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Project-Based Learning Integrating Engineering Technology and Engineering

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Abstract

Project Based Learning (PBL) provides opportunities for students to apply theoretical design knowledge to solve practical problems at all levels of the curriculum. Graduates of these programs are extremely well prepared for industry with skills including project management, team-work, and customer focused design. The programs at Western Carolina University provide a series of five PBL courses from the freshman to the senior year. The last two of these courses form the fourth year capstone sequence where students do projects for external sponsors, typically companies. Leading up to this point the students learn and apply the skills required for successfully executing major technical projects.

This paper will outline the shared PBL course sequence at Western Carolina University in the School of Engineering+Technology. The School houses disciplines ranging from Electrical to Mechanical Engineering. More uniquely, the Engineering Technology and Engineering programs are not separated into separate schools. As a result the PBL project teams contain a multidisciplinary mix of students with a range of practical and theoretical approaches. PBL instructors embrace this diversity and foster an environment that is much more productive and capable that a single program experience could offer. The PBL sequence will be described including course content and project work that concurrently addresses the ABET [7] criteria for ETAC and EAC accreditation. Lessons that have been learned will be shared for other schools hoping to create a similar curricular experience.

Introduction

Project Based Learning (PBL) [1] makes use of active learning techniques to create a student driven learning environment. The role of the instructor is to guide the students as they learn while doing project work. Projects are selected or screened to have real outcomes that the students use to determine progress and success. This method has been applied to various engineering programs. Olin College had the unique opportunity to build their engineering programs from the ground [2]. Notably this included a student partnership in design which resulted in a PBL curriculum. The School of Engineering at the University of Illinois applied the PBL model to an existing engineering curriculum. Depending on implementation this curriculum can be a departure from traditional Topic Based Learning (TBL) [3].

The primary differentiator between Engineering Technology and Engineering programs is the emphasis on theory versus application. Students in Engineering Technology programs have a better exposure to implementation, debugging, and manufacturing. Students in Engineering programs have been very well versed in analysis, simulation, and abstract design. By themselves each of these programs have strengths and weaknesses. However, when combining students from both of these program we develop teams that more closely reflect professional design teams. The ability to successfully implement complex design and build projects is enhanced.

This paper outlines the design of a program at Western Carolina University (WCU) that culminates with a senior capstone project for industry. Projects are done by teams of students mixed from the School disciplines of Electrical Engineering, Mechanical Engineering, Electrical and Computer Engineering Technology, and Applied Systems Engineering Technology. A PBL core has been created to prepare the students for the capstone project and professional practice. The core begins in the freshman year with courses of students in all disciplines. As these courses progress the students execute successively more complex projects. The project skills also provide context for theoretical and applied content seen in various courses. And, the mix of disciplines allows the courses to support multidomain design and build projects.

The courses are listed with catalog descriptions [4]. The curriculum threads of communication, project management, design, teaming, and professionalism are developed over the four years of the program. The following sections of this paper will discuss each of these threads and how they are developed.

> **ENGR 199 - Introduction to Engineering Practices and Principles I -** An introduction to the engineering discipline. Group work, oral communication, problem solving and design process will be introduced through lecture and project-based learning activities. Freshman Engineering majors only. 2 Lecture, 2 Lab.
>
> **ENGR 200 - Engineering Practices and Principles II -** Engineering practices and principles, teaming, project planning, written communications, and conceptual design processes will be introduced through lecture and project-based learning activities. 2 lecture, 2 lab.
>
> **ENGR 350 - Engineering Practices and Principles III -** Engineering project-based learning (open-ended) with emphasis on project control and engineering design processes. Special emphasis will be placed on professional, ethical, global, environmental, and contemporary issues. 2 Lecture, 2 Lab.

ENGR 400 - Engineering Capstone I - Senior engineering project selection, planning, and development. Emphasis will be placed on defining project requirements, developing project work breakdown structure, conceptual designs, and working prototypes. 1 Lecture, 4 Lab.

ENGR 450 - Engineering Capstone II - Senior engineering project design, development, fabrication, and testing. Emphasis will be placed on iterative design processes, project management and execution, fabrication and testing. 1 Lecture, 4 Lab.

Communication

Teaching communication, as a skill, is a persistent challenge in technical education. This is highlighted in the Engineer of 2020 report which described it as a need to "listen effectively as well as to communicate through oral, visual, and written mechanisms." [5] Prior to technical studies students have been immersed in the fundamentals of persuasive writing and social interaction. All technical educators build on that base to add skills for business and technical interfacing. At WCU the PBL sequence ensures an orderly development with the context of engineering project work.

