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Project-Based Learning to Enhance Teaching Embedded Systems

Belal H. Sababha, Yazan A. Alqudah, Abdelraheem Abualbasal & Esam A. AlQaralleh
Princess Sumaya University for Technology, JORDAN

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Exposing engineering students during their education to real-world problems and giving them the chance to apply what they learn in the classroom is a vital element of engineering education. The Embedded Systems course at Princess Sumaya University for Technology (PSUT) is one of the main courses that bridge the gap between theoretical electrical engineering education and the real-world. This paper presents the experience of applying project-based learning to enhance teaching the Embedded Systems course at PSUT. The feedback from students illustrated the effectiveness of this method in enhancing the understanding and the ability of students in applying embedded systems design concepts to solve real-world engineering problems.

Keywords: embedded systems design, engineering education, project-based learning, PBL

INTRODUCTION

Project-based learning (PBL) provides hands-on, real-world experiences for engineering students to enrich their understanding of technical theories and concepts. Proven to be more effective than traditional "chalk and talk" methods of teaching and learning, PBL is becoming an ideal method to enhance the education of engineering students throughout the world. PBL has shown to be most effective when paired with face-to-face learning (lectures) that introduces students to theories and concepts. PBL takes this learning further by applying it to a hands-on application (such as a lab or project) that is assigned to take place throughout the course. Literature indicates that PBL not only enhances student learning but also better prepares them for their future careers.

Research conducted by Mills and Treagust suggests that recent engineering graduates are not well prepared for their entry into a real-world, industrial environment (Mills & Treagust, 2003). The research proves that engineering students are graduating with a good fundamental knowledge of engineering and science concepts, but they do not know how to apply this information to the real world environment. Furthermore, accreditation institutions such as the Accreditation Board of Engineering and Technology (ABET) has indicated that

Correspondence: Belal H. Sababha,
Computer Engineering Department, Princess Sumaya University for Technology, Princess Sumaya University for Technology, Amman 11941, Jordan.
E-mail: b.sababha@psut.edu.jo

entry-level engineers often graduate without the 'softer' skills desired in industry. They lack the ability to work in teams, apply concepts learned in the classroom, or engage in real-world projects (ABET Engineering Accreditation Commission, 2012). Since this is often blamed on traditional "chalk and talk" methods of instruction, these institutions are encouraging universities to adapt their methods of teaching to meet industrial needs.

The American Society for Engineering Education (ASEE) has advised educational intuitions around the world to adapt their teaching methodologies and better prepare students to meet the industry's changing needs for engineering graduates:

> Today, engineering colleges must not only provide their graduates with intellectual development and superb technical capabilities, but following industry's lead, those colleges must educate their students to work as part of teams, communicate well, and understand the economic, social, environmental and international context of their professional activities. These changes are vital to the nation's industrial strength and to the ability of engineers to serve as technology and policy decision makers. (American Society of Engineering Education, ASEE, 1994)

The Accreditation Board of Engineering and Technology (ABET), establishes criteria for universities to maximize student learning and prepare them for their future endeavors. The ABET criteria is adapted yearly to keep engineering programs competitive with the changing industrial and societal needs. ABET's criteria for accrediting engineering programs for 2015-2016 requires that engineering courses be designed to meet a vast array of desired outcomes (ABET Engineering Accreditation Commission, 2014). ABET's Criteria 3 Student Outcomes, were designed to guide universities of the skills engineers need in today's industrial climate. These objectives are to be achieved by each institution at the time of a student's graduation. ABET's Engineering Accreditation objectives states that engineering students should foremost be able to apply their technical knowledge (of mathematics, science, and engineering) and have a broad educations that familiarizes them with the impact of engineering solutions on society in a global, environmental, and economical context. Students should also be familiar with contemporary engineering issues and be proficient at identifying, formulating, and solving engineering problems. Students should be able to design a system, component, or process to meet desired outcomes, (taking into account economics, environment, health and safety standards, etc.) conduct experiments, and be able to analyze and understand data. Students should also be able to utilize the modern engineering techniques, skills, and tools required for future engineers (ABET Engineering Accreditation Commission, 2014).

