AC 2011-374: INTRODUCTORY PROJECT-BASED DESIGN COURSE TO MEET SOCIOECONOMIC CHALLENGES

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INTRODUCTORY PROJECT BASED DESIGN COURSE TO MEET SOCIOECONOMIC CHALLENGES

Abstract

An active/cooperative, introductory engineering design course is planned, implemented, assessed, and evaluated using the project based learning approach to allow freshman level students to gain professional hands-on engineering design experience. The course project exposes the students to important contemporary issues, and excites their interest to address them in a creative way. The students are guided to discover by themselves how and why engineering approaches work, rather than simply providing a recipe for a solution. The open-ended design process allows the students to discover underlying complex engineering and scientific principles, and provide motivation for further study and engagement. The course was implemented for the first time in fall 2009. The students were asked to design a small wind turbine suitable for home use for energy saving purposes. Direct and indirect assessment tools indicated high level of achievement of course learning outcomes together with a high level of student satisfaction.

Keywords

Engineering design, contemporary issues, freshmen engineering students, project based learning, entrepreneurship

Introduction

A project based design course that introduces freshman students to future challenges and enhances their entrepreneurship skills was implemented. The topics of the course projects have a common goal of addressing socioeconomic challenges such as reduction of CO_2 emission and energy consumption through the use of renewable energies. The course assesses the students in developing micro-generation projects for householders, public authorities and businesses, including, small-scale wind power and solar energy technologies. Another important goal is to encourage entrepreneurship through hands-on practicing of how to design, implement and manage small projects. The direct socioeconomic benefits from entrepreneurship are to create new jobs through mini projects and to utilize the natural recourses to improve the quality of life.[1]

Renewable energy offers economic development opportunities for rural areas and reduces energy consumption and carbon emission in urban areas. Climate change mitigation is considered as a high international priority and is placed in the top of the agenda for most politicians and decision makers. The key challenge is that low-carbon sustainable technologies need to be adopted both by developed as well as developing countries.[2-4] The sustainable human development index is influenced by parameters linked to environmental sustainability and quality of life.[5,6]

The need to expand power systems to meet the demand in rural areas and improve the quality of life is identified as one of the current socioeconomic challenges in Saudi Arabia. Extending central power systems to rural areas is too costly while small-scale energy systems could meet the electricity demand in remote locations. Such limited electrical power, however, is expected to contribute greatly to the quality of life in such places.

In order to introduce freshmen students to such socioeconomic challenges, the authors started revising an active cooperative learning modeling course for freshmen, IE 202: Introduction to Engineering Design II. Project-based learning was identified as an effective learning approach.

The aim was to develop IE-202 from just a modeling course into a project-based active/cooperative learning introductory design course. The course was redesigned to allow freshman level students to gain professional hands-on engineering design experience through active/cooperative learning activities. The redesigned course was implemented for the first time in fall 2009. The students were asked to design and manufacture a small wind turbine suitable for home use in Jeddah city. Other projects were proposed and implemented in the following semesters such as photovoltaic systems for small clinics at rural area. It was planned to offer a new project each semester.

In the present paper the project based learning approach in engineering education is reviewed and the developed project based active/cooperative introductory design course is described.

Project based learning in engineering education

The term "project" is universally used in engineering practice as a "unit of work", usually defined on the basis of the client.[7] Almost every task undertaken in professional practice by an engineer will be in relation to a project. Projects will have varying time scales. A project such as the construction of a large dam or power station may take several years, whilst other engineers may be involved on numerous small projects for various clients at any given time. Projects will have varying complexity, but all will relate in some way to the fundamental theories and techniques of an engineer's discipline specialization. Small projects may only involve one area of engineering specialization, but larger projects will be multidisciplinary, not only involving engineers from different specializations, but other professional and non-professional personnel and teams. Successful completion of projects in practice requires the integration of all areas of an engineer's undergraduate training.[7]

Project based learning is a teaching and learning model (curriculum development and instructional approach) that emphasizes student-centered instruction by assigning projects. It allows students to work more autonomously to construct their own learning, and culminates in realistic student-generated products.[8]

Although engineering cornerstone and capstone projects are becoming an important part of engineering curricula in order to satisfy ABET requirements, these projects differ from the wide-spread meaning of project based learning where projects are used to as instructional tools to teach new concepts and where the whole learning process in a given area is organized around projects.