Table 1 - Typical Communication Topic Introduction in the PBL Sequence

Topic	ENGR 199	ENGR 200	ENGR 350	ENGR 400	ENGR 450
Presentation	Indiv. Oral PPT	Group Project PPT Group Poster Critical Review	Group Project PPT Group Poster Critical Review of 400/450 Groups	Frequent PPTs Response to Sponsors	Frequent PPTs Group Poster
Descriptive Writing	Project Description Engineering Feats	Ethics Essay Project Description			
Reporting	Formats Lab Measurements Sketching Units and Calcs. Executive Summ.	Templates Lab Reports	Recommendations	Activity Reporting	Activity Reporting Design Report
Verbal/Meetings			Note Taking	Agendas and Minutes	
Listening	Project Feedback	Project Feedback	Engineering Review	Recording Customer Needs Expert Consulting	

Proposals		Project Description	Project Proposal	Design Proposal	
Research	Public Sources Citation Credibility	Technical Docs	Market Research	Literature	

In the capstone project the teams are fully engaged with outside sponsors. This requires that they plan before interacting with others, keep good records, commit decisions to paper, seek approval, and work toward clear, correct, concise communication.

Project Management

The PBL sequence begins with projects that are relatively simple, but they provide an ideal vehicle to introduce the topics. In the freshman year students are provided with a basic Work Breakdown Structure (WBS) and directed to follow a Gantt chart. By their capstone year they formulate, track, and revise their charts as the work progresses. They use various tools to compare the ever increasing number of details. Upon graduation the students are ready to participate in managed projects and practicing their own skills.

Table 2 - Project Management Topic Introduction

Topic	ENGR 199	ENGR 200	ENGR 350	ENGR 400	ENGR 450
Work	Gantt Charts WBS Gate Structure MS Project	Gantt Charts PERT Diags.	Gantt Charts		
Budget	Spreadsheets Constraints	Spreadsheets Constraints/Objectiv es	Spreadsheets ROI	Spreadsheet Purchasing Sponsor Approval	Purchasing Reconciling
Documents	Project Scope	Scope Specifications	Requirements/needs Scope Specifications	Requirements/needs Scope Specifications Revision Tracking	Test Results Project Closure
Strategy	Mission, Vision, Goals		Assessment	Alternate Plans Risk Management	

Design

Most of the technical curriculum is focused on applying systematic methods to solve very complex problems. Often these problems are supplied to the students and they use them to practice the rigorous methods. In terms of the design cycle the detailed design stages is extremely well covered in all programs. Coverage of other areas such as conceptual design, building, and testing are much more situational. Generally projects are needed to emphasize the full design cycle. So, unless there is a cross program project students only see the engineering design process applied to small parts of their curriculum. Our approach is to iteratively expand the scope of the projects and self determination for each step.

Table 3 - Design Topic Introduction

Topic	ENGR 199	ENGR 200	ENGR 350	ENGR 400	ENGR 450
Needs	Constraints/Objectives	Constraints/Objectives Summarized Scope	Self Identified Needs Project Scope Specifications	Sponsor Needs Research Draft Specifications Sponsor Approval	Testing
Concepts	Brainstorming Sketches Flowcharts Layouts Crude Prototyping	Brainstorming Sketches Flowcharts Layouts Crude Prototyping	Brainstorming		
Details	Simple CAD Simple Schematics	Simple CAD Simple Schematics	Detailed design work suitable for the discipline including CAD, Calculations, Schematics, source code, etc.	Detailed design work that observes safety, regulatory, standards, etc.	
Build/Test	3D Printing Arduinos	3D Printing Arduinos	Functional Product		A functional result that is acceptable to a project sponsor. These must be tested to satisfy the sponsor needs.
Closure	Competition	Competition	Presentation Demonstration		Delivery to the sponsor A documented project handoff

Teaming

Project work is now a normal part of High School curriculum and many students arrive with some level of experience. However their experience is often situational and they do not understand teamwork as a science. Luckily the complexity of the project work escalates over four years so their understanding and teamwork skills can be developed incrementally. Freshmen level teams often misestimate the work required, do not distribute tasks wisely, or become stuck on personality issues. Typical problems include aptitude, motivation, excess assertiveness, insufficient assertiveness, and distraction. In ENGR 199 and 200 we endeavor to have the students understand their personal working styles and help them learn to work with differing styles. In the early years students select their own team members but by the capstone project, the teams are formed by the instructors to match the project needs and student interests.

Table 3 - Team Work Topic Introduction

Topic	ENGR 199	ENGR 200	ENGR 350	ENGR 400	ENGR 450
Structure	Team Roles Division of Work Communication	Personality Types Team Composition			
Problem Solving	Peer Assessment	Peer Evaluation Self Evaluation	Conflict Resolution		

Professionalism

Educators and industry alike recognize the limitations of institutions to fully prepare ‘professionals’. Some skills will only be truly internalized with years of experience. However, as educators we can lay the groundwork for the experience for those few things that will occur after graduation. For example, making a ‘damned if you do, damned if you don’t’ decision makes for an interesting discussion, but it can paralyze a professional. Likewise, how you work with others in an organization requires experience and practice in the workplace. But, educators are very well positions to teach accountability, honor, environmentalism, etc.

