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Implementation of Problem-Based Learning in Senior Engineering Design-I (ECE 485W)

Fawaz Muzaffer Hussain
Old Dominion University

IMPLEMENTATION OF PROBLEM-BASED LEARNING IN SENIOR ENGINEERING DESIGN – I (ECE 485W)

by

Fawaz Muzaffer Hussain

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Approved by:

Glenn A. Gerdin (Director)

Vishnu K. Lakdawala (Member)

Stephen A. Zahorian (Member)

ABSTRACT

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Fawaz Muzaffer Hussain
Old Dominion University, 2005
Director: Dr. Glenn A. Gerdin

Problem-Based Learning is an approach where knowledge is acquired in the context of the problem. Students are provided with the problem specifications and resources that might prove to be helpful in solving the problem. They attack these real-world problems in groups, analogous to the practice in the professional engineering world. This mode of teaching was adopted to deliver the Senior Engineering Design – I course (ECE 485W), offered to freshman engineering undergraduate students in the Electrical and Computer Engineering Department at Old Dominion University, Norfolk. This thesis documents the various pedagogical methods implemented into the course, which were introduced to address the problems in its previous version.

This thesis is dedicated to my father, may his soul rest in peace.

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CHAPTER I

INTRODUCTION

1.1 Background

The objective of this effort was to make the first senior course in the electrical engineering (EE) undergraduate curriculum, Senior Design I (ECE 485W[1]), more interesting for the students by making it a problem-based course with more emphasis on laboratory and teamwork.

Employers expect newly hired engineers to possess special skills like the art of effective communication, the ability to work in teams etc [1-3]. Engineers will be required to continually update his/her professional knowledge through additional course work or self-directed studying [4].

Traditional lecture-based courses, where the teacher "lectures" do not help develop any of these skills that are demanded by today's employers [5]. This is because such courses tend to lay more emphasis on completing the topics listed in the syllabus [6] and also, on solving problems with well-defined solutions, thus prohibiting students from being creative [7]. The topics listed in the syllabus are usually directed towards the understanding of a single subject, such as circuit theory, probability etc, where as a real-

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[1] ECE 485W is a course offered in the Electrical and Computer Engineering Department, Old Dominion University, Norfolk, VA.
The reference model used for this work is the *IEEE* Transactions.

world problem is more interdisciplinary involving electrical, mechanical, and marketing aspects to name a few.

In certain lecture-based courses, once during the span of the semester, a term paper is required, which could involve a more realistic problem. However, this paper is usually the outcome of the examination of journal papers on topics that mostly turn out to be focused on the testing, discovery or application of a single principle or device. The contents of such papers are difficult to relate to. Also, the homework assigned to the students is usually comprised of problems that are found at the end of the chapter in the text. Students usually solve these problems using novice "pattern-match" problem-solving techniques [8, 9] (i.e. they go through the already solved examples in the text and take the same approach to problem-solving) and hopefully, by applying the basic principles that have already been presented to them by the instructor.

The problems solved in lecture-based courses are not encountered on a day-to-day basis, but are designed to improve one's understanding of a few principles at a time, such as Ohm's Law, Kirchoff's Laws etc. Moreover, these problems usually have to be simplified from more realistic problems, so that the approximations needed to apply the solution are valid and/or the problem can be solved in a short period of time. This contrasts with real-world problems that are multi-faceted and take a great deal longer to achieve a solution. Thus, the problem-solving techniques gained by students in such courses are hard to apply to a typical problem in industry where the solution involves the application of several principles from many disciplines that are often in conflict (e.g. high quality versus cost production and marketability). The outcome of these courses is such that, the students end up questioning themselves as to "What is the relevance of this subject, with respect to my future job?" and/or "How can the techniques learned in this course be applied to a real engineering problem" and a host of other questions.

How does one clinch that the expertise gained by students is retained for a lifelong duration and that they become self-sufficient learners and are able to acquire knowledge on their own? Today's technologies become antiquated tomorrow, requiring engineers to be constantly updating their learning skills in today's competitive world [4, 10]. Students have teachers to guide them in the present and also to 'feed' them what is to be learned, but once they graduate, these services will cease to be offered [7].

Problem-Based Learning (PBL) is a technique of imparting knowledge, where the students work on real-life problems [3, 4-8, 11-18] in groups [1, 6, 18-23]. Since there are groups of students that attack the problem, and also, the time allotted for solving the problem is longer; more complex and realistic problems can be selected for a PBL course. The students then are able to see the relevance of the problem to their future careers and become more motivated, since they are actively involved in the learning process. In solving the problem, the students select the resources they need, i.e. they practice self-directed studying [3, 8, 18, 19, 24-26], while the teacher supervises. These resources are based either on the principles that have been previously presented to them, in formal courses, or a new principle or technique that they will need to acquire. Here the instructor acts as a facilitator [1, 4-8, 12, 14, 17-19, 23, 25] to help them acquire the necessary resources. The instructor 'shows them the ropes' so to speak. This method of learning gives the students an opportunity to apply the knowledge gained from lectures and other resources to solving problems [3, 4, 27], which also motivates them and helps answer their self-imposed questions.

The following sections describe the previous version of ECE 485W and also discuss the various problems that were encountered in its delivery. Following the overview of the 'old' ECE 485W, the goals that were set for the newer version of the same course are discussed. Although, both the old and new versions of ECE 485W can be classified as PBL courses, the latter is more structured, organized and student-centered.

1.2 Previous version of the course

This version of the course was offered in the EE undergraduate curriculum at Old Dominion University (ODU) for three years i.e. 6 semesters. The students who registered for this course were to be in the first semester of their senior year. A brief description of this version of the course and the problems encountered with its delivery are given below.

1.2.1 Description: This version of ECE 485W can be categorized as a capstone[2] design course. The students were to design a sensor system with a digital readout, which emulated a real-world problem. The system was to be based on the specifications of a similar product that was found in a catalog. The first two-thirds of the course consisted of

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[2] In a capstone design course, a faculty member assigns a real-world problem at the beginning of the semester to a group of students and this group works with the faculty member through out the semester and presents their results to a panel of faculty members at the semester's end.

lectures on analog circuits design, based on examples from the texts [28, 29]; including aspects such as, selecting components based on an error budget etc. The error in turn was based on the specifications of the system, such as the % accuracy.

During this period, the students submitted these documents: a project proposal, a set of design specifications, a solution plan including a Gantt chart, a preliminary design report and a component selection table [29]. After these documents were submitted and approved, students were able to obtain the selected components. Thus, the course was about two-thirds over by the time students could even start assembling the components and begin testing the resulting circuitry.

1.2.2 Problems with the older version: As mentioned earlier, students would have possession of their components during the last third of the course. When students started working on their projects in the laboratory, their cognitive skills in the laboratory began to show. The prerequisites for the design course included only two laboratory courses: a digital electronics lab and an analog electronics lab. Students who had more background than that (in the first offerings of the course, several of them were lab technicians at a local NASA research laboratory and were in the process of obtaining a B.S. degree in Electrical Engineering) would do a superb job of getting the circuitry operational, fully tested and calibrated. The better students with only the prerequisite background would put in the extra effort to design a successful project, either by asking the instructor for assistance or by acquiring the required information from other students and/or sources. The more average students would struggle and when the deadlines were imminent, would only approach the instructor for assistance. Then, it was often too late to bail the project out completely, especially if a key integrated circuit became damaged with not enough time left to obtain a new component.

In the last couple of semesters, the percentage of the students who were mediocre increased. These students would attend the class and try their best, but apparently all the concepts pertaining to the design of the project were just out of their grasp. Eventually, the students lost interest in the course and this turned out to be frustrating for both the staff and students. Being the first of only two capstone design courses, this course could not be discontinued. It called for a 'make over' and more drastic steps needed to be taken, in order to make it both appealing to the students and hopefully giving them the requisite lab experience to be more successful in the second capstone design course (ECE 486). The staff then set specific goals that needed to be achieved in the newer and better version of the ECE 485W course.

1.3 Goals for the new version of ECE 485W

The previous version of the course, as discussed earlier, involved the use of analog electronic components. Most of the design concepts, typically associated with analog components, are too complicated to relate to for students with very little lab experience. Bearing these facts in mind, the following goals were etched out for the new course to achieve.

- More realistic projects.
- More experience with hardware.
- Assessment methods in tune with the real world.

1.3.1 More realistic projects: The problem provides the students with both the impetus and context for learning and the acquisition of skills [12]. Students can better understand if they are assigned a project that they can relate to something they use everyday [13]. One of the main reasons why the students appeared to have lost interest in the project (of the older version) might have been due to their lack of motivation while working on the project, since they were not able to relate to it. This called for the use of more realistic projects that would act as a stimulus for the students. This approach would hopefully make the course more immediate in its delivery, as compared to the older version.

1.3.2 More experience with hardware: The newer version of the course had to be designed with more lab hours. It also had to be more specific in terms of content so that students are given more exposure to as many different electrical components as possible [30]. Being a lab-based course, attendance should be mandatory in order to ensure that students attend all the lab sessions and therefore, get the same amount of exposure.

1.3.3 Assessment methods in tune with the real world: Some years ago this course was given a 'W' assignment, which in the curriculum at ODU implies that at least 55% of the grade must be assigned based on the students' writing skills. This heavy emphasis on the writing skills is actually due to the fact that in the real world the performance of engineers is judged from the quality of their reports and presentations.

Employers generally complain about their newly hired engineers' inability to express themselves in written reports or oral presentations. Students can better their performance on the report grades in the new course through feedback from the faculty. Permitting one resubmission of the reports, where the comments made by the faculty member have been addressed, can help students improve their writing skills. Since the student's efforts in a course are directed to those areas that are most heavily weighted in the assignment of grades, it is appropriate to base a significant percentage of the grades in a PBL course on presentations and reports. This helps improve the skills of the students in this area and also ensures that they place the necessary emphasis on this aspect of the project as well. It is natural to grade the students on these aspects, as they would be by their supervisors in the professional world. Of course, they should also be graded on both content and style. Hence, doing a good job on the non-report aspects of the project, such as the logic behind the hardware and the software development should also get some weighting.

CHAPTER II

PROBLEM-BASED LEARNING

A quick look at the goals set aside for the new course, as discussed earlier in Section 1.3, made it clear that these goals were similar to the goals of PBL, with certain added benefits.

2.1 Problem-Based Learning

This section discusses the motivation behind choosing PBL as a technique to implement the new version. It also formally defines PBL and discusses both the positive and negative outcomes of taking such a pedagogical approach.

2.1.1 Motivation: As mentioned earlier, it was noted that the goals set for the new course to achieve were nearly identical to the underlying principles of PBL. In addition, the adoption of a PBL approach would bring with it other benefits, which are discussed in section 2.1.3. PBL is also a terrific format for helping students learn how to do engineering design [22]. Since ECE 485W is an engineering design course, it made sense to opt for a PBL approach to implement the newer version.

2.1.2 Definition of PBL: In PBL courses, problems are the starting point [3, 6, 7, 12, 14, 17, 23, 31, 32]. Students attack these real-life problems in small groups [1, 6, 14, 18-23]. These problems are realistic in nature so that students can not only relate to them, but also are motivated to learn [12, 15, 17, 20]. These problems may or may not have a solution [1, 3, 7, 8], which makes them analogous to the problems that students will encounter in their future professional careers. Also, information on how to solve these problems is not usually provided to the students [5, 33].

The teacher acts as a facilitator [1, 4-6, 8, 12, 14, 17-19, 23, 25], whose role is to only guide the students through out their learning experience. Due to this, students have to decide for themselves as to what information is required to obtain a feasible solution to the assigned problem [3, 8, 18, 19, 25, 26].

In a PBL course, student activity is the main focus [31]. Thus, the course may also include activities like presentations, formal report writing etc to help develop desired professional skills in the student.

2.1.3 Principles of PBL: In a traditional lecture-based course, the teacher organizes the course in the form of a course syllabus, which is handed out to the students usually on the first day of class. Thus, students know what to expect during the course of the semester. Lectures and presentations are delivered in almost every class. The end-of-chapter problems in the textbook are usually used as examples that are solved in class and/or assigned as homework [9]. The students just follow the path that the teacher 'shows' them. From past experiences, students expect the teacher to test them on the same concepts that they were either taught in class or from the assigned homework. Thus, it can be concluded that in a traditional lecture-based course, the teacher has control over what content the students need to learn [8, 34]. Due to this, students' creativity is confined a great deal [7], since they do not get the opportunity to think critically (asking why they are using a certain methodology or questioning a project specification or goal).

The underlying principle of PBL is to transfer the reigns of control over the course content from the teacher to the students, in the sense that the students decide what they need to learn [3, 8, 18, 19, 25, 26]. The students then are responsible for their own learning, while the teacher only supervises. A real life problem [3, 4, 6, 8, 11-18] is given to the students, with not much information on what the solution might be [5, 33]. The students then go through the problem and decide for themselves as to what information they need to gather, so that they are able to find a feasible solution to the problem at hand. The students will also need to acquire special skills such as selective-learning i.e. the ability to differentiate useful information from that, which may prove to be useful at a later stage [4]. These steps are similar to the responsibilities expected from today's engineers by their employers, who expect their employees to be able to work on their own, with little supervision.

2.1.4 Benefits of PBL: There are a lot more advantages to implementing PBL than there are disadvantages. Almost all of these advantages motivated the implementation of PBL into the new ECE 485W course. The benefits of PBL are an outcome of students being motivated from their learning experiences [24]. The advantages of using PBL are listed below, followed by a detailed discussion of each advantage.

- Personality development and honing of various skills.
- "Deep" learning [18, 19, 23].
- Value of teamwork.
- Value of organizational skills.
- Self-sufficient and self-motivated [24].
- Development of creative thinking skills.
- Selective learning.
- Better equipped for professional life.

2.1.4.1 Personality development and honing of various skills: The focus in PBL models is more on student activity [31]. These activities include working in groups, formal report writing, presentations etc. Not many lecture-based courses emphasize such activities that result in the development of desirable skills [5]. Prior to enrolling into a PBL course, students mostly practice or follow formal problem-solving techniques to solve simplified and abstract problems that are based on previously learned principles. Very rarely are they given the opportunity to tackle more complex projects, such as developing a digital alarm clock etc; projects which are more likely to be a major chunk of their future professional life. PBL helps students to develop special skills and attitudes, which are desirable in today's modern engineering firms [14, 18, 22, 35]. These generic skills comprise of good communication skills [6, 18, 23, 24, 36], problem-solving skills [6, 8, 16, 18, 23, 24], the ability to participate in collaborative learning [7, 37, 38], professional writing skills etc [4].

2.1.4.2 'Deep' learning [18, 19, 23]: Deep learning is that process of learning, where students process the information learned i.e. take new knowledge, understand it, check if it fits with their existing knowledge and then incorporate it into their present framework of knowledge [19]. PBL makes use of real-life problems or situations to motivate students, which in turn encourages the students to take a deep approach to learning [18, 19, 23]. Students get to interact with the learning materials and are also able to relate concepts learned to their everyday activities and hence, improve their understanding [18].