Project based learning, as well as problem-based learning, has its roots in constructionism learning theory.[8] Constructionism[9] posits that individuals learn best when they are constructing an artifact that can be shared with others. Dewey[10], Piaget[11], Brunner[12], and others have contributed to the foundation of these methods as an outgrowth of cognitive and later constructivist, theory of learning.[13]

Thomas[14] in his review of research on project based learning noticed that all of the research on Project Based Learning has taken place in the past 20 years and most of it in just the last few years. This goes in line with his definition of project based learning:

> *"Project Based Learning (PBL) is a model that organizes learning around projects. ….. Projects are complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making, or investigative activities; give students the opportunity to work relatively autonomously over extended periods of time; and culminate in realistic products or presentations."* [14]

Research on project based learning is highly attributed to recent reforms in Engineering Education. The significant changes that accompanied the appearance of ABET 2000 document in 1998[15] reflected the observation by academia and industry that engineering education needed to change to better prepare engineering graduates for the current work environment.[16, 17]

Modern engineering profession deals constantly with uncertainty, with incomplete data and competing (often conflicting) demands from clients, governments, environmental groups and the general public. It requires skills in human relations as well as technical competence. Whilst trying to incorporate more "human" skills into their knowledge base and professional practice, today's engineers must also cope with continual technological and organizational change in the workplace. In addition, they must cope with the commercial realities of industrial practice in the modern world, as well as the legal consequences of every professional decision they make.[7]

Despite these challenges, Mills and Treagust[7] noticed that the predominant model of engineering education remains similar to that practiced in the 1950's **- "chalk and talk"**, with large classes and single-discipline, lecture-based delivery the norm, particularly in the early years of study. They consider that developments in student-centered learning such as problem-based and project based learning have so far had relatively little impact on mainstream engineering education.

On the other hand, Mills and Treagust[7] were able to find several examples of project based learning being used in individual or a few courses in engineering programs that have been reported in the literature. They noticed that some of these examples use the term project based, others use the term "problem-based learning", but are actually project based learning. Still others use the terms interchangeably, which points to the grey area that exists in engineering between these terms. The courses reported cover a range of discipline areas and program levels and include:

- Final semester undergraduate industry projects in all disciplines at the Engineering College at Hogskolen i Telemark, Norway.[18]
- Projects in the EPICS courses in first and second year at the Colorado School of Mines, USA.[19]
- Several US examples cited in Rosenbaum[20] including Rose-Hulman Institute of Technology, Carnegie Mellon and Worcester Polytechnic Institute.

Heitmann[21] differentiates between "project-oriented studies" and "project-organized curriculum." According to Heitmann, project-oriented study involves the use of small projects within individual courses, progressing to a final year project course. The projects are usually combined with traditional teaching methods within the same course. They focus on the application, and possibly the integration of previously acquired knowledge. Projects may be carried out by individual students or in small groups. Project-organized curricula use projects as the structuring principle of the entire curriculum, with subject-oriented courses eliminated or reduced to a minimum and related to a certain project. Students work in small groups with a project team of instructors who are advisers and consultants. Projects are undertaken throughout the length of the course and vary in duration from a few weeks up to a whole year. Mills and Treagust[7] notice that a completely project-organized curriculum does not yet exist, and the closest are programs where projects and project-related courses make up 75% of the program, as at Aalborg University in Denmark.

Perrenet et al[22] compare problem based and project based learning. They noted that the similarities between the two strategies are that they are both based on self-direction and collaboration, and that they both have a multidisciplinary orientation. The differences that they noticed included:

- Project based tasks are closer to professional reality and therefore take a longer period of time than problem-based learning problems (which may extend over only a single session, a week or a few weeks).
- Project work is more directed to the *application* of knowledge, whereas problem-based learning is more directed to the *acquisition* of knowledge.
- Management of time and resources by the students as well as task and role differentiation are very important in project based learning.