State of the literature

- Hands-on learning techniques such as problem-based and project-based learning (PBL) have become highly sought after in the engineering classroom.
- Some of the significant benefits gained through the PBL course are more self-directed learning and augmenting students' problem solving skills.
- Learning real-world challenges in academic environment is enhanced through a combination of traditional and project-based learning methods in embedded systems.

Contribution of this paper to the literature

- A project-based learning approach has been presented to enhance the teaching of an undergraduate level microprocessor-based embedded systems course.
- Exposing engineering students during their education to real-world problems is achieved through requiring students to design and implement comprehensive system-level prototypes within predefined system requirements and realistic constraints.
- PBL method in teaching this course has helped bridging the gap between theoretical electrical engineering education and the real world. The feedback from students confirmed the effectiveness of the presented method in enhancing the understanding and the ability of students in applying embedded systems design concepts to solve real-world engineering problems.

ABET's student outcomes also incorporates a host of "softer skills" into its criteria. These skills, while not technical in nature, aid engineers in their post graduate work in academic or industrial settings. They include excellent communication skills, the ability to work in a multidisciplinary team-based environment, the desire to act in an ethical and professional manner, and possess the attributes of a life-longer learner (ABET Engineering Accreditation Commission, 2014).

Based on ABET's criteria and society's needs for today's engineers, an educational change is needed to better prepare engineers for their futures. Hands-on learning techniques such as Project-Based Learning (PBL), has been introduced into engineering courses around the world with remarkable success. By definition, 'Project-based learning begins with an assignment to carry out one or more tasks that lead to the production of a final product—a design, a model, a device or a computer simulation. The culmination of the project is normally a written and/or oral report summarizing the procedure used to produce the product and presenting the outcome (Prince & Felder, 2009).'

PSUT has adopted project-based learning in several of its electrical engineering courses (Alqudah & Al-Qaralleh, Project based learning to enhance teaching digital signal processing, Nov. 2012), (Alqudah & Mace, Project Based Learning in wireless communications utilizing deployed wireless networks, May 2014). By offering a hands-on, applied approach to learning, PSUT hopes that students will have a learning experience that better-prepares them for future field work in their respected fields of engineering.

This paper is organized as follows. Section II summarizes related work. Section III gives an overview about the Embedded Systems course coverage, objectives and outcomes. Sections IV describe the design projects, their requirements, expectations, assessments and shows sample projects. Results are shown and discussed in Section V. Finally Section VI concludes the paper.

RELATED WORK

In recent years, hands-on learning techniques such as problem-based and project-based learning (PBL) have become highly sought after in the engineering classroom (Maskell & Grabau, May 1998) (Hamblen, Aug. 2008) (Kim & Jeon, Feb. 2009) (Kim J. , Feb. 2012) (Kumar, Fernando, & Panicker, Nov. 2013) (Hu, Li, & Chen, Feb. 2015). Since its introduction, project-based learning has shown to greatly impact students' knowledge of core concepts taught in the classes and takes this learning further by allowing students to apply this knowledge to real-world applications.

In literature, Macias-Guarasa *et. al.* (Macías-Guarasa, Montero, San-Segundo, Araujo, & Nieto-Taladriz, AUGUST 2006), introduce a new Electronic Systems curriculum to address the need for a more hands-on learning approach. They introduced a curriculum including four theoretical, four project-based courses, and a graduate level thesis. The PBL courses required students to work in teams to develop highly sophisticated, multidisciplinary systems. Due to the complexity of this initiative, the university invested in numerous resources such as software tools and hardware. This method has been undertaken for the past four years and has proven to be effective both in enhancing student interest in the course material and achieving substantial academic success.