2.1.4.3 Value of teamwork: Students in PBL courses work on projects in groups [1, 6, 18-23]. Being part of a team, the students realize that the end product - the project - works if every team member has carried out their assigned tasks. Thus, students learn to take responsibility for their share of the project. All team members have the same goal in mind, which is the successful completion of the project prior to the set deadline; students tend to motivate each other [4]. Working as a team, students also share what they have learned [7]. Students become leaders and teachers as well as team players [24]. Also, while working on a project, as a team, students not only learn the concepts being applied but also learn about diverse people, their likes and dislikes in addition to learning about themselves [39].

2.1.4.4 Value of organizational skills: In a PBL course, students are able to develop organizational skills [4, 7]. All projects have a deadline that they are required to meet. This calls for students to organize their work accordingly to meet these deadlines. Thus, requiring students to develop organizational skills such as:

- Set goals to achieve success.
- Define tasks to meet the set goals.
- Set a schedule to execute the defined tasks.
- Distribute the work assignments amongst students, depending on their 'specialized' skills.

Certainly, the above listed skills will prove beneficial in the design and implementation of any project. Thus, students learn that successful projects are the outcome of good organization.

2.1.4.5 Self-sufficient and self-motivated [24]: Students in teacher centered learning are bound by the limits of the knowledge covered in the course textbook and in-class lectures. Due to the reliance on the teacher for this material, not much research on a topic is done on the students' part. In contrast, learning in PBL courses is student centered [18]. The students are presented with a problem; they decide how to solve it and do the research. The teacher merely acts as a facilitator [1, 4-6, 8, 12, 14, 17-19, 23, 25], whose role is to guide the students when they encounter a problem in their design process. Moreover, the problems that the students work on in a PBL course are open-ended problems [1, 3, 7, 8]. The experience they gain in such projects helps build their confidence such that they can tackle new open-ended problems in the future (self-sufficient). This added confidence motivates them to take a more active role in a new project. Since real-life projects tend to be open-ended problems, there is no limit on the breadth of topics that can be covered because such problems tend to span over several fields of study [6, 7, 9].

2.1.4.6 Development of creative thinking skills: In their future professional lives, students will be required to be innovative if they want to survive the competition. The problems that students work on in PBL courses do not necessarily have a single 'well-defined' solution. Moreover, the students do not have any solved examples to refer to and are forced to think outside the textbook in order to reach a feasible conclusion. This is due to the uniqueness and complexity of the problem assigned. This helps foster their creative thinking skills [8, 17].

2.1.4.7 Selective learning: Engineers today are pressured to complete extremely complex projects in impossibly short durations of time. This calls for engineers to be equipped with time management skills.

PBL moulds students to become selective learners i.e. they develop the intuition to classify a piece of information as relevant to the project/problem at hand or otherwise [4, 6, 26]. Students learn to realize that time spent on learning things that may be useful later detracts them from the time available to solve the problem at hand. This ability to select the areas to be studied in order to solve a given problem helps make them more time efficient in solving problems; thereby training them for their professional lives.

2.1.4.8 Better equipped for future professional life: Skills desired by employers are unlikely to be developed on the job i.e. the employer can train one to carry out a design process, which is unique to the company and which the student may never have been exposed to. But it is highly unlikely that employers would want to have to train their engineers how to write good reports and how to be effective in communicating their design procedure to co-workers. The latter are skills that employers expect novice engineers to possess when they apply_for employment. Thus, if students are exposed to working in teams, making presentations, writing documents etc, they would be better equipped for their future professions.

2.1.5 Disadvantages of PBL: The disadvantages of PBL may be overcome if necessary steps are taken [23]. Some of the disadvantages of PBL are as listed below:

- Implications of working in a group.
- Confusing to students.
- Role models [18].
- Special skills in teachers.
- Human resources [18].
- Cost of implementation.
- Time Consuming.

2.1.5.1 Implications of working in a group: Since the project needs to be broken down into sub tasks, a student working in a group never gets to work on every aspect of the project. Students that are accomplished in certain areas, such as computer programming, can 'take over' that area completely to the exclusion of other students in the group. Working on a project in a group creates a certain amount of dependency on other students for one's learning. Some times groups have students who do not contribute much to the group activities i.e. "passengers" [1, 7, 40], which can be frustrating to the devoted students of those groups. Also, students in a group have different schedules; sometimes it may be difficult to hold group meetings outside class with full attendance [6]. Consequently students are left out of meetings, and may not be able to understand the relevance of the information discussed and/or gathered in their absence. Group activity not only requires good organizational skills, but also hard work, contrary to just sitting down and making notes [19]. Students' inability to plan and organize the project may also prove to be a hindrance in the learning process [7].

2.1.5.2 Confusing to students: In a traditional lecture-based course, teachers decide what students need to learn [8, 34, 41]. Teachers present this knowledge to students in a timely and organized manner. After taking a host of such organized lecture-based classes, when students take a course where they have to research on their own (self-directed studying), there is a possibility that they may end up being confused. This is because they are not used to applying knowledge that they have learned in theory to practice. Thus, many students find it overwhelming when they are assigned a project, because they do not know where to begin. Saba et al. [7] advise that under such circumstances, the teacher should ensure that the students finish their projects successfully and satisfactorily.

A PBL course may or may not have a fixed text or curriculum, due to which students are required to research on their own (self-directed study) [3, 8, 18, 19, 24-26]. They not only have to access different resources, but also should be able to identify these resources as being relevant or not [4]. In doing so, students may not be sure of how to focus their self-directed study and there might be an overload of information if they are not able to appropriately select the topics to study [18]. Knowledge acquired thus tends to remain unorganized [23] and the students may not get a better understanding of the subject [7].

2.1.5.3 Role models [18]: In a PBL course, the teacher is a facilitator [1, 4-6, 8, 12, 14, 17-19, 23, 25] and only guides the students when they encounter a problem. The instructor does not take the opportunity to demonstrate and/or exhibit how much knowledge he/she has gained throughout their teaching/learning career [23], which is what most students look for in an inspiring role model. While the instructor must play this role in a PBL course, to get the students to be more self-reliant, this does tend to deprive the students of role models in such a course [18, 23].

2.1.5.4 Special skills in teachers: Teachers enjoy passing out their knowledge to students [18, 23], but in a PBL course they do not get this opportunity. PBL courses require teachers to possess special teaching skills and competencies like the ability to 'guide' rather than 'teach', which many teachers do not possess [23, 42]. Moreover, they feel the lack of control since they are not the ones who get to decide directly what the students should learn [19]. Thus, they do not know what the student is learning and because of this many tutors may find facilitating PBL, both difficult and frustrating [18].

2.1.5.5 Human resources [18]: In a PBL course, students work in small groups. If the class has a lot of students, the need would arise for more facilitators/tutors to monitor all the groups [42]. Thus, more staff will be required to participate in the tutoring process [18]. If none of these instructors or tutors has had prior experience teaching a PBL course, they would be required to attend workshops that would help them get used to this new method of teaching.

2.1.5.6 Cost of implementation: PBL based courses assign real-life problems to the students [3, 4, 6, 8, 11-18]. Sometimes, this may require the institution to order new components or equipment so that the students 'get a feel' of the real world. This requires a significant amount of time and resources to be spent on the development of these real-world projects, which may prove to be costly for the administration. Also, as mentioned earlier, if tutors have had no prior exposure teaching a PBL course, then the administration would be required to train them, which could also be expensive [43].

2.1.5.7 Time Consuming: Real-world problems, addressed in PBL courses, are comparatively more complex in their design and take more time to research and develop. The students have to first understand the problem, and then identify what is to be learned. Following which, the students research for the required information. Only when they have all the information available, do they get the chance to work on the project. If the problem is fairly complex, this whole process might be time consuming for the students [23]. Due to the open-ended nature of the problem and the variable ability of the students to develop a solution, it is difficult to estimate the amount of time invested by the students, outside class [8]. In addition, if students are not able to complete their projects in time, they may develop a sense of failure [7].

These disadvantages can be eliminated if the necessary measures are taken [23]. For instance, take the disadvantage of having 'passengers' in a group, this can be eliminated by means of peer evaluations [1] or by changing the roles of each team member every week or so [40].

CHAPTER III

IMPLEMENTATION HISTORY

The previous chapter discussed PBL along with the benefits and drawbacks of taking such a pedagogical approach. This chapter first discusses the implementation history of PBL in general and then discusses the implementation specific to three engineering courses at three different institutions.

3.1 Implementation history of PBL

The concept of PBL is not new [22, 31]. This technique of "learning" has been around at least since the days of the Greek philosopher Socrates [2, 8, 44, 45], that is the students were guided on to the right path by asking them leading questions, i.e. questions like 'If you think that is so, what does that (logically) imply?' etc. Historically, knowledge has been acquired by "word of mouth" [8]. In the ancient days, apprenticeships were effective, where the apprentice worked on projects in the workshop and was guided by the master craftsman.

PBL found its application in medical education in the year 1969 in the M.D program at the McMaster University at Hamilton, Ontario, Canada [6, 17, 22]. Subsequently, it was implemented at the Case Western Reserve University [46] and a host of many other colleges that wanted to try this new technique of learning, including Harvard Medical School [47]. In medical education, PBL is used to get the students to work with real medical cases on real patients [18, 48]. The students learn to link the patient's symptoms with illnesses and hence treatments, much as they would do in a real life practice. An expert in the area guides them in this process.

PBL is practiced in numerous medical schools today [6, 17-19]. While the 'diagnosis' of the illness is related to the initial stages of engineering design, in that one must study the problem before one can come up with a design to solve it, the actual implementation and assessment of a treatment or design in the two disciplines (medicine and engineering) is quite different. So, a comparison of the present course with PBL implementations in science and engineering are more relevant.

There have been several implementations of PBL in the engineering arena [1, 3, 6, 13, 22, 45, 49, 50]. Since in-depth analyses of three implementations have been provided in the literature [6, 13, 45, 51], only these three are discussed here:

- North Dakota State University (NDSU) [6].
- The Department of Aeronautics, United States Air Force Academy (USAFA) [45, 51], Colorado.
- Massachusetts Institute of technology (MIT) [13]

At the North Dakota State University (NDSU) [6] a PBL approach was implemented in a mechanical measurement class (ME 412). The course structure comprised of two 50-minute recitations and one two-hour laboratory. The Department of Aeronautics, United

States Air Force Academy (USAFA) [45, 51], Colorado, adopted a PBL approach to one of the courses (ENGR 110Z - Project Falcon Base: An Introduction to Engineering) offered at their academy. This course was designed to lay more emphasis on the development of skills in freshman cadets. These skills include problem solving, independent learning, teamwork, and communication skills. At the Massachusetts Institute of technology (MIT) [13], in the Aeronautics and Astronautics department, the entire undergraduate curriculum underwent reform, such that problem-based learning and design-build experiences were integrated through out the program.

3.2 PBL courses at NDSU [6], USAFA [45, 51] and MIT [13].

This section briefly summarizes the implementation of PBL at NDSU, USAFA and MIT, followed by the faculty observations and assessment results. The features, incorporated in the courses offered at these schools are discussed in the context of the various characteristics of PBL. These characteristics are elaborated in detail in the next chapter while listing the goals for the new version of ECE 485W.

3.2.1 Students address real-life problems: At NDSU [6], students of ME 412 worked on a problem to design a temperature measurement unit. The students were required to suggest instruments that could be used to measure the temperatures of water/steam at the vent and the outlet of a boiler, turbine and condenser of a power plant (Appendix A).

The real-life problem that USAFA [45, 51] cadets taking ENGR 110Z had to work on was to design a plan to deploy a manned mission to Mars. In order to develop the necessary problem solving skills that may prove to be beneficial while working on the project, the cadets were required to attend twelve specially designed workshops [45].

At MIT [13], students enrolled in the Aeronautics and Astronautics program, are gradually given exposure to PBL. The initial courses, which they take in their undergraduate degree program, are more structured when compared to the courses in the final years. Even then, students work on real-life problems through out the program. In their freshman year, students learn to design, build and fly radio controlled (R/C) Lighter-Than-Air (LTA) vehicles (in the course "*Introduction to Aerospace and Design*"). In their sophomore year, students design, build and fly R/C electric propulsion aircraft (in the course "*Unified Engineering*"). In the advanced course in "*Aerodynamics*", students work on a case study from either an industry or a government undertaking. In the past, Lockheed Martin Tactical Aircraft Systems has provided such authentic problems [13], which are typically encountered in the aircraft industry.

From the preceding paragraphs, it may be noted that all these schools have used real-life problems pertaining to their corresponding fields of interest, in order to provide the students with a stimulus for learning.

3.2.2 Subject content crosses traditional subject boundaries. The subject content in a PBL course crosses traditional subject boundaries. This aspect of a PBL course can be seen in the implementations of PBL at NDSU, USAFA and MIT.

The temperature measurement problem assigned to the students of ME 412 (NDSU) [6], gives them exposure to different types of sensors, concepts in error analysis, signal conditioning, and computerized data acquisitions systems.

In ENGR 110Z (USAFA) [45, 51], students had to work on the manned mission to Mars problem; this project could be divided into sub-tasks. A task such as traveling to Mars requires knowledge of orbital mechanics; another task on energy requirements, would require students to know concepts related to thermodynamics. Similarly, a task on the issue of living on Mars requires knowledge in civil, electrical and mechanical engineering. Also, in order to address physiological and psychological issues, knowledge on ethics, sociological, health and safety are required.

The Director of the Learning Lab for Complex Systems in MIT's Aero/Astro Department [13] suggests four levels of problems that are to be addressed in the undergraduate program. All problem-based learning approaches that are to be incorporated in the program are categorized into four levels. Experiences at levels 3 and 4 conform more to PBL characteristics.

The Level 3, Macro Labs (MIT), consists of problems that are longer in duration. Examples of problems in such labs include wind tunnel testing, aircraft models, mechanical projects, lighter-than-air blimps, and electrical aircraft design. The Level 4, capstone Conceive-Design-Implement-Operate (CDIO) Labs, consists of capstone laboratory experiences that integrate core engineering disciplines in a systems' context

[13]. Examples for these CDIO labs include autonomous satellites, a sparse optical array project, and electromagnetic flight formation vehicles.

From the preceding paragraphs, it may be noted that, students not only learn different concepts and techniques, but also are able to get a "hands-on" experience on their applications. Learning concepts from the lectures or a text does not give the students the experience to apply them to complex and realistic problems. Thus, by means of projects, students are given exposure on how to apply various concepts in the real world.

3.2.3 Students collaborate in small groups: Students of ME 412 (NDSU) [6] worked in small groups for the PBL part of the course, which was 40% of the entire mechanical measurements course. The remaining percentage consisted of traditional teaching methods (Non-PBL).