One result of the changes introduced by the outcome-based ABET EC2000 criteria is that design, communication skills, managerial skills, working in multidisciplinary teams, and life-long learning have been given increasingly important treatment in undergraduate engineering curricula. Project based courses have been gaining acceptance as a means to introduce design, managerial skills, and teamwork experiences into the curriculum prior to the senior capstone design course.[23,24] In many cases, communication skills are integrated into the engineering content of these project based courses.[26] In 2001 the University of Sherbrook, Québec, Canada, used a combination of project based and problem based learning to develop the students' life-long learning skills in a freshman engineering course where the students are required to develop and reflect on their learning strategies.[27]

The response of academia to these accreditation criteria through project based learning was not limited to to introductory design courses. One can easily find several examples of project based courses in statics[28], structures[29], vehicle engineering[30,31], architecture[8], computer sciences[32], energy conservation[33], energy conversion[34], and industrial engineering.[35]

In the late 1990, MIT's Department of Aeronautics and Astronautics engaged in a rigorous process to determine the knowledge, skills and attitudes that graduating engineers should possess. This resulted in a framework known as CDIO, short for Conceive, Design, Implement, and Operate.[36] CDIO initiative aimed at introducing Curriculum reform to ensure that students have opportunities to develop the knowledge, skills and attitudes to conceive and design complex systems and products.[37] The Approach uses both project based and problem based learning and provides a flexible, open architecture, along with enabling tools and resources that can be applied to any engineering discipline at any school. CDIO approach is based on two main elements, namely: the CDIO Syllabus and CDIO Standards. The CDIO Syllabus is an organized list of the areas of knowledge, skills and attributes that an engineering graduate could reasonably be expected to possess. The CDIO Standards focus primarily on the delivery of an engineering program, rather than its content, and include 12 main elements.[38] In the context of the present work, 3 of these 12 elements are of particular interest namely; Introduction to Engineering, Design-Build Experiences, and Active learning.

Recently[39] "The First Bell" news briefings published by the American Society of Engineering Education (ASEE) briefed a report by R. Callahan, the Associated Press Writer. The report indicated that "*Youngsters taught science in classes where the goal was to design and build a device to perform a specific task scored significantly higher on a final test than students who got traditional classroom instruction, according to a study from Purdue University. The findings suggest that hands-on, problem-solving learning may have advantages over traditional lecture- and textbook-based methods of teaching students about engineering and technology. The study focused on students who learned about the principles of water purification and water quality in science classes. Those who learned mostly through hands-on instruction, working to design and build a water-purification device to make water taken from the Wabash River suitable for drinking, had an average score on the following test that was 20 points higher than those that learned through traditional instruction.*" Samantha A. Murray, the American Society for Engineering Education's K-12 coordinator, called the findings "timely and relevant," adding, "It hopefully will spur additional research efforts focused on the use of hands-on projects to successfully engage students in engineering concepts at an early age."

Outlines of the IE-202 project based course

IE-202 is a required introductory engineering active learning project based course, which should be taken by all engineering students. The course has conserved its time structure by dividing the course content and the classroom activities into two 2-hour sessions per week.

The developed IE-202 course allows freshmen students to gain professional hands-on engineering design experience through a well planed active/cooperative learning course. The students practice conceptual design, procedures of mock-up tests, detailed design, final planning, manufacturing, inspection and testing. This gives the students a solid background of practical engineering design through a cornerstone design project before joining their selected engineering programs.

Although IE 202 course is considered as a key course for ABET Student Learning Outcomes 3c and 3d, it partially addresses another 4 student outcomes of the 12 ABET accredited engineering programs at King Abdulaziz University, namely 3e, 3g, 3i and 3k. The course also addresses several key qualities of successful entrepreneurs.

