Applying Learner-Centered Project-Oriented Approach to Enhance STEM Education Experience – A Case Study

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Abstract

Hands-on experience is extremely important for engineering education. Recently undergraduate research is getting increased attention in the university education systems. Due to the recent developments in science, technology, engineering, and mathematics (STEM) related areas, typical pedagogies for engineering education are not adequate to generate skilled workforce to fulfil the industry needs. This work presents a case study where a learner-centered team-project approach is applied in a microprocessor based system design course that is intended for seniors and graduate students of a College of Engineering. Team-project is introduced in this course so that students can work in a lab as groups and enhance their hands-on experience. Because of the diverse backgrounds, each group is encouraged to find a topic of their interest within the objective of the course. The pedagogy for this course is improved for the classroom and laboratory activities so that the new approach helps increase students' involvement with the course materials. Based on the final grades, this approach helps improve students' academic performance. Some course-projects are selected for presenting in a university-wide research and scholarly projects symposium. Feedbacks from the student perception of teaching effectiveness (SPTE) and ABET evaluations show that the student-centered project-oriented approach is promising to increase the learning experience in STEM education.

Keywords: Hands-on experience; learner-centered education; microprocessor based systems; STEM education; team-project;

Introduction

In STEM education, important goals include generating skilled workforce to fulfil the industry requirements and preparing researchers to deal with the future challenges. There are various issues that to be addressed for success in STEM education at university level. Studies suggest that some students may not be prepared for a specific subject, prior to starting their undergraduate studies (Verginis et al., 2011). Undergraduate students are exposed to various STEM areas (such as Math, Chemistry, Physics, Programming, and Engineering). Some (senior and graduate) students may have inadequate understanding of the materials and the lack of expertise in a specific subject. Because various topics are covered in a course, lack of understanding the concepts becomes a challenge to complete labs and/or projects.

To overcome these problems, various strategies are proposed and used to increase the inclination of students toward learning more about the given course contents (Koile et al., 2006; Merrick, 2010; Parhami, 2009; Verginis et al., 2011). In engineering courses, different simulation tools and advanced software, such as MATLAB (a simulation tool for engineering design) and MULTISIM (a simulation and circuit design software), are used to facilitate the teaching process and make the subject more comprehensive. It is conceivable that the incorporation of basic hands-on practice into the purely theoretical courses for engineering students would augment their understanding of and interest in the course materials. In addition to the theoretical knowledge, students are expected to have hands-on experience to solve a problem, to be good team-players, and capable of developing new/better solutions.

Undergraduate research is receiving more attention than ever before. Various studies try to investigate and propose methodologies to help the students benefit more from experience of doing research (Kardash, 2000; Kremer et al., 1990). Most of the students who are involved with research on their undergraduate studies, show more interest to continue researching and attend more to graduate studies (Kardash, 2000; Laursen et al., 2010; Lopatto et al., 2010). Furthermore, for the underrepresented minority students and also women, it can provide the environment to interact more with the other students and scientists, helping them to thrive more in their studies and careers (Barlow et al., 2004; Eagan et al., 2011; Gregerman et al., 1998). Therefore, various approaches are proposed to encourage more students to get involved with research activities (Wei et al., 2011). One approach that is garnering increased attention is called a *course-based undergraduate research experience* (CURE) (Auchincloss et al., 2014). CURE involves a whole class of students in addressing a research questions or problems that are of interest to the related scientific/engineering community. The CURE comprises three elements: (i) instructor-report of an extent to which the learning experience resembles the practice of research (e.g., the outcomes of the research are unknown, students have some input into the focus or design of the research); (ii) student-report of learning gains; and (iii) student-report of attitudes toward science and engineering. It is important to recognize that given the limited time frame and scope of any single CURE, students will not participate in all possible activities or achieve all possible outcomes. Rather, CURE instructors could define a particular path and use it as a guide for designing program evaluations and assessing student outcomes.