In ENGR 110Z (USAFA) [45], each class-section became a project team; they had to select a team manager and also task leaders to head sub-groups. The sub-groups were assigned different tasks as discussed earlier (Section 3.2.2). The team manager was responsible for organizing the project, maintaining the team schedules and the team products i.e. written and oral reports. The task teams were also responsible for sharing the knowledge learned, with the entire team, while working on their respective tasks.

In the "Experimental Projects Lab" course (MIT) [13], students worked in pairs to learn various methods and processes involved in conceiving, designing, constructing, executing and documenting an experimental project.

3.2.4 Assisted by facilitator: The instructors of the courses ME 412 (NDSU) [6] and ENGR 110Z (USAFA) [45] assumed the roles of facilitators, steering the students to the right path by posing questions (Socratic technique).

At MIT [13], problems in the Level 1 (Problem Sets) and Level 2 (Mini Labs) categories were more structured. On the other hand, problems in the Level 3 and Level 4 categories were student-generated, unconstrained, complex and multi-faceted. Students were guided in the design process and provided content for experimental designs by the course instructors, who served roles similar to thesis advisers.

3.2.5 Information on how to develop solutions is not usually given: In PBL courses, students are encouraged to think critically. If students are not "spoon-fed" with information they are forced to decide as to which of the various possible methodologies to solve the problem should be applied. This is beneficial for the students in the long run, for when on the job they will have to make such decisions by themselves.

During the PBL project, in ME 412 (NDSU) [6], the instructor assumed the role of a facilitator, hence there were not many lectures given to the students, except for when the instructor felt that the concept was very difficult for the students to grasp. This meant that the students had to think about the project on their own. If they needed guidance, the instructor was present to give them hints and/or ask leading questions.

ENGR 110Z (USAFA) [45] did not have a course syllabus or textbook. Students were "tuned" to problem-solving skills, by means of mini-workshops [51]. With the workshop assignments, the students were only provided with learning objectives and access to an information resource (a website) containing data and references on engineering, Mars, and tools like concept maps, searches etc, and also tips on developing problem-solving skills, oral presentations, technical reports etc (Appendix B: Figure 12).

In the undergraduate course at MIT [13], problems at Level 3 and 4 were generally, student-generated. These problems were unconstrained, complex, multifaceted and highly motivating to the students. Here the faculty acted as thesis advisers directing the students toward investigating certain areas, and thereafter, discussing the results with fellow team members helped them pursue new areas of learning based on their conclusions.

3.2.6 Students identify the needed areas of learning: Students of ME 412 (NDSU) [6] studied the temperature measurement techniques on their own while working on the PBL project.

One of the main purposes for the development of the course (ENGR 110Z) at the USAFA [45] was to foster independent learning skills in students. As mentioned earlier, students were only provided a list of learning objectives and a web site [51], along with their assignment sheet. Thus, in order to be able to research for relevant data, students needed to be able to identify it first.

At MIT [13], in the PBL courses, students identified problems of interest to them and conducted experiments to find the appropriate solutions, as well as design complex systems that integrated engineering fundamentals at a multidisciplinary level.

3.2.7 Assessment should reinforce these characteristics: Assessment is done in order to ascertain how something is functioning or performing. In educational institutions assessment is done of both the students' performance and the course's impact. This section will discuss how students' assessments and course evaluations were done at these institutions [6, 13, 45] for the PBL approach.

3.2.7.1 Student Assessment: At the end of the semester, student grades are assigned on the basis of various assessment techniques such as exams, reports and/or homework assignments. Students tend to learn strategically [19], i.e. they try to focus their efforts and excel only in the areas that will be covered in the assessment schemes. Thus, if exams' results make up an overwhelming proportion of the grade, then students will study to do well in the exams, whether there is an additional PBL based component in the course or not.

PBL courses are not taught like traditional courses, hence, it requires that such courses be assessed differently [6]. Since in the real world, both employers and funding agencies assess the performance of engineers working on a project based on a presentation and/or a report, it stands to reason that this method of assessment should also be applied to a PBL-based course. Real-world problems are complex in nature. Hence, it is nearly impossible to ask students to develop a design for such a project on an exam. That is, it takes a considerable amount of time to develop a realistic solution. Also, the additional pressure of doing this during an exam does not help either the students (develop it) or the instructor (evaluate the students' actual ability to perform this process). Thus students taking a PBL-based course should mainly be assessed on the basis of reports and/or presentations, since these are standard methods of assessment in the real world.

The characteristics mentioned earlier, should not only be incorporated into a course, but also should be reinforced by various assessment techniques. For example, the PBL characteristic of working in groups can be reinforced if students are provided with peer evaluation forms at the end of the semester. This way, one can ensure that everyone in the team is making an effort towards the success of the project.

The different assessment techniques used in the different implementations [6, 13, 45, 51] are discussed below. Their course evaluation results are also provided.

ME 412 (NDSU) [6]: The assessment tools for this course included traditional tests, which used numerical problems and multiple-choice questions, and also a project on a real-world problem. The project was evaluated based on a group report (30 % of the grade), a group presentation (10 %), individual research work (30 %), individual critical evaluation of PBL (15 %), and peer evaluation (15%).

Table 1 [6] summarizes the scores from two traditional tests and also the PBL project, the data is for a class of 43 students.

Table 1[6]: Data from the Two Tests and the PBL Project (with N = 43)

ITEMS	Average Score	Max. Possible Score	Std. Dev.	Average Score in Percentage
Test – 1 Numerical Problems (Non-PBL)	13.4	20	4.2	67
Test – 1 Concept Questions (Non-PBL)	7.1	10	1.5	71
Test – 1 Total (Non- PBL)	20.4	30	5.1	68
Test – 2 Numerical Problems (Non-PBL)	11.0	14	2.7	79
Test – 2 Numerical Problem (PBL)	5.1	6	1.4	86
Test – 2 Concept Question (Non-PBL)	3.1	5	0.9	63
Test – 2 Concept Questions (PBL)	3.5	5	1.1	69
Test – 2 Total	22.8	30	4.1	76
PBL Project	27.0	30	1.1	90

From Table 1, it may be noted that in spite of self-directed learning, students' performance on the PBL parts of the regular tests did not decrease. From the same results Mehta [6] concludes that PBL courses must be evaluated in multiple ways.

ENGR 110 Z (USAFA) [45, 51]: In order to gauge the effectiveness of the course a variety of assessment techniques were used. These assessment techniques included examinations, written and oral projects, mini-workshops exercises [51], and peer evaluations. No information on how the grade was divided between these assessment techniques was provided in the literature.

Aeronautics and Astronautics program (MIT) [13]: Examples of some of the PBL courses in the undergraduate program and their assessment techniques are listed below:

- Experimental Projects Lab: Students were assessed in this course, by means of laboratory notebooks, design reviews, technical briefings, and written reports.
- Space Systems Engineering: In this course, students designed a complex space system. Assessment was based on design reviews, technical briefings, written documents, teamwork, project organization, and integration of more than one discipline.

In some of the above PBL experiences, students were graded individually for group projects when the individual contributions were clearly identifiable.

3.2.7.2 Course Evaluations: This section briefly summarizes the various results provided by the instructors of the various PBL approaches, mentioned earlier.

NDSU [6]: At the end of the semester, students of ME 412 were asked to compare skills enhanced in the PBL course with other similar, non-PBL courses. The rating scale used was: very good (5), good (4), neutral (3), poor (2), and very poor (1). The results of the feedback indicated that PBL has an advantage over traditional courses for enhancing skills such as:

- The ability to analyze and solve open-ended real-world problems.
- To be able to research, evaluate (as relevant or not), and use appropriate learning resources.
- The ability to work cooperatively in teams.
- Ability to communicate effectively, both verbally and in writing.

USAFA [45, 51]: The Behavioral Science Department at USAFA conducted a survey of the Class of 2000 to assess entry-level attitudes towards learning. The survey was taken twice in the first semester. The survey consisted of 34 questions, of which the results of 4 are given in the literature [45]. The results show an increase in the learning attitudes of the cadets enrolled in ENGR 110Z, and a decrease for all the other cadets. The authors [45] assert that a plausible explanation for this result is that the cadets in ENGR 110Z were being challenged, comparatively more, by the Mars project than their peers were being challenged in other courses. Also, students were asked to take a survey, designed to determine if ENGR 110Z was fulfilling its objective of making an impact on the students. From the results provided in the literature by the authors/instructors (Appendix B: Figure 13), it is evident that ENGR 110Z encouraged the cadets to think more (critically), in comparison to other non-PBL courses. The authors conclude that the PBL approach taken for ENGR 110Z proved to be the best, since it encouraged the students to be engaged in active learning.

MIT [13]: In the end-of-term course evaluations for the academic year 2000-2001, students were asked to rate the effectiveness of the PBL based approach taken, using a 3-point scale of *not effective*, *somewhat effective*, and *very effective* (Appendix B: Table 2). Approximately 75% +/- 3% of the students agreed that the PBL courses offered were very effective in terms of hands-on experience and the relevance of the term projects.

Students were also asked to *agree* or *disagree*, whether a course was *relevant* or if it was *worthwhile*. The scale used was a standard Likert[3] agreement scale. The overall ratings (worthwhile course) for the courses that had PBL experiences were the highest among all undergraduate aerospace engineering courses in the department [13].

3.3 Thesis Organization

This thesis is a report on an attempt to incorporate a PBL approach into teaching ECE 458W in order to make it more effective both in content and delivery. This was done in order to eliminate, if not reduce, the problems that already prevailed in the older version.

The various characteristics of PBL courses and their similarity to the goals that were set for the new course to achieve are discussed in depth in Chapter IV. In the same chapter it will be shown, how these goals can help eliminate the problems with the old course. Chapter V outlines the planning involved in the implementation. It provides a

[3] Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree.

detail of the framework developed in order to implement the new approach. Chapter VI discusses the observations made while executing the plans chalked out in Chapter V.

Chapter VII enlists the conclusions and the various observations made while making the transition from the older version to the newer one.

CHAPTER IV

GOALS FOR IMPLEMENTING PBL IN ECE 485W

As mentioned earlier in section 1.2.2, there were several problems with the older version of ECE 485W. In order to eliminate these problems, the administration set new goals to be achieved by means of a newer version. Since these goals were noticed to be similar to the characteristics of PBL it was decided to adopt a PBL approach to deliver the newer version. The characteristics of PBL are discussed in detail in this chapter. Also, the deficiencies of the older version and the goals that the new course should ideally achieve are discussed in the context of the characteristics of PBL.

4.1 Characteristics of PBL

There are no universally agreed set of rules or practices, based on which a course can be classified as a problem-based course. PBL courses tend to have various characteristics in common. The following are the characteristics of a PBL course [5]:

1. Students address real-life problems.
2. Subject content crosses traditional subject boundaries.
3. Students collaborate in small groups.
4. Assisted by facilitator.
5. Information on how to develop solutions is not usually given.
6. Students identify the needed areas of learning.

7. Assessment should reinforce these characteristics.

The following sections discuss these characteristics in the context of the old version, its shortcomings and the features that need to be incorporated into the new version of the course in order to overcome the shortcomings.

4.1.1 Students address real-life problems: In a PBL course, the students work on real-life problems [3, 4, 6, 8, 11-18] that act as a stimulus for learning. Working on such problems helps students to relate to the concepts applied, which in turn also motivates them.

In the older version of the course, the students worked on an analog sensor with a digital read out. This project required the application of various abstract analog theories and concepts to designing and implementing the sensor. Although, one can argue that an analog sensor can make for an interesting project to work on, one also needs to bear in mind that most undergraduate students have little prior experience working on projects (by themselves, or in a team). Even if the students are given lectures, designed to help realize a successful project, they might still not know what to do. Such students would require constant guidance through out the design process.

Earlier, the students were not as motivated as they would have been while working on a project that they could relate to. The students were not being challenged to develop something on their own; all they had to do was follow the class examples and they were home free. This showed a low level of interest and the lack of motivation on their part. Consequently, some students just gave up on the course and appeared to give just enough effort to be able to get by. This was evident from the reports that they submitted, which would often be a slightly modified reproduction of the examples covered in class.

The new course needed to address these issues and try to eliminate them. This would require the projects to be appealing to the students in terms of context. Thus, the projects that the students would work on, in the new course, would need to emulate real world projects, in which there would be no examples to follow. Since such projects would challenge the students to develop something they perceive to be useful, students would then be more motivated to learn and also to successfully design the project. Also, the teacher needs to assume the role of a facilitator and should not just 'lecture' the students how to develop the solution; thereby, encouraging them to solve problems on their own.

In order to provide a significant number of real-world projects, considering even a microwave oven needs to be programmed these days, a micro controller (μC) would need to be incorporated into the course. This μC should be able to work in tandem with both analog and digital components, providing a wider range of concepts to implement in projects that would also prove to be stimulating to the students.

4.2.2 Subject content crosses traditional subject boundaries: In a PBL course, the course structure is not that well defined as compared to a traditional lecture based course. In a lecture-based course, students are provided with a list of the topics (course syllabus) to be covered in the subject. Students tend to use the syllabus, lectures and the textbook as a guide to acquiring knowledge, because they know that exams and assignments will be based only on those topics [19]. Thus, in a traditional course, the subject is "bounded" by the course syllabus, lectures and the textbook.

In a PBL based course, the course may or may not have a "topic-wise" syllabus. The course is bounded, not by the syllabus, but by the project at hand [44]. A real world project such as the development of an incubator would require knowledge of not only electrical engineering concepts but also concepts from other areas like physics etc. This is because such a project normally could involve sensing the current temperature by means of a thermocouple (physics), comparing that with the set temperature by means of a μC program (programming skills), the electronic control of a heating source (electrical engineering), insulation of the chamber (heat transfer) etc.

It may be noted that when students learn concepts and also get to apply them, they tend to retain the acquired knowledge for a longer duration [52]. Thus, if the projects in the new version are selected such that, it requires the students to learn and apply different concepts from different fields, the students will then, not only acquire a wide range of knowledge but will also be able to retain it.

4.2.3 Students collaborate in small groups: Today's professionals work in teams consisting of people who have different knowledge and/or skills and are from diverse cultures. Emulating such an environment at the college level helps prepare the students for future professional life [6, 12]. Group work also helps promote collaborative learning i.e. the students learn together and also from each other [7, 37, 38].

In the older version of the course the students worked on the project as a group. The complexity of the project required these groups to hold meetings on a regular basis to discuss the possible solutions (for the project) and also to share knowledge. The groups were unable to convene during class hours nor otherwise. Class time was mostly spent taking notes. Also, outside the class, different work and class schedules made it difficult to hold group meetings. Thus, usually not all the members could be present for the team meetings. Consequently, some of the team members had to be left out, which meant that they did not get proper exposure and were also not able to benefit from their team members.