Research conducted by Wildermoth and Rowlands (Wildermoth & Rowlands, 2012) applies the project-based learning principles to a compulsory fourth (and final) year embedded electronics design course. The course covers the areas of digital design, embedded systems development, and digital signal processing through the use of a reconfigurable development platform (Nanoboard 3000).

Utilizing a structured lab component and a game-based project, this course has been applied for the past four years with noteworthy levels of success. Some of the significant benefits gained through the PBL course (as presented through student evaluations) were more self-directed learning and augmenting students' problem solving skills.

Davcev and Stojkoska applied a combination of traditional and project-based learning methods to an embedded systems course (Davcev, Stojkoska, Kalajdziski, & Trivodaliev, Jan. 2008). The PBL focused on a wireless sensor monitoring of a real-world greenhouse environment. Students adopted a Unified Modelling Language (UML) tool to model and design the embedded system to implement an object-oriented paradigm. Having the students work directly with the hardware allowed students to learn the details of the embedded architecture firsthand. Results showed that students found this work valuable in learning real-world challenges in the academic environment.

Given the need for engineering graduates to have a sound knowledge and experience with embedded systems design, Wang and Wang introduced an innovative project-based course to meet the needs (Wang, Wang, Harris, & Cole, June 2013). The course consisted of system design lectures, a series of six labs, a final project, and students' demonstrations and presentations. Student feedback was overwhelming positive with students agreeing that the labs were useful in learning embedded system design. Students were most excited about the course final project component. Students were asked to create a project that integrated two different peripherals (design data that supports data streaming through a DMA device and implement a data processing algorithm). Students' projects allowed them to use their creativity while applying the information they learned through the course. The results proved that the students learned the coursework and had an enjoyable learning experience as well.

COURSE COVERAGE, OBJECTIVES AND OUTCOMES

In this work, the Embedded Systems course is a senior-level undergraduate course that is mandatory in the electrical engineering program curriculum at PSUT. The course is designed to achieve specific outcomes that cover four of ABET‟s a-k outcomes. The primary objective of the course is to learn how to design hardware and software for microprocessor-based embedded systems. As a medium for learning, a Microchip midrange family microcontroller unit (MCU) is adopted. The concepts learned in the course can be adapted to other microcontrollers.

The course covers fundamental topics in Embedded Systems including: Microprocessor-Based Embedded systems characteristics, Microcontrollers characteristics and General-purpose microcontrollers, Microcontroller architectures, Interrupts and Resets, Counters, timers and PWM, Input / Output ports, Microcontroller programming and Instruction set, Program development and use of assemblers and cross compilers, Memory maps and addressing modes, Digital to analog and analog to digital conversion in microcontrollers, Data acquisition and distribution, Serial and parallel communications, Real-time systems and constraints, Interfacing to external devices, Power consumption consideration.

The outcomes of the Embedded Systems course are:

- Understand the fundamentals of embedded systems and their input/output communication models.
- Learn how to program and debug embedded systems.
- Learn how to interface the microcontroller with parallel I/O devices such as: Switches, LEDs, seven segment displays, time multiplexing multiple seven segment displays.

- Learn to configure, program and deal with software and hardware interrupts.

The course fulfills ABET outcomes (c), (d), (e) and (g). The remaining of this section shows these outcomes and briefly describes how they are considered in this course.

ABET Outcome (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, safety, manufacturability, and sustainability”. In this course students learn how to design embedded systems with their hardware and software components. Design requirements are set to produce a system that meets realistic constraints such as real-time constraints, power consumption constraints, budget constraints, safety constraints...etc. This outcome is measured through different direct and indirect methods. Direct methods are such as direct exam design problems. In addition to a final design project in which students have to turn in a design report and a working prototype for a real-world prototype that is comprehensive and includes most of the concepts learned in class.