Project-oriented teaching (POT) / project-based learning (PBL) is the process of using a defined project to draw the attention and focus of students toward learning activities on a need-to-know basis. PBL contrasts with subject-based learning (SBL); in SBL, a student is presented with discipline-based material and is then given a problem of its use (Helle et al., 2006). Cooperative learning develops personal skills including conflict resolution and social skills as well as developing interdependence and individual and group accountability (Doug et al. 1998). POT is ideal for engineering education as it encourages a multidisciplinary approach to problem-solving (which is essential for modern engineering practice) and develops techniques and confidence to develop the projects and ideas which have not been conveyed before similarly. Combining POT with cooperative learning provides a mechanism for students to maximize their own and other group members' learning by working in teams to accomplish a common task or goal.

All the methods and approaches previously discussed are beneficial and efficient in different aspects. Studies show that most of the students do not show interests to continue working on their projects after the semester ends (Auchincloss, 2014; Kardash, 2000; Laursen et al. 2010); Lopatto, 2004). As the undergraduate research is becoming more important and receiving more attention, the projects should be designed in a way that the willingness of the students to work and learn more about these topics does not stop at the end of the semester. The students should continue working and researching on their ideas as undergraduate research and/or graduate thesis/project. The ultimate goal is to help the student think more about real-life problems and come up with their own ideas to solve those problems.

In the rest of the paper, we present the proposed approach, a case study, and a conclusion. Key features of the proposed approach include hands-on experience, team-based project, and learner-centered education. A computer engineering course, offered mainly for senior and graduate students is used for the case study.

Proposed Approach

A typical curriculum design consists of analysis, design, development, implementation, and evaluation activities, which are operationalized in specific tactics (Asaduzzaman et al., 2013; Dick et al., 1985; Gustafson et al., 2002; Hardre, 2003; Lunenberg, 2002; Richey et al., 2001, Seels et al., 1991; and Whitman et al., 2014). Six types of knowledge and skills, based on activities in the existing curriculum and instructional design models, identified as relevant for teachers for enacting design processes are (Huizinga, 2009):

(1) Knowledge and skills to formulate a problem statement
(2) Idea generation skills
(3) Systematic curriculum design skills
(4) Formative and summative evaluation skills
(5) Curricular decision-making skills
(6) Implementation management skills

We integrate the typical curriculum design concepts to the proposed learner-centered project-oriented approach. In addition, we consider the present/future industry needs, related research focus, and related courses (such as prerequisite and follow-up courses) in our proposed approach. To accomplish the course goals, we divide the new pedagogy into four major parts: Lecture, Lab, Team-Project, and Test. Figure 1 shows the key elements accompanying to the proposed approach.

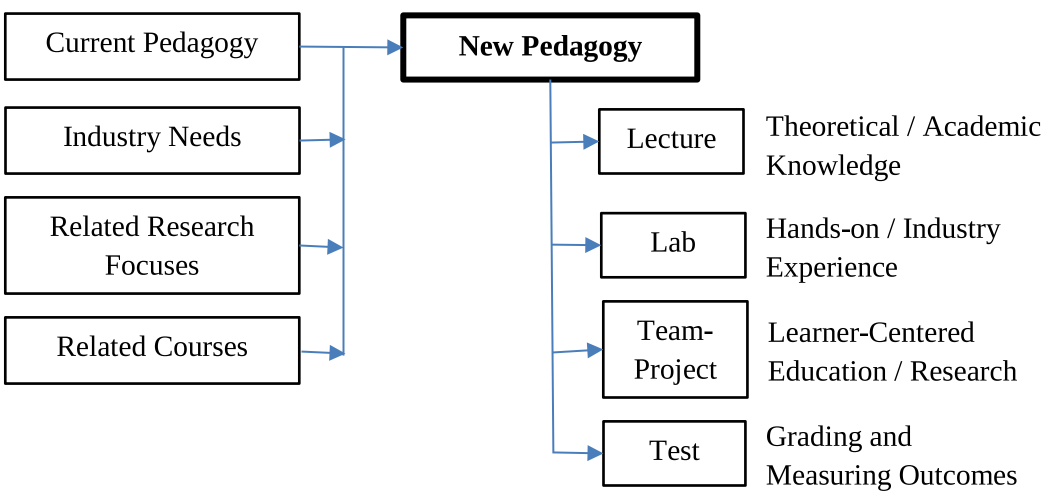

Figure 1. Important components associated to the proposed course design-flow.