In the new version, the students should work in groups on relatively smaller and simpler projects in a laboratory-based class. Selecting simpler projects for the students to work on would not require meetings on a regular basis (outside class). Also, the absence of lectures, except for brief introductions to a new project, would give students more in-class time for group discussions and to work on their projects. This in turn would give students the opportunity to interact more with team members and also to share knowledge. Another added benefit of collaborative learning is the improvement of communication skills [18]. Students also learn to lead and follow as required [36]. In order to ensure that students are present at all lab sessions, so that the groups can convene, attendance should be made mandatory.

4.2.4 Assisted by facilitator: Unlike traditional lecture based courses where the teacher is an expert on the subject [8] and delivers lectures in class, in a PBL course the facilitator need not be an expert in the field [5]. Also, the instructor plays the role of a facilitator [1, 4-6, 8, 12, 14, 17-19, 23, 25], who in a way, "shows the ropes" to the students i.e. shows the students how the necessary components and/or instruments that are needed to carry on the project function, without actually showing them the complete solution.

In the older version, as mentioned earlier, class hours were mostly spent taking notes delivered by the instructor. Thus, the students would usually work on their projects outside class. Hence, there was little opportunity for the instructor to supervise the progress of these projects. Also, if any team had a problem with their project, they were advised and encouraged to approach the instructor with queries, but not many students would follow this advice in a timely manner and would usually end up with an unsuccessful project. Hence, there was not much one-on-one interaction between the instructor and the students. In order to overcome these shortcomings it was required that all the students should convene in the lab, during the allotted class time, to work on their projects in the presence of the instructor.

As mentioned earlier, making attendance mandatory would ensure all teams to show up in full strength to the class. The members can then work on their projects while the facilitator moves from group to group, monitoring their progress and probing students for understanding of the subject [53]. If a team faces a problem in their design, the facilitator will always be there to guide them and help them overcome the problem. Also, to ensure more one-on-one interaction, a graduate student can be deployed as a tutor. Thus, the students will be able to approach either facilitator with possible problems, for advice and guidance.

4.2.5 Information on how to develop solutions is not usually given: In a PBL based course, since the instructor assumes the role of a facilitator, content-based lectures that would usually provide information to the students are absent. Thus, not all the information on how to design the project is given to the students. This gives the students the opportunity to think critically [8, 17, 24, 36].

In the older version of this course, most of the students had no prior experience designing projects on their own, thus the instructor had to deliver lectures in order to steer these students onto the right path. If the project required one to just follow the in-class examples (with minor modifications), this principle was not being followed. If any bumps in the road occurred, the students expected the instructor to bail them out. The end result was such that the most of the students appeared to just replicate the examples given in the class lectures, which were given to only act as guidelines. There was no necessity for the students to think critically and there was very little need to modify the examples to realize a successful project.

In the newer version, with more resources available to the students like the web etc, students should be able to select the needed information and techniques, if guided appropriately by the facilitators. When students encounter a problem, in order to avoid an overload of information, they should not be guided to information beyond the project specifications.

4.2.6 Students identify the needed areas of learning: The teacher, in a PBL course, empowers the students to become self-directed learners [8]: a consequence of the information not being given to the students. In such courses, solving problems is the starting point [3, 6, 7, 12, 14, 17, 23, 31, 32]. The problem specifications help the students categorize knowledge as that which they already know, and that which is needed to be research in order to be able to design a successful solution to the project. Thus, students set their own learning goals [18, 19]. Following which the students research the various resources made available to them (the library, text books, the internet etc). Through their research, the students train themselves to be able to classify information as being relevant or not. They are forced to do this so that they are able to spend more time designing the project rather than spending valuable time just searching for resources.

In the old course, the concepts that were to be applied in the project were provided in the lectures. Thus, it was the instructor who defined the subject matter and not the students. Due to this, students relied mostly on the lectures given in class. The lectures were comprehensive in nature, and a strict adherence to the concepts taught while designing the project, would have yielded a well thought out design. However, this would take more effort than some students were prepared to make, because they were not forced to use all these concepts (such as an error budget etc) to order the components necessary for a working project. They had little invested in this effort, which was due to a lack of motivation.

In a PBL course explicit attention should be paid to students' existing knowledge base and the activation/stimulation of this knowledge to provide them with a framework for learning [13]. Thus, the new course needed to address projects of lesser complexity based on students existing knowledge, so that the students would find it easier to identify the needed areas of learning. These projects need to be based on topics that would appeal to the students, invoke curiosity and in turn encourage them to research for information to reach a successful solution. However, examples on how to solve the problem cannot be given, so that the students are forced to carefully study the problem specifications. This close examination of the problem specification will help the students identify the topics to be studied. In this process, the students also get the opportunity to self-assess their knowledge and upgrade it as required [24]. This approach would also help students develop their time management skills, since the students would learn to spend time efficiently to acquire knowledge that is relevant to the project and apply the concepts learned. In their professional life, employers would most likely want them to be able to finish projects as soon as possible. Arming the students with the intuition to learn based on projects will prove beneficial for them in the near future [3, 6].

4.2.7 Assessment should reinforce these characteristics: In the previous version, 55% of the grade was based on formal reports, but there were no lab notebooks that would serve the purpose of monitoring the group's progress on the project. In addition to the previous grade requirements (formal reports), the students should make formal presentations and maintain lab notebooks in the new version of the course. Formal presentations would help improve their oral presentation skills, which would help them on the job. The lab notebooks would help the students reflect on their progress [1]. Also, the instructor would be able to monitor students' progress, by going through the lab notebooks. These lab notebooks should be one of the bases of the final grade, thus the students will make it a routine to update the lab notebooks regularly.

This chapter discussed the various goals for implementing PBL in ECE 485W. Also, the new goals were compared with the features of the old version, within the context of the characteristics of PBL. The following chapter will discuss the outline of these goals i.e. how the administration decided to implement these goals and the framework designed based on the characteristics of PBL.

CHAPTER V

OUTLINE FOR THE IMPLEMENTATION OF PBL

In Chapter IV, the characteristics of PBL were discussed in detail along with a brief description of the old course, problems with the old course and the goals the new course should ideally achieve. This chapter outlines the framework that was developed by the administration to incorporate each characteristic of PBL (from Section 4.1) into the newer version of ECE 485W to help achieve the previously mentioned goals (in Section 1.3).

5.1 Framework to implement the PBL characteristics

5.1.1 Students address real-life problems: Students prefer real-life engineering problems to abstract theories in textbooks because they get closer to what they envision as the type of problems that they will work with on the job [4]. Hence, in order to get the students more motivated in a PBL course, it makes sense to select more realistic problems. Since there is generally only one problem or project assigned per week or over a few weeks, more complex or real-world problems can be selected. Thus, students would get more time to design such complex problems.

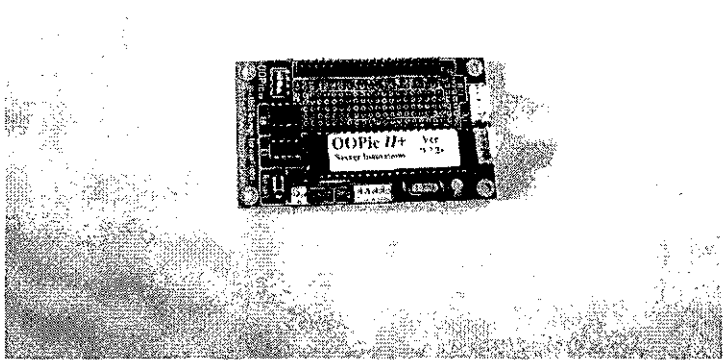
The projects that would be assigned to the students in the new course should be close to "real-life" projects. These projects can be designed to emulate every day appliances such as: alarm clocks, security devices, incubators, or conventional ovens etc. The main objective behind such projects would be to motivate the students (as engineers) and also to help them understand the functionality of certain devices, which they use and/or see in their day-to-day lives (as consumers). This in turn would help students understand the underlying principles better and retain the knowledge gained for longer durations of time because they see a connection between the concepts learned and what they come across in their everyday lives [18, 52].

Surely the design of analog circuits to replicate the basic principle of operation behind most of these home appliances would be too complicated (if it were even possible for those that are programmable) for a course spanning just one semester. Hence, for an electrical engineering design course there is a need to have µC-based projects that would help cover a wider range of more feasible and interesting projects. Most present day appliances have µCs (programmable toasters, stoves, microwave ovens, home security systems etc); not having µC-based projects would severely limit the possibilities of real-life projects. Moreover, if the µC could also be extended to a 'robotic' environment, it would make an exciting design challenge. Thus, it was decided to introduce a µC for these real-life projects.

The next issue that needed to be addressed was the language to develop the programs in high-level or assembly language? With the course being only one semester long, there would not be enough time to first teach assembly language and then let the students develop the projects. Thus, the µC needed to be programmable in a high level language that the students might have learned prior to taking this course. It may be noted that the students registering for this course were only required to take a single course in a high level language (C++) at the introductory level.

After taking the previously mentioned requirements into consideration, it was then decided to use an Object Oriented Programming Integrated Chip (OOPic™) [54] micro-controller as shown in Figure 1. The OOPic™ can be programmed in three different high-level languages i.e. BASIC, Java and C [55]. This would give students the option to develop programs in either language. Since most of the examples provided with the OOPic™ compiler were developed in BASIC and also since BASIC and C++ are quite similar, it made more sense to choose BASIC as the programming language for the course.

Figure 1: The OOPic II+ - Based Microcontroller.



Software using object-oriented programming is the realm of computer science and electrical engineering. To ease the problem of hardware interfacing, the firmware on the OOPic™ is composed of objects that are readily available with the compiler and are designed to work with various I/O hardware components. Examples of these components include the on-chip analog to digital converter (ADC), sensor drivers, liquid crystal display drivers (Figure 2), keypad drivers (Figure 3), serial port drivers etc, which by nature are components in real life EE projects. In object-oriented programming, if the objects are provided, the programmer merely has to set the various properties of the objects in a straightforward manner, following which the corresponding interface or function is customized to fit the problem. For example, oDio1 is defined as a 1-bit input/output line. It has the properties: direction (input or output), IOLine number, Value ('1' or '0') etc. Use of these objects would greatly reduce the complexity in programming, thereby giving students more time to spend on the development of the overall project.

Figure 2: LCD on a panel.

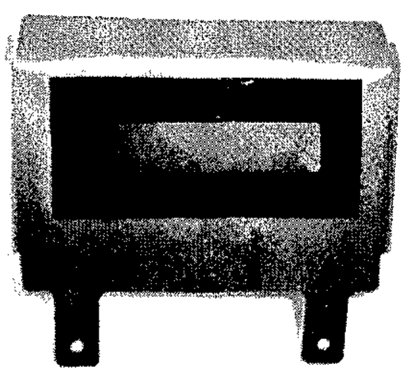
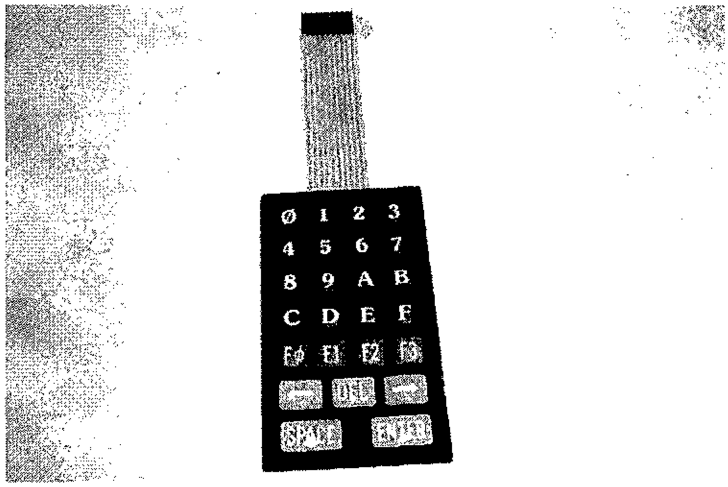


Figure 3: A Keypad



Components such as LEDs, LCDs, keypads etc can be used as I/O hardware to make some of the projects more realistic; the more the user interaction with the OOPic™, the more realistic the projects would appear. For example, in an 'Incubator' project, a keypad can be used to enter a desired set temperature and an LCD module can display both the current and the set temperature of an oven. In such a project, the temperature (T) can be 'sensed' by a thermocouple [56] and then can be converted to a voltage (linear with respect to 'T') by a signal-conditioning chip (ADJ 594) [57]. This linear voltage can then be converted to a 10-bit binary value by the on-chip 10-bit ADC, which in turn can be displayed on an LCD after it has been processed by means of a simple algorithm. In another project, the real-time clock, switches can be used to emulate the different functions (set time/alarm, alarm ON/OFF, increment hours/minutes/seconds etc). Depending on which switch is pressed, the corresponding prompt ("Set Time" etc) can be displayed on an LCD, thereby instructing the user as to what is expected.

The methods for interfacing that would be used for these projects are important in electrical engineering design, since they would demonstrate the ability to interface a μC with components that are needed for a real system.

5.1.2 Subject content crosses traditional subject boundaries: Hardware I/O components that can be interfaced with the OOPic^{TM} based μC cover wide areas in physics and electronics.

Sensors, motors, LEDs, switches, LCDs, keypads and serial/parallel port interfaces can all be controlled or modeled to interact with the OOPic^{TM}. Examples of sensors that can be used are infrared (IR), ultra sonic (US) [58] detectors, opto switches etc, which can be used for tasks like motion detection, distance approximation etc. In order to be able to use these sensors in conjunction with the OOPic^{TM} based μC, students would need to understand the underlying physics in these sensors. Specific labs can be designed to help the students observe the various waveforms (on an oscilloscope) and measure the voltages (with a multi meter), thus helping them better understand the functionality of these sensors and also giving them an opportunity to familiarize themselves with various laboratory instruments. The μC has an in-built ADC that can convert the output voltage of any transducer to a digital value, which can then be processed as required by the problem specifications. Students would need to understand the analog-to-digital conversion process if they intend to use the ADC in their projects. Thus, we see that by the use of real world projects that require various components, students would not only be learning electrical engineering design, but will also be exposed to concepts from physics, mechanics etc.

5.1.3 Students collaborate in small groups: The course should be lab-based and not lecture-based, which would make this mode of instruction more compatible with PBL. Based on the PBL characteristic to allow students to work in groups, thereby simulating the work environment they will face in their professional lives, students can be divided into groups of 3- 4 students. Another reason for a group-oriented class would be the limited availability of laboratory equipment and computer workstations.

Working in a group would allow the students to share their knowledge and take responsibility for their work. Being part of a team would also help the students improve their communication skills, since in order to be able to express their opinion they would need to be able to explain it clearly to fellow team members [7]. Students would also learn to assign tasks depending on the skills of the individual team members.