ABET Outcome (d): “An ability to function in multi-disciplinary teams”: The course requires all students to team up in groups of two to four students from the three different electrical engineering majors (Electronics, Computer, and Communications Engineering) who take this class to work on a design project. This outcome is indirectly measured by having students report how they planned for the project and how they distributed tasks among them as well as how they met and assured integration of all pieces done by all team members. By the end of the class, each team member is required to turn in a peer evaluation form in which every student talks about his teamwork experience and his opinion about how everybody in the team behaved.

ABET Outcome (e): “An ability to identify, formulate and solve engineering problems”: This outcome is measured in this class using different direct and indirect methods. Direct assessments are achieved through direct exam problems. Moreover, students are required to include a separate section in their final design project report about the problems they encountered during their work on the project and how they worked on solving such problems.

ABET Outcome (g): “An ability to communicate effectively”: All final design project teams are required to turn in a written report about their design project. The report is used to measure the students’ written communication skills. In addition, all students are required to do an oral presentation about their design project experience. The presentations, in addition to a YouTube video taken by the students about their project are used by the instructor to indirectly measure their oral communication skills.

DESIGN PROJECTS

The Project-Based Learning (PBL) part of this class is achieved through requiring students to design and develop a non-trivial embedded system or device that performs some real-world useful function. The design shall incorporate most of the concepts and modules learned in class. Hence, every project is to include an acceptable amount of the following features: Use a digital input device such as Pushbuttons and Switches, Key Pads, Digital sensors, etc. Use an analog input device or sensor such as Temperature sensor, Humidity sensor, Light sensor, Range finder IR or Ultrasonic sensor, Reflective sensor. Use a method of serial communication to communicate with other computers, microcontrollers, mobile devices or smart sensors. Use a Human-Machine interface such as LCD or LED displays. Control an actuator such as DC motor, Stepper Motor, Servo Motor, Linear Actuator. Use a switching device such as H-Bridge, Solid State and Mechanical relays to interface with output devices as motors, heaters, compressors and others. Use the Timer modules to generate PWM signals to control motor speeds, servo motor positions or anything else.

To achieve the required amount of the above components in every project, teams are required to submit a proposal about the project they intend to do. Proposals have to be approved by the course instructor before the team starts working on the project. A project proposal shall include the following components. A list of the team members. A brief background about the topic. Explanation of the idea of the project. Specify the design requirements and constraints. A list of all hardware components to be used to build the project and explain for what every hardware component is going to be used. A brief description of the proposed embedded software design. Provide cost analysis. Write the work plan and divide the work into tasks within a time table.

The course instructor studies the proposals. If the proposed project is found within an acceptable level of complexity and uses most of the required features and modules learned in class, the proposal is then approved and students are notified to proceed in their work. Every team is asked to turn in a progress report in the middle of the time period allowed for the project. This is studied by the course instructor and teaching assistants to make sure everybody is on the right track.

By the end of the semester and before the project evaluation day, students are required to submit online to the class wiki the following material:

- A final report that includes the following sections: Abstract, Introduction and Background, The Design (Mechanical, Electrical and Embedded Software), Results, Problems and Recommendations, and Conclusion.
- A Poster file that would be printed and used in the final presentations and demonstrations of the projects.
- The Embedded Software Code and project folder.
- A few pictures of the prototype.
- A link to a YouTube Video describing the project.

Afterwards, in the presentations day, every team would do a poster presentation about the project and would demonstrate their prototypes. Several evaluators would walk around between the teams evaluating their work such as: student's presentation skills, team work, design, understanding and problem solving skills. Every member of a team would also turn in a peer evaluation form valuating from their perspective other members of the team.

Some of the projects are shown in Figure 1. Namely: (a) Hotdog Machine, (b) Voice Controlled Robot, (c) Smart Water Fall, (d) Prosthetic Hand, (e) Drawing Machine, (f) Smart Irrigation System, (g) Chess Playing Robot, (h) Snack Vending Machine, (i) Pacman Robotic Game, (j) Ilizarov Apparatus, (k) Crane, (l) 3D Printer.