Lectures should provide adequate fundamental knowledge so that students understand the core concepts and find the subject materials important/interesting. Students are expected to use their theoretical knowledge in the lab activities.

Lab assignments are prepared considering the industry necessities to provide students hands-on experience. Some labs require essential knowledge and each student is asked to work on them individually. Other labs require creativity/research and students are asked to work on them as a team. Labs should give students hands-on / industry experience.

According to (Helle et al., 2006), project-oriented teaching requires two key factors: the project must involve the solution of a problem and the project results in some sort of end-product being produced. The proposed approach includes team-project where a group of students work on a single topic. We encourage each group of students to find a problem (related to the course objective) for their project and conduct research to come up with the best solution/product.

Finally, tests are conducted for determining grades and measuring students' learning outcomes. To accommodate various teaching/learning styles/preferences, we assign homework and perform quiz and exam. Students should get at least a week to work on a homework problem at home. Quiz (about 30 minutes) and exam (about 60 minutes) should be held in a classroom.

A Case Study – Microprocessor Based System Design (CS 594) Course

We use CS 594 (Microprocessor Based System Design) course where we apply the proposed approach and measure students' learning experience. CS 594 is a mandatory core course for BS in computer engineering (CE) program and a technical elective course for computer science (CE) and electrical engineering (EE) programs.

Course Objective/Overview

The objective of this course is to study the basic microprocessor organization (hardware) and how to program it (software). Particular attention is given to the following areas: handling interrupts and interfacing analog/digital input/output devices. Laboratory work should give students hands-on experience. Pre-requisites include Introduction to Computer Architecture and Programming in Assembly/C Languages. Examples of topics/activities include microprocessor organization, interrupt service routine (ISR), interfacing input/output signals, programming ADC, DAC/PWM, Sensors, etc. Development board (such as NXP DEMOEM board), software package (such as NXP CodeWarrior), and peripherals (such as LED, light sensor, temperature sensors, motor, LCD display, etc.) are used to design and develop microprocessor based embedded systems.

Course Outline

As a typical engineering course, CS 594 has classroom lectures and lab activities. In order to satisfy different teaching/learning preferences, this course include homework, quiz, exam, lab assignment, and project activities to evaluate students' performance. A high-level outline of CS 594 course for a typical fall semester is presented in Table 1.

Table 1. Tentative CS 594 Course Plan for a Fall Semester

Week	Topics/Activities
1	Introduction to CS 594 Course; Syllabus; Knowledge Probe; Homework-1 (assign); Microprocessor Organization/Programming;
2	Assembly Language Programming; IDE68K Package; Homework-1 (due);
3	Assembly Language Programming – Subroutine; Team-Project: Groups, Project Components, Grading, Topics; Homework-2 (due); Quiz-1 (30-minutes); Lab-Introduction;
4	Assembly Language – Exceptions; Homework-3 (due); Lab-1 (due);
5	Assembly Language – Interrupts; Interrupt Service Routines; Homework-4 (due); Quiz-2 (30-minutes); Lab-2 (due);
6	Assembly Language – Interfacing Input / Output Signals/Devices; Lab-3 (due);
7	Software Delay Routine; Hardware Timers; Overview: Exam-1; Exam-1 (60 minutes); Lab-4 (due);
8	Team-Project; C for Programming Embedded Systems; Homework-5 (assign); Project Proposal with literature survey (due);
9 Fall Break	DEMOEM Development Board; CodeWarrior Software; “Blinking LED” – the first Microprocessor Based Embedded System;
10	Hardware Timers; Analog-to-Digital Converter (ADC), Homework-5 (due); Lab-5 (due);
11	Input / Output Signals; Digital-to-Analog Converter (DAC); Analog-to-Digital Converter (ADC), Pulse Width Modulation (PWM); Homework-6 (due); Quiz-3 (30-minutes); Lab-6 (due);
12	Programming LCD Display; Programming sensors; Homework-7 (due); Lab-7 (due);
13	Serial/Parallel Input / Output Communication; Homework-8 (due); Quiz-4 (30-minutes); Lab-8 (due);
14 Thanksgiving Break	Guest Speaker and/or Industry Visit;
15	Embedded Programming – ASM with C; Overview: Exam-2; Exam-2 (60 minutes);
16	Project Presentation / Report Submission by Students (one per group);
Final Week	Project Presentation / Report Submission by Students (one per group); Final Exam (optional, if needed);