5.1.4 Assisted by facilitator: In a PBL course, the instructor assumes the role of a facilitator [1, 4-8, 12, 14, 17-23, 25]. This implies that there should not be many lectures delivered in class. Thus the Socratic style [2, 6, 8, 44, 45] of teaching can be adopted, where the students are steered to the right path by posing questions. This would require the instructor to be present in class and move from group to group in order to monitor students' progress. If any group is observed to be progressing slow or even taking a wrong approach, then the facilitator should guide the students towards the proper solutions.

The instructor should also develop the problem specifications, which may be handed out to the students in the class, thus emulating the process in today's engineering profession where the engineer is given a set of specifications desired by the clientele on what is expected from the final product. The problem specifications may be accompanied with experimental write up outlines for the software program and/or the required hardware set up. These outlines should provide students with a starting point and a framework upon which the software may be developed. Also, the facilitator should design the bigger and more complex projects as multiple stages, so that the students can work on each stage one at a time [33]. In order to facilitate their design process, the students should be provided with a range of resources (hand outs, the internet etc) [14].

With the class being just 1.25 hours long, the students would need to be able to spend as much possible time on designing and/or implementing their project rather than taking notes. This can be made possible by replacing lectures with handouts, thus saving time.

5.1.5 Information on how to develop the solutions is not usually given: Being a facilitator, the instructor plays a passive role in the students learning process [8]. As mentioned earlier, the instructor should only provide the students with the problem specifications posing as a 'client'. In the case, where it is felt that the problem specifications are a bit too complex for the students to comprehend, suggestive hints such as flow charts may also be supplied to them. Also, since the software approach taken is an objected-oriented one, the students can be provided with a list of the objects they could possibly use in order to actualize the assigned project successfully. In addition to this, a list of all the objects supported by the OOPic^{TM} compiler is readily available online [59]. For projects that use chips, the specification sheets should also be provided.

When the students are assigned comparatively more complex and bigger projects, the instructor should break the specifications into two or more sub-projects, in order to introduce the students to a 'divide and conquer' approach to designing such projects. For example, the incubator project, which is a comparatively complex project, can be broken down into sub-projects: a project to use the LCD as a monitor and a project to program the OOPic^{TM} to behave as a thermometer using a sensor (thermocouple) along with a signal-conditioning chip. After successfully designing these sub-projects, the students can then be asked to combine them to realize the incubator. In the case of the real-time clock with alarm feature, the students can first work on developing only the real-time clock. In the next stage they can work on adding certain functions such as setting the time etc. In conventional clocks it may be noted that all the features that are related with setting the time are also applicable to setting the alarm. Hence, after successfully designing the real-time clock, students can repeat the same process for adding the alarm feature.

Although, not a whole lot of information on how to develop the bigger projects is to be given, information required for a successful project design needs to be 'embedded' in the smaller projects that the students would work on. It is this information that the students should need to seek out and deploy in a productive fashion to successfully design the bigger projects.

5.1.6 Students identify the needed areas of learning: The handouts should contain only the problem specifications, the hardware set up etc; the students can expend the information supplied. From the specifications the students would need to identify the necessary information to realize a successful project. For example, if the project requires the result to be displayed on the LCD, or the use of a certain sensor, the students would need to understand the initialization and the various properties of the software objects related with these components. Thus, students would identify the extra knowledge to be acquired to help them solve the problem at hand.

5.1.7 Assessment should reinforce these characteristics: Students tend to perform a task or fulfill a duty only if they are given an incentive (grades) in return. In order to enforce the students to record the experiments conducted on a particular day, in the form of a lab notebook, the assessment scheme should include assignment of grades based on the lab notebook. Thus, a plausible weighting of the grade assessments for the course would be as follows:

- 60% of the grade would be based on lab notebooks (group) and formal reports (individual).
- 25% of the grade would be based on group presentation of final robot project.

- 15% of the grade would be based on the performance of the final robot project in the inter-group competition.

CHAPTER VI

COURSE AS DELIVERED: WHAT WENT RIGHT, WRONG AND WHY?

This chapter discusses the newer version of ECE 485W and its delivery to the students. The outcomes, both positive and negative of taking a PBL approach are discussed in the context of the characteristics of PBL.

6.1 PBL characteristics and the new course

6.1.1 Students address real-life problems: The projects that the students worked on can be classified into two categories: introductory labs and labs based on real-life projects.

Introductory labs were conducted in the beginning of the semester. These labs were more structured i.e. the hardware set up and the software programs were both provided to the students. The students completed the laboratory in a series of specified steps, much as any typical introductory laboratory. The main purpose of these labs was to introduce the students not only to the concepts of Object-Oriented Programming, but also to programming the OOPic^{TM} μC. In addition to this, these labs

- taught the students how to interface the μC with various hardware components like LED's, push-button switches etc
- helped the students familiarize themselves with various laboratory instruments like oscilloscopes, multi-meters etc, which could help them obtain data and/or debug their hardware and/or software while working on the projects.

Examples of such labs included experiments to turn an LED ON/OFF at a set rate, to perform basic 'AND' and 'OR' gate operations with the OOPic™'s internal clocks, to realize a virtual circuit[1] that can be event driven, and to perform analog-to-digital (A2D) conversions using the on-chip A2D converter. This approach contrasts with the previous course, where the students had no hands-on experience with structured laboratories that demonstrated how to program and interface components with a μC and in many cases they had never used a μC. By first making them go through structured laboratories (in the newer version) they learned how to use a μC and this gave them a much better understanding for applying the μC to solve the more complex problems.

After working on the introductory experiments, the students were assigned less well-defined projects. These projects required a comparatively more amount of time and effort. Projects were based on real-life projects like a smart traffic signal, a real-time clock [61], a voltmeter with digital read out, a temperature sensor with a digital display etc. These real-life projects were selected in order to motivate the students to try and realize successful solutions with minimal help and support from the instructor.

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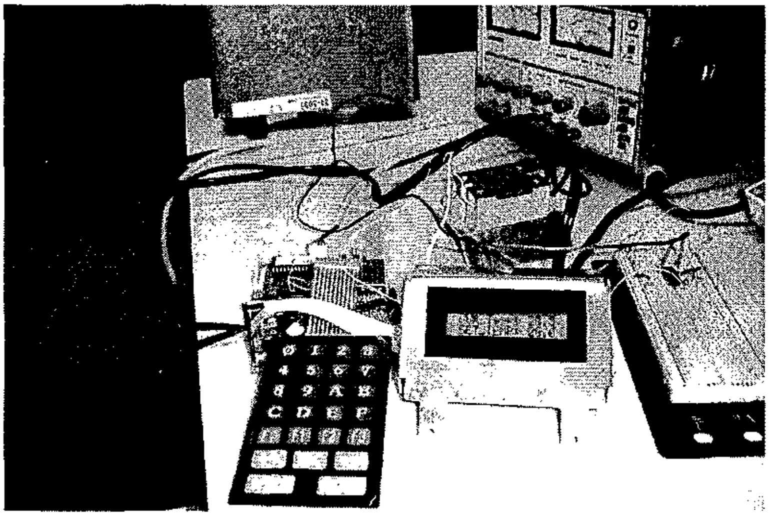
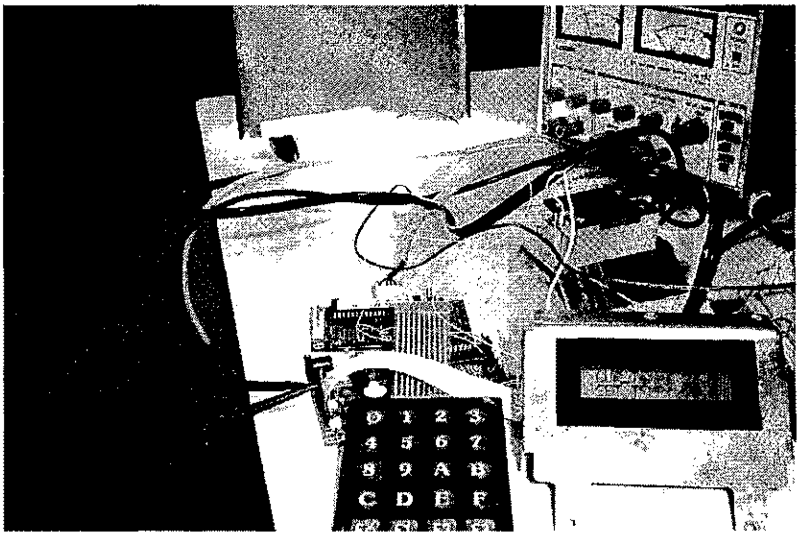
[1] A virtual circuit is a means of linking the various firmware components (objects) that are supported by the OOPic™ to acquire the data input to the OOPic™ by the hardware components and process it to output the responses of the system to these inputs [60].

Figure 4: Incubator: Cur_Temp >= Set_Temp -When the current temperature is greater than or equal to the set temperature in the box; the heat source (bulb) is OFF.



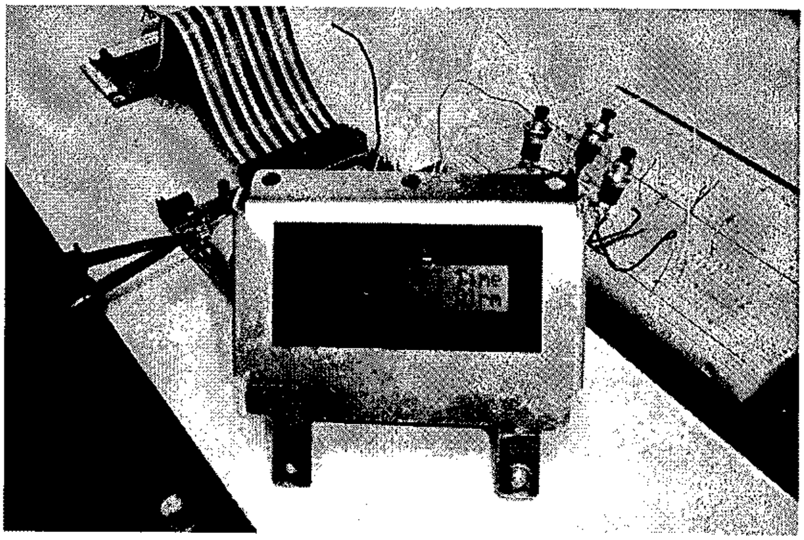
In the Spring 2004 semester, a comparatively complex project like the incubator, where the OOPic™ is programmed to control the temperature in a closed environment, was divided into multiple stages. The students learned to program the OOPic™ to work as a voltmeter, subsequently they were asked to add a thermocouple [56] (J-type) and a signal conditioning chip (ADJ 595) [57] and program the OOPic™ to display the temperature on an LCD. In the following weeks, students were then asked to interface a 4 X 4 keypad and an LCD, in order to be able to set the temperature of the incubator and use the LCD to display both the set temperature (Set_Temp) and current temperature (Cur_Temp). Following this, the students were asked to join these two already functioning sub-projects and realize an incubator as shown in Figures 4 and 5.

Figure 5: Incubator: Cur_Temp < Set_Temp - When the current temperature is lesser than the set temperature in the box, the heat source (bulb) is turned ON.



Similarly, in the Fall of 2004, the students were first asked to work on the real-time clock (RTC) example provided in the textbook [61]. After being able to display the time, students were then asked to add push button switches and implement the 'set time', 'increment hours', 'increment minutes', 'increment seconds', and the 'cursor' functions. Following a successful implementation, the students were asked to add the alarm feature to the already designed RTC. Since the students had already implemented the various functions for the time 'feature' of the clock they just had to repeat the same procedure (use the same push buttons for implementing the same functions) for adding the alarm feature. The real-time clock is shown in Figure 6.

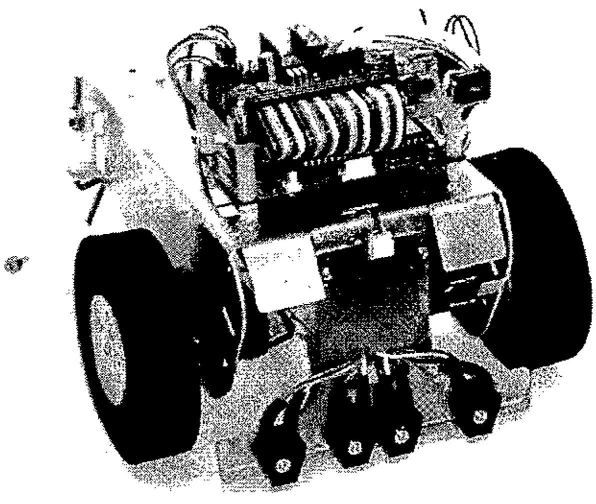
Figure 6: A Real-Time Clock with Alarm Feature.



Due to the modular and structured approach taken, all the groups were able to successfully finish all their projects. If the approach had not been as such, students would have been discouraged and stressed because they were not used to designing projects of such complexity on their own to meet deadlines. As was the case in the previous course where the students had no idea as to designing a complex project, such as that of a temperature sensor with a digital read out and had much less success.

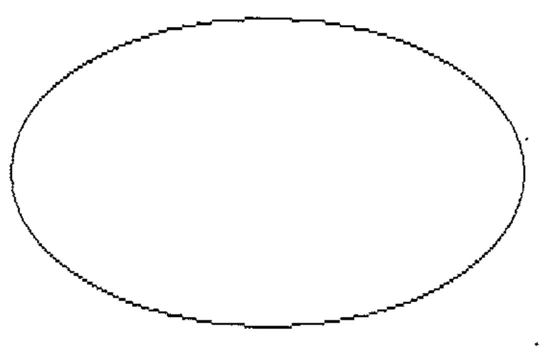
The final project (Spring 2004) was a line follower project as shown in Figure 7, one of the very numerous projects that can be realized by modifying the super droid trekker [62], which is an autonomous robot kit with sensors such as the IR, US etc and can be controlled by an OOPic'-based μC.

Figure 7 [62]: Superdroid Trekker: Line Follower.



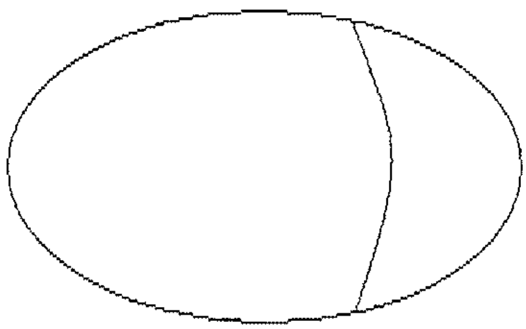
The objective of this project was to program the trekker to follow a pre-defined course for three laps in the shortest time. A starting program that could in principle follow the line on the track, as in Figure 8, was readily available for use from the super droid trekker web site [63].

Figure 8: A Conventional Track



The students were given a more challenging track with a short cut as shown in Figure 9, which required the modification of the delivered program. The trekker had to follow the outer track for at least one of the three laps.

Figure 9: Conventional Track: A Modification.