RESULTS AND DISCUSSION

A survey has been conducted asking the 41 students who toke the class in the fall semester of 2013 to answer six main questions. The questions aimed to measure the benefits which were gained by students through the projects' experience; students were asked to give each question a ranking on a scale from 0 to 5 where 0 refers to the lowest ranking (strongly disagree) and 5 refers to the highest ranking (strongly agree). The results are discussed in the next section.

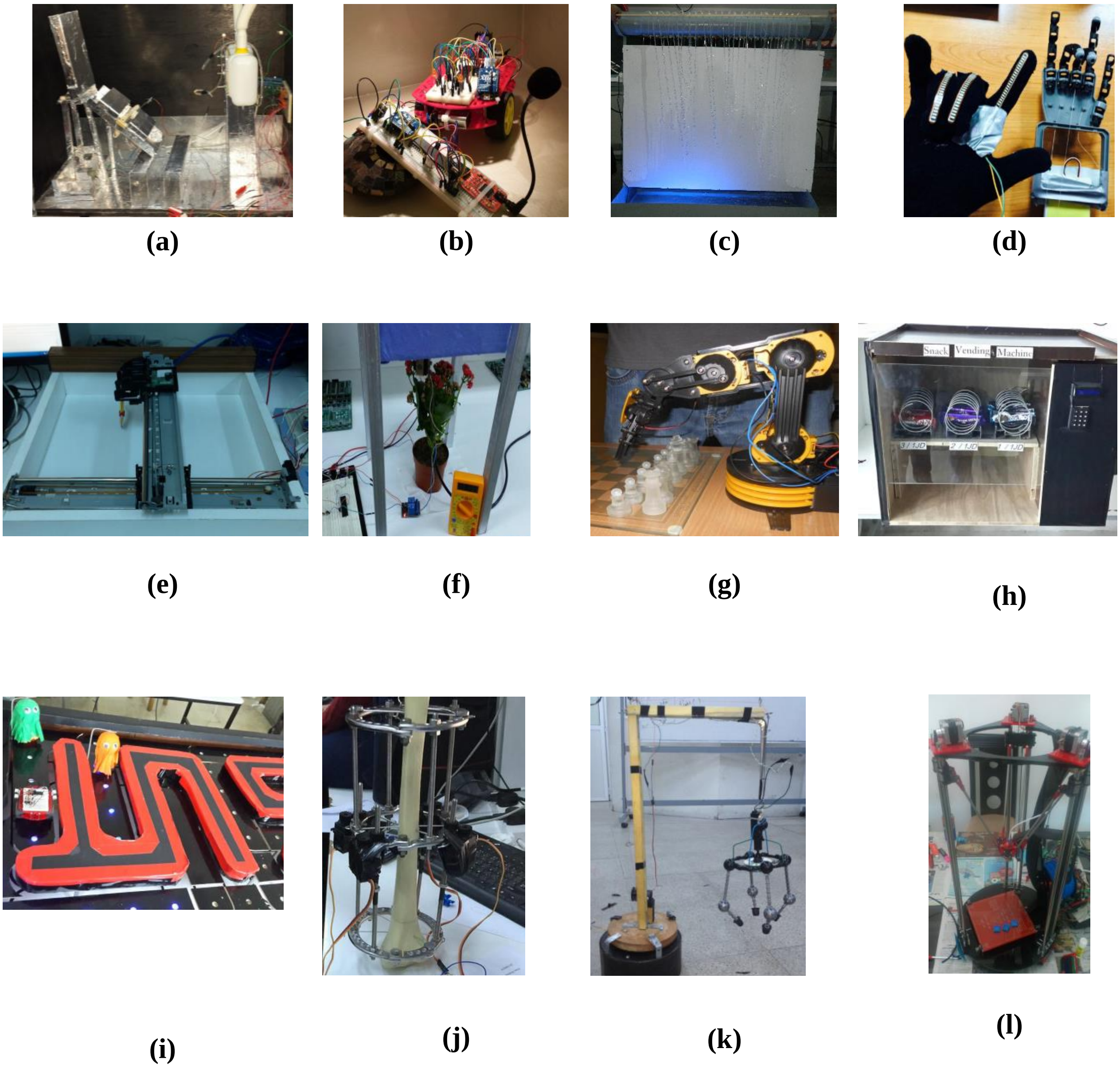

Figure 1. Sample Projects, (a) Hotdog Machine, (b) Voice Controlled Robot, (c) Smart Water Fall, (d) Prosthetic Hand, (e) Drawing Machine, (f) Smart Irrigation System, (g) Chess Playing Robot, (h) Snack Vending Machine, (i) Pacman Robotic Game, (j) Ilizarov Apparatus, (k) Crane, (l) 3D Printer

Table 1 shows a brief summary of the analysis. The first question aimed to measure the perceived benefits of project-based learning among students; they were asked to rate how the project has reinforced concepts learnt in the class. The results showed that the mean of the students' answers was 4.61 which is high and that means the concepts learnt in class were strongly reinforced through the group project. As shown in Figure 2, 97.5% of the students gave a ranking of 4 or 5 for this question.

The purpose of the second question was to measure how students' interest in electrical engineering was affected by project-based learning; the mean of the answers was 4.56 which proves that students' interest in electrical engineering was raised by project-based learning. As shown in Figure 3, 90.2% of the students strongly agreed that project-based learning raised their interest in electrical engineering.

Question three was generally similar to question two as it aimed to measure how students' interest in embedded systems was affected by project-based learning; here the mean of the answers was 4.46 which is also high and indicates that students' interest in embedded systems was raised by project-based learning. Figure 4, shows that 92.7% of the students gave a ranking of 4 or 5 to this question.

Table 1. Descriptive analysis

Q No.	Question	N	Mean	Std. Deviation	Variance
Q1	The project reinforced concepts learned in class.	41	4.61	0.541	0.294
Q2	The project raised my interest in Electrical Engineering.	41	4.56	0.673	0.452
Q3	The project raised my interest in Embedded Systems.	41	4.46	0.636	0.405
Q4	Having real engineering problems made the project more interesting.	41	4.49	0.675	0.456
Q5	The project raised my teamwork capabilities.	41	4.15	1.062	1.128
Q6	The project is worth the time and effort.	41	4.66	0.575	0.330