Table 3 - Professionalism Topic Introduction

Topic	ENGR 199	ENGR 200	ENGR 350	ENGR 400	ENGR 450
Ethics	Honor Code Plagiarism Codes of ethics	Ethical Dilemmas	Environment Globalism Sustainability	Sponsor Needs	
Demeanor	Workplace Expectations Responsibility	Self Direction Effectiveness	Unwritten Laws of Engineering [6]	Autonomy Self Directed Learning	Accountability Lifelong Learning

Accreditation

Although not a motivation, this approach does simplify ABET accreditation. Normally project work and professional skills are distributed through a TBL curriculum. This makes it very difficult to isolate and assess these topics. A common approach is to create one course to carry many of the topics, or heap most of the assessment categories into the capstone course. With a PBL core the assessment topics can be assessed at a natural pace in the spirit of continuous improvement. For reference the ABET ETAC and EAC criteria are listed [7].

Engineering Accreditation Commission (EAC) Criteria:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
* (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
* (d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
* (f) an understanding of professional and ethical responsibility
* (g) an ability to communicate effectively
* (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (i) a recognition of the need for, and an ability to engage in life-long learning
* (j) a knowledge of contemporary issues
* (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Engineering Technology Accreditation Commission (ETAC) Criteria:

a. an ability to select and apply the knowledge, techniques, skills, and modern tools of the discipline to broadly-defined engineering technology activities;
b. an ability to select and apply a knowledge of mathematics, science, engineering, and technology to engineering technology problems that require the application of principles and applied procedures or methodologies;
c. an ability to conduct standard tests and measurements; to conduct, analyze, and interpret experiments; and to apply experimental results to improve processes;
d. an ability to design systems, components, or processes for broadly-defined engineering technology problems appropriate to program educational objectives;
* e. an ability to function effectively as a member or leader on a technical team;

* f. an ability to identify, analyze, and solve broadly-defined engineering technology problems;
* g. an ability to apply written, oral, and graphical communication in both technical and nontechnical environments; and an ability to identify and use appropriate technical literature;
* h. an understanding of the need for and an ability to engage in self-directed continuing professional development;
* i. an understanding of and a commitment to address professional and ethical responsibilities including a respect for diversity;
* j. a knowledge of the impact of engineering technology solutions in a societal and global context; and
* k. a commitment to quality, timeliness, and continuous improvement.

Conclusion

The PBL core described in this paper is very effective at developing Engineers and Engineering Technologists. When these students are working together they are able to span more phases and domains of design and build projects. The PBL core is formed as a baseline set of knowledge and skills for all graduates of the program. As a core it ensures that these topics are covered consistently and uniformly for all graduates. In the freshman year of the program students are introduced to multiple disciplines and learn to work as integrated teams. By the senior year the capstone projects are executed at a mature level for external sponsors. Examples of the final projects are listed and limited video examples are available on the School's Facebook page [8].

1. PLI Cards Tool Punch Count System – Tagging/Reader System
2. PLI Cards Tool Removal & Insertion Mechanism in Punches
3. Eaton Corp. Dynamic Brake for Medium Voltage Drives
4. BorgWarner Turbo Syst. High Speed Motor Driven Power Train
5. Edmonds Consulting Jet Engine Test Cell
6. MT&T Wheelchair Situational Awareness Technology
7. Cervical Collar Design (Neckoskeleton)
8. Bath Tub Hair Shredder
9. Stuart Locklear Personal Clinic Pill Dispensing Cartridge
10. Army Research Office Integrated Collar for Military Working Dogs
11. Navy Sling for High-Speed Boats
12. Army Special Operations Command Thin Under Door Flashlight
13. College of Business Induction Charging Roadway
14. OCC Fiber Optic Debris Development
15. OCC FPGA System Development

16. Southwestern NC RC&D Council Hydro-power Site in Graham County
17. Multiple Joint Project with Tec de Monterrey, Mexico
18. Snap-on Tools Rotor and Vane Assembly System
19. Overhead Assistive Robot with Gesture-based Control
20. Functional Electrical Stimulation Recumbent Bicycle for Stroke Rehabilitation
21. Eco-Panels Evaluation of Pre-Manufactured Corners for Shear Load
22. Meritor Gear Set "Lapping" Standardization
23. BW-Thermal BorgWarner Kaizen Event
24. GE Aviation CNC Lock-Out Protection
25. GE Aviation Engine 2-piece Assembly System
26. Duotech Services PCB Design
27. Collective Behavior of Swarm Robotics Using Kilobots
28. Eaton Corp. Medium Voltage Drive Control Interface

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