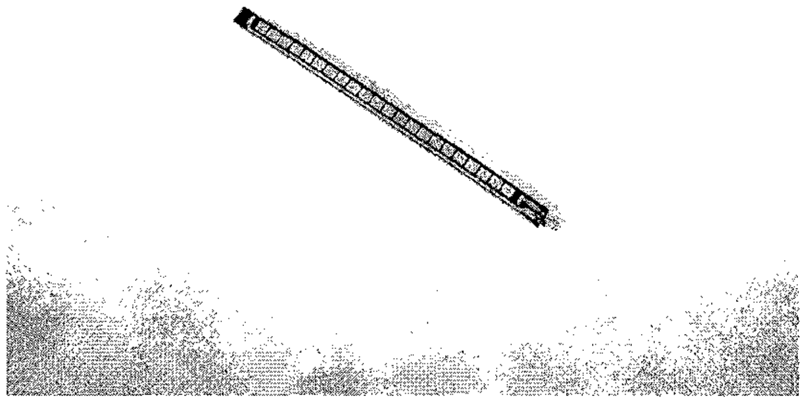


If a group did not modify the original program, then in that case the trekker would only follow the outer track, bypassing the short cut and hence resulting in longer lap times. On the other hand, if a group modified the program such that the trekker followed only the shorter track, they would then be violating the rules. So, a more complex program needed to be developed in order to have a winning time without violating the rules. This proved to be fun and challenging to both students and the instructors.

The final project in the Fall 2004 semester required the students to control a robotic arm [64] and pick 3 dowels and drop them in a small box. In the introductory classes of the same semester students had worked on the 'Push my finger' experiment in the text

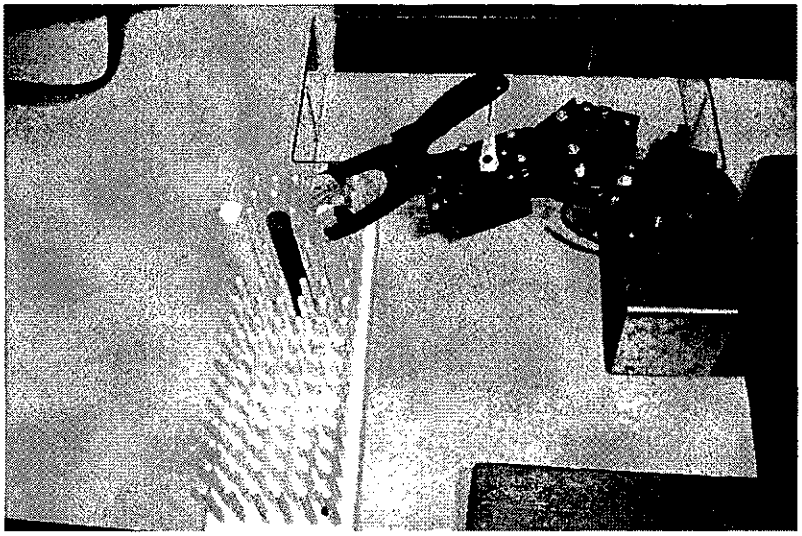
[65]. This allowed the students to control a servo's movements by means of bending a bend sensor [56] shown in Figure 10.

Figure 10: Bend Sensor



Since the students knew how to move one servo, controlling the robotic arm that contained a total of 4 servos proved to be challenging and fun. The robotic arm set up is shown in Figure 11.

Figure 11: Robotic Arm.



6.1.2 Subject crosses traditional subject boundaries: The course did not have a prescribed textbook in the Spring 2004 semester. Subsequently, a text [66] was prescribed for the Fall 2004 semester. The syllabus, handouts containing the problem specifications, and various web sites [54, 67] were the only guides that the students (Spring 2004) had on the topics to be covered during the course. While selecting the projects for the students, the instructor made sure that each project would give the students exposure to different hardware components, both analog and digital. Some of the components used in this class were, sensors such as infrared sensors, ultrasonic sensors, opto switch sensors, LCD's, keypads, thermocouples, solid-state switches, bend sensors etc. Use of sensors such as the IR, US, thermocouples etc, required the students to understand the physics of these sensors. In order to be able to use the signal conditioning chip (AD 595) [57] and the thermocouple for A2D conversions, or to quantify the IR voltage values in terms of real-world distances (inches), students had to understand the electronics of these hardware components. Also, to process the data output by the various sensors, the students had to understand the programming aspects of engineering. Thus, in order to be able to understand the principles of operation of these components, students were required to understand various concepts not only in electrical engineering, but also in physics, electronics and software programming.

6.1.3 Students collaborate in small groups: In the spring of 2004, a total of 25 students had registered for the course and a total of 21 students had taken the course in the fall of 2004. Due to the constraints on resources, like the number of OOPics, computer stations etc the students had to be divided into groups of 3 - 4. After the lab assignments/project specifications were handed out, one member would be seen working on the hardware, while one would be working on the software and the remainder would get to update the lab notebook. Some groups (in the Spring 2004 semester) were also noticed to have appointed a team leader to assign different tasks for fellow team members to perform.

In contrast to the above observations, for certain experiments, some groups would also have a few 'passengers' [1, 7], i.e. students just sitting there and not really contributing much. Some of these students had high grade-point averages, which indicated that they were good students. In this class they chose not to contribute much to the project because of two reasons. One reason was that the initial labs were too simple and required a comparatively lesser amount of effort from groups with 4 members. The second reason was that even for the bigger projects, once the hardware was set up, the only work left was implementing the software. The programming would usually be done by the best programmer in the group, especially in groups where they had a computer engineer as a member of the group. This was noticed to be a factor in only two of the six groups of the Spring 2004 semester.

In order to eliminate the possibility of 'passengers' in the Fall 2004 semester, the following measures were taken

- The students were asked to sign a code of cooperation [11] and paste it in their lab notebooks.
- The students were instructed to rotate roles such as hardware implementer, accuracy coach, and recorder [68].

6.1.4 Assisted by facilitator: Brief lectures were usually delivered at the beginning of a project to introduce the students to the project specifications. Unlike the older version of the course, where the instructor was not able to be present in the lab to monitor students' progress, in the new version the instructor and the teaching assistant would both be present in the lab through out the semester. Both the instructors assumed the roles of facilitators. They would move from group to group, monitoring students' progress and also probing them for their understanding of the project. Since the facilitators were both present in the class, most students felt comfortable approaching either facilitator with questions and problems. Also, the assistant had office hours allotted just before class.

This helped the groups that were lagging behind in their project and the groups that wished to get a head start on the project, to come in early before class and benefit from the presence of one of the facilitators.

As the progress of the students was being monitored, if it were ever noticed that a certain group was taking an approach that might not prove to be productive, they would usually be discouraged by questions, posed by the instructors, which would help the students get back on the right track. This usually involved assigning dummy values to the program variables and then asking the students to step-through the program. When the students were assigned new projects, students who were interested in adding more features (other than the problem specifications requirements) would approach the facilitators with questions like "We want to also add this feature to the project, are there any software objects available with the OOPic™ compiler that could help us achieve the same in a more efficient manner?" The usual response to such a question would be to list a few objects available with the OOPic™ compiler that could help the students achieve their task and then direct them to the OOPic™ website [54]. As a result, students would research the listed objects to analyze and decide for themselves, which objects they could use in their project.

Groups that had hardware and/or software issues would usually approach the instructor for assistance or guidance. At times like these, the facilitator would usually step in and help troubleshoot the circuit to ascertain the problem. Most of the times, before trouble shooting the circuit, the students would usually be asked questions based on the common mistakes that students tend to make. Examples of such questions are: "Are the 'grounds' of all these different circuits connected together?" "Are you sure the OOPic™ is being supplied the correct amount of power? If you do not know, please check it by means of a multi-meter" etc. After determining the cause of the problem, the students would take the necessary corrective steps to eliminate the problem. There have been cases were the traditional debugging approaches failed. This sometimes required both the facilitators to stay late after class to help the students overcome their difficulty. Sometimes the problem would not be so obvious; in such cases the facilitator would ask the students to raise the question in the next lab. This gave the facilitator (not an expert on the subject) more time to analyze the project and reach a valid conclusion that would in turn help in guiding the students.

All the facilitation done on both the instructors' parts helped to ensure that all groups finished their projects in time, in order to eliminate any sense of failure that maybe caused [7] .The teams that were noticed to be comparatively slower in their progress were given comparatively more one-on-one attention/facilitation.

6.1.5 Information on how to develop solutions is not usually given: As mentioned above, the instructors acted as facilitators. This implied that there were not many lectures delivered nor was there a textbook assigned for the course. Brief lectures at the start of the class would be delivered only to introduce the students to the project specifications. If the students found the project to be a bit complex, they were given hints such as flowcharts on the virtual circuits, which if implemented in the program, would result in a successful project.

With the problem specification, a list of objects was also provided. This list contained a detailed description of the different objects that the students could possibly use as building blocks for their programs and was accompanied with an example that illustrated how a certain object could be instantiated and used. Thus, the students would be equipped with only the problem specifications, basic flowcharts, and/or the processing objects. This information not only acted as the starting point for their design but also encouraged them to think about the various possible approaches to a particular problem.

6.1.6 Students identify the needed areas of learning: There was no textbook used and not many lectures were given in class. Since information was not given to the students on how to develop a successful project; the students were required to acquire knowledge on their own.

Several of the projects that were assigned to the students during the semester were designed in such a fashion that these projects could all be combined into a system. An example is the voltmeter, thermocouple and keypad projects that could be combined to realize an incubator with the addition of a solid state AC power switch that can be turned ON/OFF with the application of a mere 4.0 V (TTL voltage output by the OOPic™) and 0 V respectively.

The students were encouraged to record their progress and observations (for all experiments performed) in their lab notebooks, so that in the event a team member could not attend a particular lab, he/she could then have a documented version of the task executed on that particular day. Also, the projects usually required the students to refer to the previous projects (from the introductory labs) that were designed. As a result the students were able to realize the value of well-documented projects. For instance, when the students were assigned the voltmeter project to program the OOPic™ μC to read an input analog voltage (0 to 5V) and then display the corresponding voltage on an LCD display, the problem specification would state that the students should use the A2D converter. This would cause the students to refer back to the introductory experiment that they had performed earlier on the A2D converter, which would then act as a reference example. Similarly, after working on the voltmeter application of the OOPic™, the students were then asked to work on the thermometer application. Such a project required the students to refer back to the voltmeter application, since both these projects (i.e. the voltmeter application and the thermometer application) worked on the same underlying electrical and physical principles. Thus, the students found it necessary to refer to the knowledge acquired in the previous weeks (via the lab notebook) with the new knowledge they needed to acquire for the project at hand.

During the course the students had access to various resources. The most frequently referenced resource was the OOPic™ website [54], which lists all the various objects that can be used with the OOPic™ μC. Before a project was assigned to the students, the instructor and the teaching assistant would both design a trial version of the project, in order to ascertain the degree of difficulty of the project with respect to students' existing knowledge. While designing these projects, the instructor and the teaching assistant would always use concepts from the resources that are available to the students. In doing so, they were in effect replicating the design process the students would follow. If any of the concepts applied seemed to be difficult for the students to locate for themselves, the students would either be provided that resource along with the problem specifications or would be pointed towards it. Examples of such resources are data sheets for the J-type thermocouple [56], the ADJ 595 signal-conditioning chip [57], etc.

6.1.7 Assessment should reinforce these characteristics: Assessment can be further categorized as student assessment and the course evaluations. The following sections describe these two forms of assessment.

- Student assessment.
- Course evaluation.

6.1.7.1 Student assessment: The grade awarded to each student at the end of the semester was based on the student's demonstrations and submissions during the span of the whole semester. The grades were based on the OOPic™ programming homework (group work) (10%), reports, proposals and designs (individual) (55%), presentations (group work) (25%) and project demonstration (group work) (10%).

In the Spring of 2004, the students were also awarded a small percentage of their final grade based on peer evaluations. Most of the students did not appear to take these evaluations seriously. This was evident since 10/21 students had given maximum ratings (5) to all their team members. In addition, 3/21 students did not turn their peer evaluations in at all.

6.1.7.2 Course evaluation: It is crucial to evaluate every course at the end of the semester to in order to ascertain the impact made on the students enrolled in it. The course evaluations from the Fall 2001, Fall 2002, Spring 2004 and Fall2004 semesters is given in Appendix C. Although there is no standard deviation provided for the Fall 2001 semester, one can assume that this value would have been somewhat the same as the Fall 2002 standard deviation values. The Spring 2003 batch showed the weakest performance; unfortunately, there are no results/surveys from that particular semester.

The survey consisted of 14 questions. Although some of the questions might seem to have scored higher in the Fall 2001 (older version) semester than the Spring 2004 and the Fall 2004 (new versions), there is no statistical significance in terms of the standard deviation of the results. One can see that the results of the Fall 2001 and Fall 2002 semester do not exhibit any significant statistical difference, but the results of the two semesters when the new course was offered show a certain level of consistency. This clearly indicates that the course has been achieving the set goals. Another factor maybe due to the experience the students had gained by working at NASA. The following paragraphs discuss these results in detail.

The previous version involved designing analog circuits based on mathematical calculations. In contrast, the current version of the course involved a microcontroller and required comparatively lesser application of mathematical techniques. Hence, the higher scores (Fall 2001: 4.07; Fall 2002: 3.73 +/- 0.850) for question 1, which asked students if the methods taught improved their ability to apply mathematical techniques to solving engineering problems.

The earlier version involved the use of components such as resistors and capacitors in addition to some integrated chips. In contrast, the current version allowed students to design projects (incubator, real-time clock, smart traffic light, voltmeter etc) and conduct experiments (quantify the voltage output by the IR/US sensor in terms of real world distances etc) that involved the use of various sensors. This alteration required them to be able to understand the underlying physics of these sensors in order to be able to use them. Students from the PBL versions – Spring 2004 and Fall 2004 – gave higher scores (3.94 +/- 0.813 and 4.56 +/- 0.704) to question 2, whereas the scores from the non-PBL courses were: Fall 2001 – 3.71 and Fall 2002 - 3.67 +/- 0.603. Of the four batches of students surveyed, the students of Fall 2004 gave the highest score. This indicates that the course is indeed evolving in terms of content as well as reaching out to students of different calibers and experiences.

Question 3, which asked the students if the methods employed improved their ability to apply software tools and programming techniques to solve engineering problems, scored higher in the PBL versions (Spring 2004: 4.11+/- 0.829 and Fall 2004: 4.29 +/- 0.955). In spite of the absence of programming techniques in the earlier versions, question 3 got the same score for both versions (Fall 2001: 4.00 and Fall 2002: 3.31 +/- 1.129). This score might have been due to the fact that some of the students in the earlier version (Fall 2001) had used a microcontroller such as the MC68HC11 (Motorola 6811). This explains the scores for the Fall 2001 semester, but why the students gave a score such as 3.31+/- 1.129 in the Fall 2002 semester is difficult to fathom.