Much literature on entrepreneurship focuses on the person, characteristics and qualities of a successful entrepreneur.[40] Recent studies in the field describe dozens of these qualities.[41, 42] Nevertheless authors are interested in the qualities that can be nurtured or taught. Ten of these qualities were identified, namely creativity and innovation, organizational skills, leadership and team management skills, responsibility, punctuality, time management, openness to change, dealing with ambiguity and uncertainty, attraction to challenges and desire to compete, and communication skills.

Intended Course Learning Outcomes

The intended course learning outcomes are mapped to ABET Student Learning Outcomes and the qualities of successful entrepreneurs using the mapping matrix presented in Fig. 1.

COURSE NUMBER AND NAME				PROGRAM OUTCOMES (PO)											Qualities of Entrepreneurs									
IE-202 INTRODUCTION TO ENGINEERING DESIGN II		Level of Learning (In)	Level of Learning (Out)	Apply math, science & eng	Design & conduct experiments	Design a system, component	Function on multidisciplinary teams	Identify, formulate & solve eng. Prob.	Professional & ethical responsibility	Communicate effectively	Impact of engineering Solutions	Life long learning	Contemporary issues	Modern engineering tools	Creativity and Innovation	Organizational skills	Leadership and team management skills	Responsibility	Punctuality	Time management	Openness to Change	Dealing with ambiguity and uncertainty	Attraction to Challenges, desire to compete	Communication skills
COURSE LEARNING OBJECTIVES (CLO)				a	b	c	d	e	f	g	h	i	j	k										
1	Define the problem, identify customer needs, and transform the needs into design requirements.	1	2			2																		
2	Access information from a variety of sources, and critically evaluate their quality, validity and accuracy.	2	3									3												
3	Plan an effective design strategy with manageable subtasks and timelines.	2	3			3																		
4	Develop and compare alternative solutions to select a baseline design.	1	2			2																		
5	Consider realistic constraints such as economic, environmental, social, manufacturability, and sustainability.	1	2			2																		
6	Integrate prior knowledge of science and mathematics with engineering principles, heuristics and modeling techniques to formulate unstructured engineering problems.	1	2					2																
7	Effectively use modern engineering tools to carryon design and performance calculations.	1	2											2										
8	Evaluate the baseline design and argue suitable improvements and changes.	1	3			3																		
9	Work in a student team to Build, test, and evaluate a working prototype of the designed artifact.	1	2			2																		
10	Document the design procedure, communicate design details and express thoughts clearly and concisely, both orally and in writing.	1	3							3														
11	Demonstrate ability to achieve objectives using independent, well organized, and regularly reported multidisciplinary team management techniques.	2	3				3																	
	Level of Learning Legand	1:		Knowledge/Comprehension										3:	Synthessis/Evaluation									
		2:		Application/Analysis																				

Figure 1: Mapping matrix of the developed course

The Structure of the Course

The course structure allows minimum effort in achieving the course goals. It also allows the student to practice a real design project from the beginning of the semester to its end. The 3-4 member teams receive the project statement, which includes the customer needs, in the beginning of the semester. The project is divided into five assignments, or five modules, joined together to form the whole project. With each assignment the students are allowed to update and resubmit the previous one after receiving detailed comments from the instructor. The updated version of the previous assignment is combined with the current one to form a new progress report such that resubmission is just an updating that increases the sense of continuous improvement. After five assignments the project becomes ready. Fig. 2 shows the course calendar. It could be noticed that the first five assignments covers the whole technical part of the project, while the remaining assignments are designed to assess communications skills through a design notebook, an oral presentation, and a poster. The course structure allows for a new project every semester/year using the same instructional materials and assessment instruments. The instructor's materials and student's materials just contain the design concepts. One detailed checklist is used to assess all successive assignments and has a serial number to indicate the updated versions.

Direct Assessment Tools

Course assignments are used as the primary direct assessment tool in the cognitive domain. The student's work is evaluated as Exceeds Expectations **(E)**, Meets Expectations **(M)**, Acceptable **(AC)**, Needs Improvement **(NI)**, or represents No Credible Effort **(NCE)**. The items of a detailed assessment checklist are mapped into the intended course learning outcomes (CLOs) they are used to assess and into the corresponding course supported student learning outcomes (SLOs) specified in criterion 3 of ABET EAC Criteria. Unsatisfactory work that is considered to *Need Improvement* and that representing *No Credible Effort* should be improved and resubmitted with the following assignment. The maximum grade after resubmission is AC.

