplished something", and the presentation and application of the design process all are noted as positives repeatedly. The project was generally considered fun and a useful training ground for applying the course material. Many students express appreciation for a course so different, having reduced academic pressure but great learning value.

This course has had a significant impact on the follow-on course, *Principles of Design*. In the *Engineering Practice* course, we introduce students to a Product Design Specifications or Requirements Document, and Project Schedule, the concept of proposing a design, writing test plan, and so on, all in a relatively relaxed environment focused on a well-structured project. In this way, the students can see how these tools relate to the task at hand and help organize their work. In *Principles of Design* course, the students will author these documents, and write a project proposal, perhaps for their senior project in the following year. So the experience in the first class gives them working knowledge of how the document is actually used, albeit in a simple project. The feedback from the instructors in the *Principles of Design* class indicates that the students are eager to engage in the work and understand the purpose of the documentation from their experiences in *Engineering Practice*.

There is also anecdotal evidence that the team skills, design training, and writing skills practiced in the junior courses are having an impact in the senior design project. While difficult to quantify, writing results have improved, team and project management results have improved, and the faculty have been able to push forward higher expectations in the course deliverables.

Referring then to the course objectives of Figure 2, the course seems to be meeting the objectives in that the students are able to perform the listed activities in this and follow-on courses. Some comments from the evaluations summarize this section:

- "I really liked the emphasis on effective meetings and letting people take roles in the group that they might not otherwise do. The project was an extremely effective tool for learning." (fall 2003-04)
- "This course gave me a good feeling of how a design project team operates, and that things are never as simple as we want them to be." (fall 2005-06)
- "More examples of the writing assignments should be given." (fall 2005-06) (author: more room for improvement!)

Conclusion

The ECE design sequence at RHIT begins with a successful introductory course, *Engineering Practice*, which introduces students to the process and practice of design through a team-based project integrated with classroom assignments. Students are taken from a view that they can work on their own time and in their own fashion (usual homework style) and introduced to the design process and teamwork where schedules not of their own making and interaction with others dominate how they work. By introducing these ideas in the context of an enjoyable project, the students indicate they are able to integrate the concepts and practice engineering effectively. The students perform well against the course objectives, and student evaluations and faculty feedback indicate the course is successful.

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