Grading

The final letter grades are based on students’ performance on the following components: classroom performance, homework, quiz, exam, lab assignments, and team-project. Different grading scales will be used for undergraduate and graduate students. For lab assignments and team-project, graduate students are expected to do more activities.

Homework: There are eight homework assignments. Homework questions are made available at least one week before the due date. Students are expected to solve the homework problems individually and submit in-person in classroom. Homework provides an excellent opportunity for students to study and grasp the materials, and ask questions if they have any. Homework helps students prepare for quiz and exam tests.

Quiz: There are four quiz tests. Each 30-minute closed-book quiz is conducted at the beginning of a class. Each quiz covers materials that were taught in the previous couple of weeks. Quiz helps students prepare for the upcoming exam. In addition, students get a chance to catch-up with any topics, as/if needed.

Exam: Three are two exams. Each 60-minute closed-book exam is conducted in a class. Exam-1 is right before the Mid-Term point and exam-2 is before the semester ends. Exam-1 is administered based on the material covered since the beginning of the semester. Exam-2 is cumulative; however, the primary focus is on the material covered since Exam-1.

Lab: There are ten lab assignments. Lab assignments are pre-defined and made available at the beginning of the semester. Assembly Language based IDE68K related assignments should be completed individually. However, C Language based CodeWarrior/DEMOEM related problems should be solved as a group. If a group has at least one graduate student, it should be considered as a graduate group for grading purposes. Each lab has two parts: an individual short-quiz and lab-work.

Team-Project: There is one final team-project for a group of students. Each group should consist of about three students. If a group has any graduate students, it should be considered as a graduate group for grading purposes. Each project should have three major components – project proposal with literature survey, demo/oral presentation, and written final report. Some project ideas are discussed and shared with the students. However, students are encouraged to come up with their own topics/problems for their projects.

Measurable Student Learning Outcomes: Undergraduate Level

After passing this course, undergraduate students will be able to:

- Understand the fundamental concepts, challenges, and opportunities of microprocessor based embedded systems.
- Design and develop simple to moderate microprocessor based systems using hardware (such as DEMOEM board) and software (such as CodeWarrior).

Measurable Student Learning Outcomes: Graduate Level

After passing this course, graduate students will be able to:

- Understand the importance and benefits of designing embedded systems and engage in life-long learning of embedded systems for professional success.
- Design, develop, and assess various embedded systems using hardware (such as DEMOEM board) and software (such as CodeWarrior).

Assessment and Results

The results presented in this section are based on the feedbacks from the engineering students enrolled in CS 594 course in fall 2016 semester. BS in CE students take CS 594 as a mandatory core course. A total of 32 students enroll in CS 594 fall 2016 course, and most of them are in the engineering program. Students' feedbacks are collected during the SPTE and ABET evaluations before the end of the semester.

Students' Feedback during ABET Evaluation

The following two outcomes are assessed in fall 2016 semester.

Outcome i: Students understand the benefits of learning microprocessor based systems and engage in life-long learning of embedded systems.