Class Topic	Week		Presentation	Class Work	Book's Tasks	Due	Checklists and Evaluation Forms	Mark	Teamwork	Individual	Surveys	Hard Copies
Registration	W0	0										
First Day Materials	W1	1										First Day Materials
Introduction to Project	W1	2										Project Matrials
Introduction to Excel	W2	1										Introduction to Excel
Introduction to Excel	W2	2										Introduction to Excel
Assignment 1	W3	1									Entry Survey	
Chapter 1	W3	2										How to Model It Book
Chapter 1	W4	1										How to Model It Book
Assignment 2	W4	2				Assignment 1	Checklist 1	5	5			
Chapter 2	W5	1										How to Model It Book
Chapter 2	W5	2										How to Model It Book
Chapter 2	W6	1										
Assignment 3	W6	2				Assignment 2	Checklist 2	10	10			
Chapter 4	W7	1										How to Model It Book
Chapter 4	W7	2										How to Model It Book
Assignment 4	W8	1				Assignment 3	Checklist 3	10	10			
Introduction to Project- Phase 3	W8	2				In class Assignment I	InClass Ass. Checklist	10		10		
InClass I	W9	1										Project Matrials
Chapter 5	W9	2				Assignment 4	Checklist 4	10	10			How to Model It Book
Chapter 5	W10	1										How to Model It Book
Chapter 5	W10	2										
Assignment 5	W11	1										
Workshop	W11	2									Exit Survey	How to Model It Book
Workshop	W12	1				Assignment 5	Checklist 5	10	10		Outcome Survey	How to Model It Book
Workshop	W12	2										
Workshop	W13	1				Prototype	InClass Ass. Checklist	10	10			
Poster & Prototype	W13	2				Poster	Prototype & Poster EF's	10	10			
Celebration	W14	1				Project Presentation	Presentation EF	10	5	5	Course Evaluation	
Defect Removal	W14	2				Design Notebook	Design Notebook EF	15	15			
								100	85	15		

Figure 2: Calendar for the project based course (Fall 2009)

On the other hand the major checklist items that receive "Null" or "Poor" are to be corrected and resubmitted, no matter what the final grade is. The grade remains as is after successful resubmission; otherwise it becomes one grade lower. This approach clearly enforces customer-based quality principles and continuous improvement philosophy. Work is accepted only if it *Meets* or *Exceeds* customer's expectations.

Self-regulation lapses (loss of 1% of the final course grade) are used to punish any unprofessional behavior in the affective domain. Defects, on the other hand, are associated with repeated lapses (5 lapses is one defect, 6 or 7 lapses is 2 defects, more than 7 lapses is 3 defects) and with final NCE (1defect) or NI (0.5 defect) after resubmission. Accumulation of 3 defects results in course failure. The final course mark that the student receives is calculated using the following formula:

$$\text{Final Mark out of 100} = \frac{\text{No. of E's} * 100 + \text{No. of M's} * 84 + \text{No. of AC's} * 69}{\text{Total No. of Assignments}} - \text{No. of Lapses}$$

A smart checklist is developed to convert the grades in each assignment into levels of achievement of course learning outcomes. This permits the instructor to periodically monitor the achievement of the course learning outcomes.

Phases of the design project

The course starts with a project manual that includes the project statement, required communications and step by step learning and instructional guide. The project statement describes the customer needs and the sponsor of the project. The required communications are as follows:
1. Final comprehensive, well organized design notebook, which includes parametric design, recommendations, rationale and plans for implementing changes, prototype drawings, and the project Gantt chart and deployment chart.
2. Comprehensive oral team presentation for a general audience.
3. A0 poster for exhibition.
4. Built, tested and analyzed project artifact or prototype.