Questions 4 and question 5 ask similar questions as to whether the students agree if they were able to improve their ability to design and conduct engineering experiments through component design etc. The scores given by the students for the PBL courses (Spring 2004: Q.4 – 3.95 +/- 0.875, Q.5 – 3.79 +/- 1.002 and Fall 2004: Q.4 – 4.53 +/- 0.696, Q.5 – 4.41 +/- 0.771) indicate some improvement of the course in terms of content thereby allowing students to take new approaches to engineering design. Although the scores for the Spring 2004 semester are not as good as the score for the Fall 2001 semester (Q.4 – 4.07, Q.5 – 4.47), they are notably better than the Fall 2002 scores (Q.4 – 3.58 +/- 0.775, Q.5 – 3.50 +/- 1.041). The Fall 2004 scores fall in the same range as the Fall 2001 semester scores, indicating improvement in the delivery of the course.

Question 6 asked the students if they were able to participate in a team environment and whether or not it led to the improvement of their team skills. This question scored the highest in the Fall 2004 semester (4.70 +/- 0.570) and the second highest in Spring 2004 (4.42 +/- 0.95). After Spring 2004, both the instructor and his assistant decided to implement group strategies such as peer evaluations and rotation of roles in order to solve the problems with passengers, which was observed in the Spring 2004 semester. As a result of which, most of the students in the Fall 2004 semester were given a chance to shoulder the various responsibilities involved in working on a project in a team. The strategies adopted helped students to hone their team participation skills. These results show an improvement over the Fall 2002 semester, but not over that of the Fall 2001. As discussed, the NASA strained students (Fall 2001) were used to working in groups from the workplace. Consequently, their team skills were already highly developed.

Questions 7 and 8 show no significant rise in the scores, nor do they show any decline (as compared to the Fall 2002 scores). Question 9 shows an increase in the scores for the PBL versions (Spring and Fall 2004) when compared with the Fall 2002 semester. The scores for these questions in the PBL versions indicate consistency, which is absent in the scores of the non-PBL versions (Fall 2001 and 2002).

Question 11 and 12 (that are based on similar lines) asked the students whether they had to use computer-based tools to aid in the design process, scored high for the PBL versions (Spring 2004: Q.11 – 4.42 +/- 0.754, Q.12 – 4.11 +/- 0.829; Fall 2004: Q.11 – 4.52 +/- 0.499, Q.12 – 4.375 +/-0.484). These scores show significant improvement than the scores from the non-PBL versions. Question 11 scored a 2.75 +/- 1.010 with the Fall 2002 students, but on similar lines Q.12 scored a 4.20 +/- 1.166 with the same students.

Question 13 inquires if students were able to improve upon their oral presentation skills. Both versions (PBL and non-PBL) of the course required students to make presentations. The PBL versions scored lower than the non-PBL version (Fall 2001).

Question 14 asked the students if they were able to develop their writing skills. The scores for this question show a significant change for the PBL versions (Spring 2004: 4.47 +/- 0.702; Fall 2004: 4.13 +/- 0.984) over both the non-PBL versions of the course (Fall 2001: 3.33; Fall 2002: 3.40 +/- 0.663). This seems to be due to the fact that students were allowed to make one resubmission of their reports, thereby allowing them to make the necessary changes as mentioned in the feedback from the instructor.

CHAPTER VII

CONCLUSIONS

Implementing a PBL framework into a lecture-based course can be challenging to both the students and the lecturer. Making a transition from a lecture-based format to a PBL format is an evolving process. If it is evident that the course has shortcomings, then necessary steps must be taken to improve the delivery of future courses. The following are the observations that were made in the Spring 2004 semester. Subsequently in the Fall 2004 semester, necessary actions were taken to overcome some of these shortcomings.

- The development of real-life projects can be quite time-consuming. This also has cost implications, since real-life projects tend to use components that are oftentimes quite expensive if ordered in large quantities. Thus, one is left with only a handful of real-life projects that are 'recycled' every alternate semester.
- There is also the problem with 'passengers'. This was observed in the implementation of PBL in the Spring 2004 semester. In order to tackle the problem and to ensure that the grades assigned to the students were what they actually deserved, the concept of peer evaluation forms was introduced in the Fall semester.
- Students would merely perform the same task for all the projects. For instance, if student 'A' was developing the software for a certain project then s/he would perform the same task for the subsequent projects as well. This did not help to ensure that the students were being exposed to various design concepts of a

project. Students were encouraged to assume a different role (hardware implementer, software implementer, accuracy coach or lab notebook recorder) for each class session [68] in the Fall 2004 semester. In addition, the students were asked to make a note in their lab notebooks of the roles for each project/experiment.

- Facilitation can sometimes be quite demanding for a class duration of 1.25 hours. Either PBL courses should be implemented in classes with lab durations of at least 2 hours, or more assistants need to be hired to ensure all groups get proper guidance.
- ECE 485 W is a design-based course and since the objective of this course is to teach students to be good designers, students need to learn the proper approach to software design and also should be expected to practice it. They need to realize that the flowchart comes prior to the program and not after it. Thus, submitting a flowchart for the program ought to be one of the criteria for the student assessment.
- Another challenge faced was students failing to take the peer evaluations seriously. The evaluations were taken in the Fall 2004 semester and as mentioned earlier (Sections 6.1.7.1), despite the fact that 10/21 students had given full ratings, 3/21 students did not turn their peer evaluations in. One way to address this issue might be to make the peer evaluation score as a weighting factor (WF). This WF can be used to determine the score of an individual in activities done as a group. If a group scores a 'B+' which may be a score of 87, then the individual score (IS) of a student of that group would be IS = 50 + WF * (87 – 50); the WF

can be calculated as: WF = Individuals average on the peer evaluation /team's average on the peer evaluation. A detailed scheme is provided in Appendix D, which was handed out to students of the Spring 2005 semester.

- Since a PBL course differs significantly from a traditional course, it is very difficult to assess students in a PBL course. Consequently, the students cannot be tested on multiple-choice questions and/or analytical questions.

From the survey provided in Appendix C one can conclude that a PBL-based teaching method for the delivery of the ECE 485W course has shown significant improvement in areas associated with the course content and assessment schemes. A PBL course is always evolving in these areas. Each PBL experience offers something new that is to be discovered and implemented the next time the course is offered.

A PBL course is very innovative as well as extremely challenging for both the staff and the students, yet this experience can be fun for both the former and the latter. Schools need to have more courses based on problems. Another possible approach might be a class offered by both the computer and electrical departments in partnership. Thereby, demonstrating to the students what is demanded in today's market; a partnership between engineers in solving problems.

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APPENDIX A

A Typical PBL Project assigned to the students at NDSU [6].

From the desk of Chief Engineer

Basin Electric Power Cooperative, Bismarck, ND

February 29, 20xx

Dear Members of Instrumentation Engineering Team,

As you are aware that the construction for unit 2 at the Leland Olds Station in Stanton, ND began in July 1971 at a cost of $109 million. It has a capacity of 440 MW. This second unit began commercial operation in December 1975. This unit is going through complete remodeling and I would like your team to suggest instruments for measuring water/steam temperatures at the inlet and outlet of the boiler, turbine, and condenser.

I would like you to give your final selections, the rational for selecting them and cost of the units. In the appendix, please include other alternatives considered and their advantages and disadvantages.

I will appreciate it, if your group can present the results at the board meeting to be held in the week of March 20 during your lab period.

If you have any questions, please let me know.

Sincerely,

Sudhir Mehta

APPENDIX B

FIGURES AND GRAPHS FOR CHAPTER III

Figure 12 [51]: Skills and Tools Web Page.

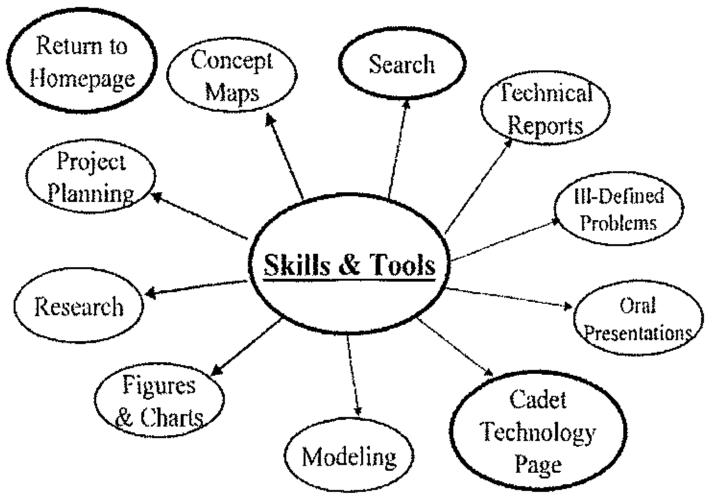
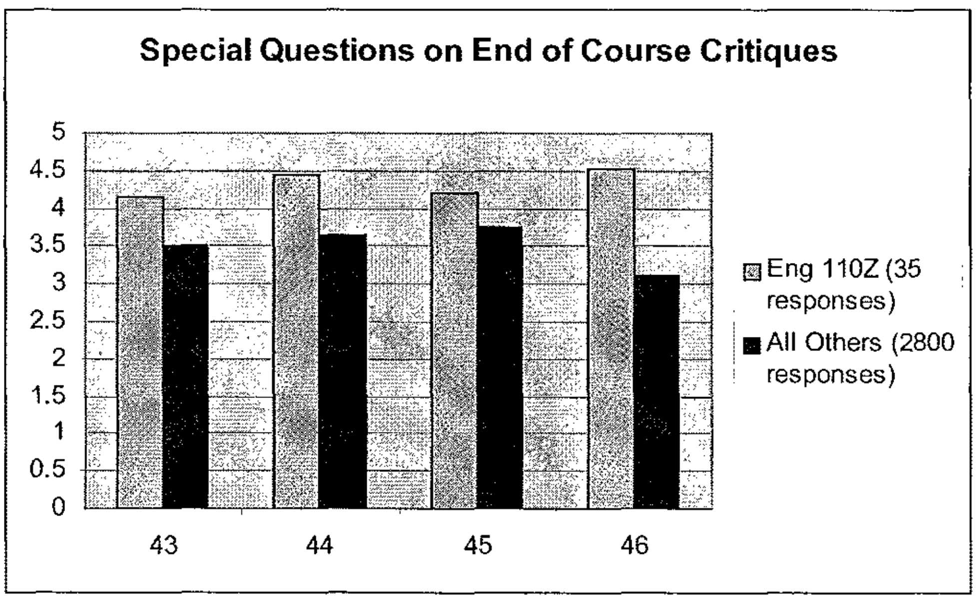


Figure 13 [52]: Student Perspective on Critical Thinking Skills Development.



43. I was an active participant in class.
44. My instructor provided time for discussion and/or group work.
45. My instructor designed activities that made me think.
46. This course required me to be actively involved in my learning.

Table 2[13]: Effectiveness of PBL Methods and Satisfaction with the Course.

Course	**Hands-On experiences (% Very effective)**	***Term Projects (% Very effective)***		**Relevant (% Agree and Strongly agree)**	**Worthwhile (%agree and strongly agree)**
Intro. To Aerospace Design	85	88		58	63
Unified Engineering I	78	--		97	94
Unified Engineering II	48	--		95	94
Aerodynamics	68	64		90	82
Experimental Methods I	67	70		92	96
Experimental Methods II	78	65		78	74
CDIO Capstone (Part I)	75	50		100	75
Space Systems Design	72	94		100	83

APPENDIX C

ECE 485W

ABET SURVEY RESULTS

Earlier Versions: Fall 2001 and Fall 2002

PBL Version: Spring 2004 and Fall 2004

Numerical Scoring on Question:
- 5 – strongly agree with the statement
- 4 – agree with the statement
- 3 – neutral (from slightly agree to slightly disagree)
- 2 – disagree with the statement
- 1 – strongly disagree with the statement
- N/A – no basis to judge.

Note: The N/A responses were thrown out in the calculations of the average and the standard deviation.

Number of Respondents: Fall 2001: Not available, Fall 2002: 13, Spring 2004: 19, Fall 2004: 17.

1. The methods taught in this course improved my ability to apply mathematical techniques to solve engineering problems:

   a. Fall 2001: Ave: 4.07 (out of 5) Standard Deviation: Not Available
   b. Fall 2002: Ave: 3.73 (out of 5) Standard. Deviation: 0.850
   c. Spring 2004: Ave: 3.58 (out of 5) Standard Deviation: 0.986
   d. Fall 2004: Ave: 3.56 (out of 5) Standard. Deviation: 1.152

2. The methods learned in this course improved my ability to model components, processes, and/or systems based on their underlying physics, and apply these models to solve engineering problems.

   a. Fall 2001: Ave: 3.71 (out of 5) Standard Deviation: Not Available
   b. Fall 2002: Ave: 3.67 (out of 5) Standard. Deviation: 0.603
   c. Spring 2004: Ave: 3.95 (out of 5) Standard Deviation: 0.813
   d. Fall 2004: Ave: 4.56 (out of 5) Standard. Deviation: 0.704

3. The methods learned in this course improved my ability to apply software tools and programming techniques to solve engineering problems.

a. Fall 2001: Ave: 4.00 (out of 5) Standard Deviation: Not Available
b. Fall 2002: Ave: 3.31 (out of 5) Standard. Deviation: 1.129
c. Spring 2004: Ave: 4.11 (out of 5) Standard Deviation: 0.829
d. Fall 2004: Ave: 4.29 (out of 5) Standard. Deviation: 0.955

4. This course improved my ability to design and conduct an engineering experiment and to analyze and interpret the data.

a. Fall 2001: Ave: 4.07 (out of 5) Standard Deviation: Not Available
b. Fall 2002: Ave: 3.58 (out of 5) Standard. Deviation: 0.775
c. Spring 2004: Ave: 3.95 (out of 5) Standard Deviation: 0.875
d. Fall 2004: Ave: 4.53 (out of 5) Standard. Deviation: 0.696

5. In this course, my ability to design a component, process, program, or system that met specified requirements improved.

a. Fall 2001: Ave: 4.47 (out of 5) Standard Deviation: Not Available
b. Fall 2002: Ave: 3.50 (out of 5) Standard. Deviation: 1.041
c. Spring 2004: Ave: 3.79 (out of 5) Standard Deviation: 1.002
d. Fall 2004: Ave: 4.41 (out of 5) Standard. Deviation: 0.771

6. In this course I participated in a team environment or learned skills that will assist me in participating in a team environment.

a. Fall 2001: Ave: 4.20 (out of 5) Standard Deviation: Not Available
b. Fall 2002: Ave: 3.36 (out of 5) Standard. Deviation: 0.787
c. Spring 2004: Ave: 4.42 (out of 5) Standard Deviation: 0.995
d. Fall 2004: Ave: 4.70 (out of 5) Standard. Deviation: 0.570