Outcome k: Students become capable of using NXP DEMOEM board (hardware) and NXP CodeWarrior tool (software) to develop and test microprocessor based embedded systems for engineering practice.

The questions, rubric for each question, and students' feedbacks are summarized in Table 2.

Table 2. Engineering Students' Feedbacks during ABET Evaluation

Question	Rubric	Result
(Outcome i) Briefly describe the benefits of engaging life-long learning of microprocessor based embedded systems.	This question was scored according to the materials covered in the lecture and discussion made in the classroom.	80% of the students answered this question satisfactorily. The remaining students answered this question partially satisfactorily.
(Outcome i) Students understand the benefits of learning microprocessor based systems and engage in life-long learning of embedded systems. Agree or disagree; explain why?	This question was scored either agree or disagree.	100% of the students agreed.
(Outcome k) Students become capable of using NXP DEMOEM board (hardware) and NXP CodeWarrior tool (software) to develop and test microprocessor based embedded systems for engineering practice. Agree or disagree; explain why?	This question was scored either agree or disagree.	90% of the students agreed. The remaining students disagreed.

Students' Feedback during STPE Evaluation

During SPTE evaluation, students' comments and suggestions are collected to improve the quality of the course and the instructor's performance. Important feedbacks (such as likes, dislikes, and suggestions) are summarized in Table 3.

Table 3. Engineering Students' Feedbacks during SPTE Evaluation

Likes	Dislikes	Suggestions
• Apply/practice the theory learned in classroom into microprocessor based system design in lab. • Students have an option to choose topics for their projects.	• Less time to work on projects, mainly because the actual hardware is introduced after the Mid-Term point. • Students have to use NXP Boards and CodeWarrior software.	• Allow more time to work with the microprocessor board and peripherals to enhance the hands-on experience. • Let students use any microcontroller board in their projects.

Summary of the Case Study

We apply the proposed student-centered teaching/learning approach in CS 594 (Microprocessor Based System Design) fall 2016 course and measure students' learning experience. We introduce additional lab activities in order to enhance students' hands-on experience and team-project (where students can choose their topics) in order to create an opportunity for students to explore real-world problems. Most students agree that this course helps them become capable of using integrated development suite (such as NXP DEMOEM board/hardware and CodeWarrior software) and developing microprocessor based (hardware/software) systems. This approach helps students improve the quality of their research work; a number of projects are selected for presenting in a university wide research and scholarly projects symposium.

Embedded systems are used in almost every industry today, from automobile manufacturing to mobile manufacturing. However, there are not many customized courses (such as Embedded Systems in Robotics). Industries often offer training so that embedded systems engineers may have practical learning experience in the fast-changing areas. Engaging life-long learning of microprocessor based embedded systems may help embedded systems engineers become successful in their career. All students agree that they understand the importance of learning current microprocessor based systems and engage in continuous learning of upcoming embedded systems for professional success.

Conclusion

The skills and experiences required in industries are changing with the development of new and emerging technologies. The conventional curricula for engineering (and STEM) education are no more capable of preparing students to handle the upcoming industry challenges. Studies suggest that course-based research experience and a combination of project-based learning with cooperative learning are promising for modern engineering education. In this work, we present a case study where the learner-centered project-oriented tactic is introduced in an upper-level undergraduate course for STEM students. By designing and developing microprocessor based embedded systems students get hands-on experience. Students form groups for team-projects; each group of students is encouraged to find a topic for their project. This approach is expected to motivate students to continue researching in the related areas even after the semester ends. During tests (such as quiz and exam) and evaluations (such as SPTE and ABET evaluations), students feedback are collected for assessment of the proposed approach. Based on the classroom and laboratory observations, the proposed approach helps students involve more with the course materials and improve their academic performance. According to the SPTE and ABET evaluation outcomes, the proposed approach has potential to enhance the learning experience in STEM education. Learning in groups has additional advantages; it helps reduce the demand for resources such as development boards and software licenses.

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