The project is divided into three phases. The parametric design phase maps some selected modeling chapters from the course text book.[43] After completing this phase it is expected that the student teams had modeled their artifact, calculated all design variables and performed parametric studies. This phase is covered by five team assignments. The second phase is the drawing phase in which the teams draw the parts of the artifact as a starting point before manufacturing. The third phase is the prototyping or manufacturing phase in which the teams implement their designs and manufacture the artifact.

A factory-based learning environment is used during the implementation phase where the team members are assigned different industrial roles such as planning, quality assurance, quality control, sales, and production engineering.

Evaluation of the design content of the course

In order to evaluate the developed project based course, the method of "exposure matrix" proposed by Al-Bahi[44] and systematically used by the majority of Engineering Programs in the Faculty of Engineering is used. The method uses course-level measures of achievement of the intended course learning outcomes (CLOs) to evaluate the achievement of student learning (ABET) outcomes (SLOs) on the program level. The approach is based on the fact that simple averaging is not suitable to calculate program-level achievements since each course addresses one or more SLO at a certain level of learning (which may be defined as a learning *depth*). Also the students in different courses could be exposed lightly, moderately or extensively to the same SLO (i.e. learning *breadth*). The approach is used to obtain a weighted average of achievement of SLOs by a combination of learning *depth* and learning *breadth* in different courses. A modified measure of Bloom's levels of learning, in which 1 is assigned to knowledge and comprehension, 2 to application and analysis and 3 to synthesis and evaluation, is used to quantify the learning depth while contact hours allocated to each SLO in the course are used to quantify the breadth. Students' exposure to a certain SLO in a course is then measured by multiplying its intended attainable level of learning by the contact hours allocated to that outcome.

Evaluation of the project based course indicates that (see Fig. 3) the exposure of the critical outcome 3c is 84 equivalent hours which represents 40% of the total exposures of all the outcomes addressed in the course that sum up to 208 equivalent hours. The exposure of the key outcome 3c was found to be almost six times as large as it was in the previous IE-202 modeling course, as a result of increasing both the level of learning and the contact hours allocated to this outcome.

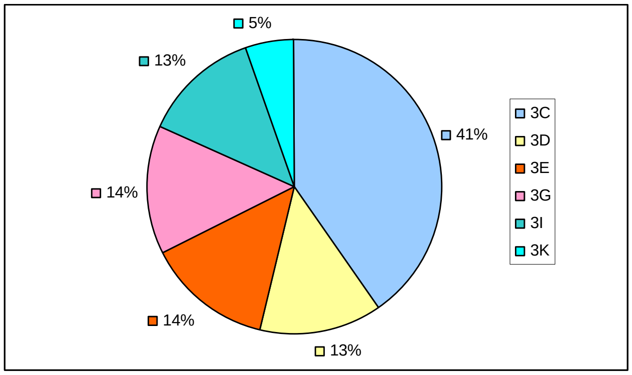

Figure 3: Percentage of the total exposure hours allocated to each ABET Student Outcome

Course implementation

The course was implemented starting from fall 2009. Two main facilities were constructed before the start of the course offering. The first is an active learning classroom equipped with 12 round tables and 48 computers to accommodate twelve teams of four students each. The second facility is a workshop equipped with essential tools needed for the manufacturing of the artifact. The course accommodates six sections for a total of 288 students. In the first week, course materials are delivered to the students including the first day materials, project assignments, students' guide, surveys, checklists and forms. The course calendar plays an important role to alert the students when they should deliver assignments and surveys. Course instructors meet regularly once a week to insure the sustainability of the course and to decide on minor continuous improvement actions.

At the end of the semester students deliver a course design notebook, a manufactured artifact and a project poster. Figure 4 shows sample pictures of the students' workshop products and activities for the small wind turbine design project, as well as the class layout.

Course evaluation

The student performance target is that, at least 70% of passing students should achieve at least 65% score in each outcome. This criterion is applied to both direct and indirect assessment methods.

Entry survey is used as an indirect assessment tool that measures the students confidence level in their abilities to achieve course addressed ABET outcomes and is usually distributed in the second week of the course. The same survey is redistributed in the last week of the course as an exit survey. Differences between the two surveys are used as a measure of the learning gain from the students' view point.