7. This course improved my ability to identify, formulate, and solve electrical and/or computer engineering problems.

a. Fall 2001: Ave: 4.13 (out of 5) Standard Deviation: Not Available
b. Fall 2002: Ave: 3.55 (out of 5) Standard. Deviation: 0.631
c. Spring 2004: Ave: 4.00 (out of 5) Standard Deviation: 0.973
d. Fall 2004: Ave: 4.17 (out of 5) Standard. Deviation: 0.705

8. I was introduced to issues related to professional and ethical responsibility in this course.

a. Fall 2001: Ave: 3.94 (out of 5) Standard Deviation: Not Available
b. Fall 2002: Ave: 3.15 (out of 5) Standard. Deviation: 1.359
c. Spring 2004: Ave: 3.61 (out of 5) Standard Deviation: 1.300
d. Fall 2004: Ave: 3.70 (out of 5) Standard. Deviation: 1.225

9. This course helped me understand how engineering practice relates to contemporary issues.

   a. Fall 2001: Ave: 4.00 (out of 5) Standard Deviation: Not Available
   b. Fall 2002: Ave: 2.85 (out of 5) Standard. Deviation: 0.937
   c. Spring 2004: Ave: 3.32 (out of 5) Standard Deviation: 1.066
   d. Fall 2004: Ave: 3.68 (out of 5) Standard. Deviation: 0.845

10. I was required to use modern engineering techniques, skills, and tools to solve analysis and/or design problems presented in this course.

    a. Fall 2001: Ave: 4.07 (out of 5) Standard Deviation: Not Available
    b. Fall 2002: Ave: 3.18 (out of 5) Standard. Deviation: 0.840
    c. Spring 2004: Ave: 4.05 (out of 5) Standard Deviation: 0.702
    d. Fall 2004: Ave: 4.11 (out of 5) Standard. Deviation: 0.831

11. I was required to use computer-based tools to aid in the analysis and/or design problems presented in this course.

    a. Fall 2001: Ave: 4.56 (out of 5) Standard Deviation: Not Available
    b. Fall 2002: Ave: 2.75 (out of 5) Standard. Deviation: 1.010
    c. Spring 2004: Ave: 4.42 (out of 5) Standard Deviation: 0.754
    d. Fall 2004: Ave: 4.52 (out of 5) Standard. Deviation: 0.499

12. This course improved the students' ability to apply advanced programming techniques to solve engineering problems.

    a. Fall 2001: Ave: 3.80 (out of 5) Standard Deviation: Not Available
    b. Fall 2002: Ave: 4.20 (out of 5) Standard. Deviation: 1.166
    c. Spring 2004: Ave: 4.11 (out of 5) Standard Deviation: 0.829
    d. Fall 2004: Ave: 4.37 (out of 5) Standard. Deviation: 0.484

13. In the presentation required for this course, I improved my ability to make effective oral presentations.

    a. Fall 2001: Ave: 4.21 (out of 5) Standard Deviation: Not Available
    b. Fall 2002: Ave: 3.09 (out of 5) Standard. Deviation: 0.903
    c. Spring 2004: Ave: 3.79 (out of 5) Standard Deviation: 1.279
    d. Fall 2004: Ave: 3.94 (out of 5) Standard. Deviation: 1.087

14. In the reports required for this course, I improved my ability to write convincing and well-documented reports.

    a. Fall 2001: Ave: 3.33(out of 5) Standard Deviation: Not Available
    b. Fall 2002: Ave: 3.40 (out of 5) Standard. Deviation: 0.663
    c. Spring 2004: Ave: 4.47 (out of 5) Standard Deviation: 0.702

d. Fall 2004: Ave: 4.13 (out of 5) Standard. Deviation: 0.984

APPENDIX D

GROUP WORK IN ECE 485W

Spring Semester

20 January 2005

Motivation:

Working in groups is a very important aspect of engineering practice. When working on a project for an engineering firm, engineers are routinely assigned into working groups with higher management making the decisions about who will be working in the group.

The goals of the group are to finish the project successfully and deliver the result on time and under budget. To accomplish this, the group is required to work as a team, with each member contributing a significant part to the success of the group, and no member claiming credit for work that they didn't deserve.

Group Work Grading:

The grading for this course involves 50% involving individual work and 50% involving group work. The individual work involves the writing of two reports 35% and the person's performance as an individual on the final presentation 15%. The group work involves the lab notebook 20%, the attendance 15%, the overall group performance on the final presentation 10%, and the group performance in the final tournament 5%.

The course is broken up into three portions or phases: Phase 1: the five initial OOPic experiments lasting 3 weeks, Phase 2: an intermediate OOPic project lasting 5 weeks, and Phase 3: a final Trekker robotic competition lasting 6 weeks. The breakdown of group versus individual work for the various phases is as follows:

Phase:	Lab Notebook: (Group)	Attendance & Competition (Group):	Report or Presentation (Individual):	Group Presentation:
1	4%	4%	10%	
2	8%	8%	25%	
3	8%	8%	15%	10%
Totals:	20%	20%	50%	10%

Attendance:

The attendance and competition group grade will be weighted by the percentage of classes attended during each of the phases. Absences can be made up by good one-page summaries on the work the group did on the day you were absent for one absence during phase 1 and for up to two absences in phases 2 and 3. Being absent more often than this will diminish your ability to make regular contributions to the success of the project. If there are extended absences are caused by an illness documented by a doctor or nurse's note, arrangements will be made so the work can be completed.

Good Performance in Groups 1: Awareness.

To begin with, a member of a group must be aware of the responsibilities associated with this position. These include:

Did you attend all the class meetings?
Did you come prepared for the laboratory?
Did you contribute to the group's discussion and effort?
Were you willing to take on different group assignments and did you contribute significantly in each role?
Were you willing to work outside of class and bring the relevant information back to the group for discussion?
Were you a good listener who respected the opinions of others?
Did you contribute to the overall experiment or project and the analysis and the conclusions?

To make sure you are aware of the basic responsibilities of being a good group member, there will be two copies of the attached 'Rules for Good Group Function' signed by each group member: one signed copy of 'Rules for ....' will be taped to the inside front cover of the lab notebook and one will be turned into your instructor. By signing this document, you are committing yourself to follow these rules, which is a good start.

Good Performance in Groups 2: Peer Review.

Three peer reviews will be performed at the end of each phase as a follow up on these good intentions. A copy of the peer review form is attached.

The mechanics of the peer review are as follows. Three times during the semester, a peer review form will be emailed to you. Each member of the group will score all the individuals in the group including themselves on the basis of 0 to 5 points on each question. The average of these scores for each individual will be divided by the average of the average score of all the members of the group to determine an individual weighting factor on the group's grade.

The weighting factor WF is applied to the points above 50, so if a group got a middle B+ or 87 for a phase, which is 37 points above 50 then the individual's score IS for that phase would be:

$$IS = 50 + WF * 37 \qquad 1).$$

So if individual #1 got an average score of 1.0 and the group average was a 2.5, this individual would get:

$$IS1 = 50 + 1.0/2.5*37 = 64.8,$$

which is a D-. If individual #2 in that same group got an average score of 5 (best possible):

IS2 = 50 + 5.0/2.5*37 = 124,

or 100 the highest possible (A+).

Finally, if all the members of a group make a pact to give every member of the group a 5 on all the questions so the individual average and the group average are both 5, the weighting factor will be 1.0. So if the group grade was a B- or 81 then all this group's members would receive:

ISall = 50 + 5.0/5.0*31 = 81.

Failure to return a peer review:

Note that failure to return a completed peer review evaluation for a phase will result in the lowering of your individual group grade by 3 points (say from a B to a B-) for that phase.

Reporting your results to you:

Your group grade, your individual group grade, your weighting factor and any comments made about you by the other group members (without revealing the name of the individual making the comment) will be reported to you after each phase.

Develop good habits for working in groups:

The peer review should give you an opportunity to 'voice' your concerns and a way of reminding you of your responsibilities to your group. Hopefully this will help you develop good habits in your role in groups during the rest of your career.

Grading Scale for this semester in ECE 485W:

93 = A; 90 = A-; 87 = B+; 84 = B; 81 = B-; 78 = C+; 75 = C; 72 = C-; 69 = D+; 66 = D, 63 = D-; F < 63.

GROUP WORK IN ECE 485W

SPRING SEMESTER 2005

Dr. Glenn Gerdin

20 January 2005

RULES FOR GOOD GROUP FUNCTION:

1. **Come to all class meetings on time. Notify the members of the group if class must be missed.**
2. **Come to class prepared, which means you have read the lab write-up, book chapter(s) and any other relevant background materials.**
3. **Contribute to the group's discussion and effort.**
4. **Be willing to take on different group assignments and to contribute significantly in each role.**
5. **Be willing to work outside of class and bring the relevant information back to the group for discussion.**
6. **Be a good listener who respects the views, values, and ideas of others.**
7. **Contribute to the overall experiment or project and the analysis and the conclusions.**

Each of us as members of this group, agree to follow these rules for the better functioning of our group. This agreement is acknowledged by our signatures shown below:

Signature	**Same name printed.**
Signature	**Same name printed.**
Signature	**Same name printed.**
Signature	**Same name printed.**

There will be two signed copies of this agreement. One copy is to be given to your instructor and another will be taped on the back inside cover of your group's laboratory notebook.

ECE 485W Spring Semester 2005

Confidential Peer Evaluation Form

Feedback Chart: In the following chart, each line describes a different characteristic of a group member. You are to fill in this chart with number 0 – 5 from the table that best describes how each member of your group rates in each of these characteristics.

Score	Meeting
0	Never – Does not describe the group member.
1	Rarely – Describes the group member only 10% of the time.
2	Occasionally - Describes the group member only 20% of the time.
3	Periodically - Describes the group member only 40% of the time.
4	Frequently - Describes the group member only 70% of the time.
5	Always - Describes the group member all of the time.

Item:	You	Member # 1	Member #2	Member #3
Is prepared for class.				
Listens to everyone's ideas.				
Shares the work load.				
Values all member's contributions.				
Helps us progress to a solution.				
Has good ideas.				
Keeps everyone on task.				
Helps the group find mistakes.				

You: Sandy Beach

Member #1: No Beta; Comments on Member #1:

Member #2: R2D2; Comments on Member #2:

Member #3: Dewey Cheatham; Comments on Member #3:

GROUP WORK IN ECE 485W

Spring Semester

20 January 2005

Roles for Group Members and Rotation

Roles for Group Members:

1. Coordinator – Leader.
   a. Keeps group on track.
   b. Maintains full participation.
   c. Leads in the analysis of data.
   d. Leads in the development of conclusions.

2. Recorder.
   a. Maintains the laboratory notebook.

3. Programmer.
   a. Sets up object flow chart to meet the goals of the program.
   b. Writes a program that implements the flow chart.
   c. Documents the program for future users.
   d. Trouble shoots program.

4. Hardware Implementer.
   a. Acquires the tools and components needed for the experiment or project.
   b. Wires the circuitry from circuit diagrams and schematics.
   c. Sets up test equipment to monitor performance and test functionality.

5. Accuracy coach.
   a. Checks hardware setup and circuitry against the appropriate diagrams for accuracy.
   b. Checks program flow chart, to see if it will lead to a solution of the software problem.
   c. Checks the program, to see if the flow chart has been properly implemented.
   d. Checks the program documentation, to see if one can follow the reasoning for the various steps in the program.
   e. Checks the analysis of the data.
   f. Checks the validity of the conclusions.

GROUP WORK IN ECE 485W

Spring Semester

20 January 2005

Roles for Group Members and Rotation.

Division of Roles for Three Member Groups:

1. Leader – Recorder – Hardware Checker.
   a. Keeps group on track.
   b. Maintains full participation.
   c. Leads in the analysis of the data.
   d. Leads in the development of conclusions.
   e. Maintains the laboratory notebook.
   f. Checks hardware setup and circuitry against the appropriate diagrams for accuracy.

2. Programmer.
   a. Sets up object flow chart to meet the goals of the program.
   b. Writes a program that implements the flow chart.
   c. Documents the program for future users.
   d. Trouble shoots program.

3. Hardware Implementer – Accuracy Coach.
   a. Acquires the tools and components needed for the experiment or project.
   b. Wires the circuitry from circuit diagrams and schematics.
   c. Sets up test equipment to monitor performance and test functionality.
   d. Checks program flow chart, to see if it will lead to a solution of the software problem.
   e. Checks the program, to see if the flow chart has been properly implemented.
   f. Checks the program documentation, to see if one can follow the reasoning for the various steps in the program.
   g. Checks the analysis of the data.
   h. Checks the validity of the conclusions.

TO INSURE THAT ALL MEMBERS OF EACH GROUP GAIN EXPERIENCE IN EACH OF THESE ROLES, I WANT YOU TO ROTATE THESE ROLES BETWEEN THE MEMBERS AFTER EACH EXPERIMENT OF PROJECT. THIS IS TO BE SHOWN IN THE LAB NOTEBOOK BY LISTING EACH OF THESE ROLES AND

THE GROUP MEMBER ASSIGNED TO IT AT THE BEGINNING OF THE EXPERIMENT OR PROJECT.

Group Work ECE 485W, Spring Semester

20 January 2005

Roles for Group Members and Rotation

Division of Roles for Four Member Groups:

1. Group Leader and Hardware Implementer.
   a. Keeps group on track.
   b. Maintains full participation.
   c. Leads in the analysis of the data.
   d. Leads in the development of conclusions.
   e. Acquires the tools and components needed for the experiment or project.
   f. Wires the circuitry from circuit diagrams and schematics.
   g. Sets up test equipment to monitor performance and test functionality.

2. Recorder.
   a. Maintains the laboratory notebook.

3. Programmer.
   a. Sets up object flow chart to meet the goals of the program.
   b. Writes a program that implements the flow chart.
   c. Documents the program for future users.
   d. Trouble shoots program.

4. Accuracy coach.
   a. Checks hardware setup and circuitry against the appropriate diagrams for accuracy.
   b. Checks program flow chart, to see if it will lead to a solution of the software problem.
   c. Checks the program, to see if the flow chart has been properly implemented.
   d. Checks the program documentation, to see if one can follow the reasoning for the various steps in the program.
   e. Checks the analysis of the data.
   f. Checks the validity of the conclusions.

TO INSURE THAT ALL MEMBERS OF EACH GROUP GAIN EXPERIENCE IN EACH OF THESE ROLES, I WANT YOU TO ROTATE THESE ROLES BETWEEN THE MEMBERS AFTER EACH EXPERIMENT OF PROJECT. THIS IS TO BE SHOWN IN THE LAB NOTEBOOK BY LISTING EACH OF THESE ROLES AND THE GROUP MEMBER ASSIGNED TO IT AT THE BEGINNING OF THE EXPERIMENT OR PROJECT.