Fig. 5 indicates the results of these 2 surveys for the fall 2009 offering of the project based course. It deserves attention to notice that the confidence levels of the students indicated in the exit survey are in good agreement with the results of the direct assessment tools as depicted in Fig. 6. This indicates that the project based offering not only increased the level of achievement of ABET outcomes; it also increased the confidence of the students in their abilities.

In the affective domain, and as a qualitative measure of the success of the updated project based course, the majority of the students concluded in their final presentation that they are valuing the design experience they obtained. Several student teams have identified the project as a potential entrepreneurship business after graduation.

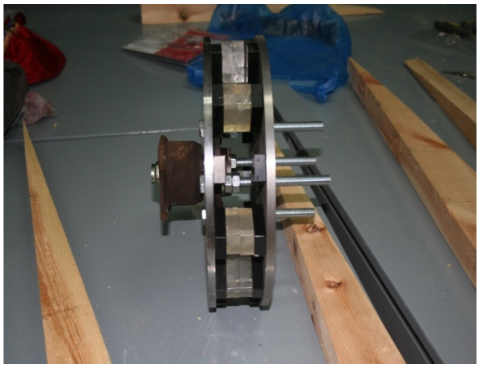

Figure 4a: Sample wind turbine rotor manufactured by a team of students

Figure 4b: Sample wind turbine stator manufactured by a team of students

Figure 4c: Sample workshop activity of graving wood to manufacture the blades

Figure 4d: Class layout.

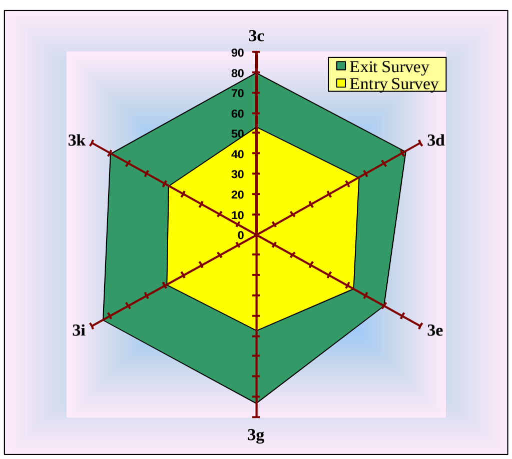

Figure 5: Students' confidence level in their abilities to achieve ABET student learning outcomes.

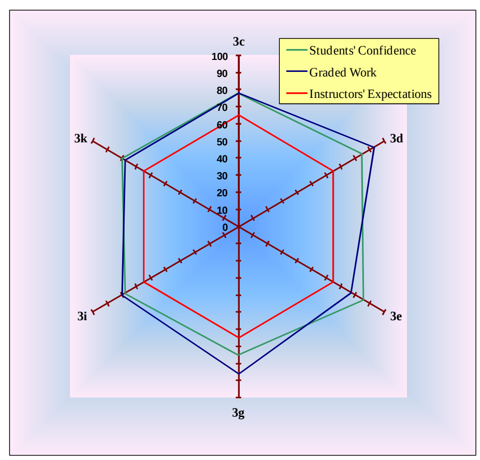

Figure 6: Results of direct and indirect assessment of ABET student learning outcomes.

Conclusions

An active/cooperative introductory design course was designed using project based learning approach to allow freshman level students to gain professional hands-on engineering design experience through well planned active/cooperative learning activities. The developed course introduces engineering design practices through guided design phases and provides the students with an opportunity to practice team work, quality principals, communication skills, life-long learning, realistic constraints, and global awareness of current domestic and global challenges. Course implementation for two successive semesters gave rise to the following conclusions which are in-line with the experience of several authors:

1. Project based learning is an efficient learning and teaching model suitable for engineering education.
2. Project based offering not only increases the level of achievement of ABET outcomes; it also increases the confidence of the students in their abilities and enhances several key qualities that pave the students' way to become successful entrepreneurs.
3. Project based learning courses require commitment and sincere work from the part of the course instructors, as well as leadership, motivation and support from the college management, to insure the sustainability of these courses.

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