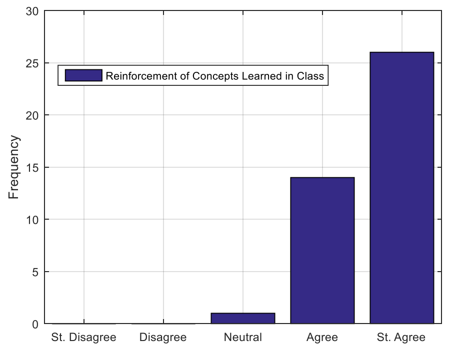

Figure 2. Question 1: The project reinforced concepts learned in class

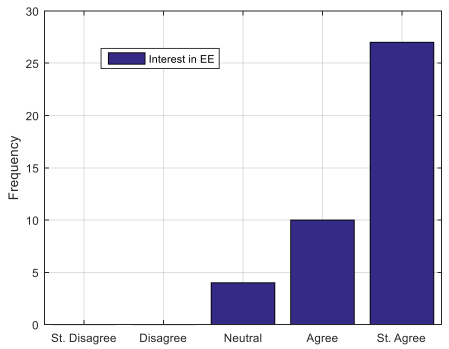

Figure 3. Question 2: The project raised my interest in Electrical Engineering

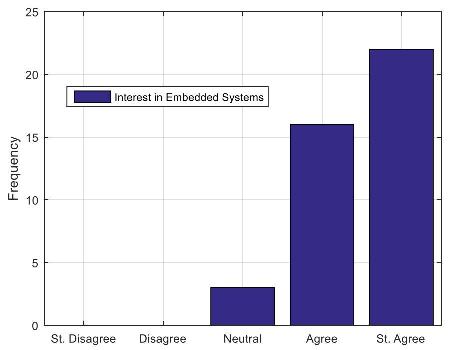

Figure 4. Question 3: The project raised my interest in Embedded Systems

We assumed that one of the major factors that support students' interest in project-based learning would be dealing with a real-life problem, so we asked the students to rate this assumption through question four and the mean was 4.49 which indicates that our assumption was correct as having a real-life problem in the project made it more interesting for the students, and as shown in Figure 5, 93.7% of the students strongly agreed with this statement by giving it a ranking of 4 or 5.

The fifth question aimed to measure another perceived benefit of project-based learning among students. The mean of 4.15 and the results shown in Figure 6, indicate that the students have perceived the improvement in their teamwork capabilities as a benefit gained from project-based learning. The results show that 80.5% of the students strongly agreed that working on the project with their group raised their teamwork capabilities.

In order to measure the overall students' interest in project-based learning we asked them if the project was worth their time and effort; the highest mean was given to this question (4.66), and as shown in Figure 7, 94.1% of the students rated this question with 4 or 5 to indicate that they strongly agreed with this statement.

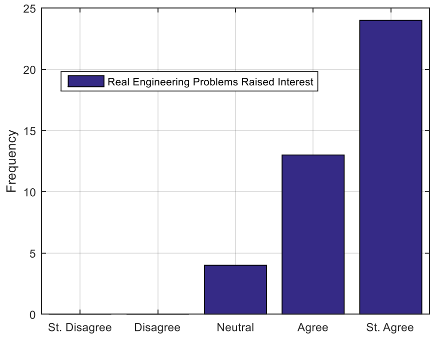

Figure 5. Question 4: Having real engineering problems made the project more interesting

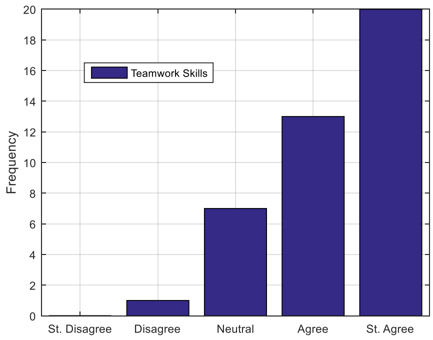

Figure 6. Question 5: The project raised my teamwork capabilities

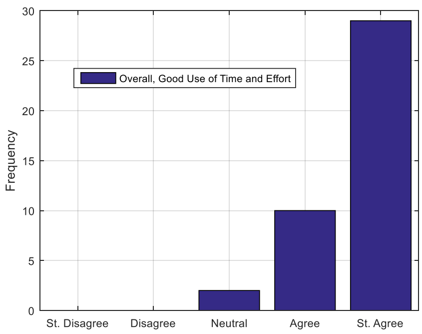

Figure 7. Question 6: The project is worth the time and effort

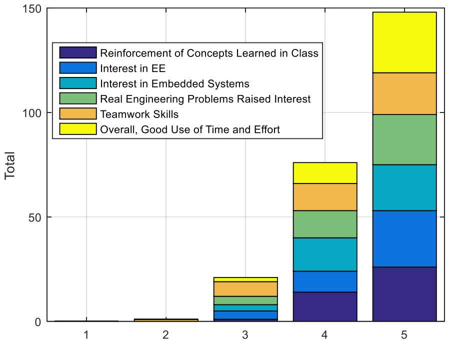

Figure 8. Descriptive statistics

The descriptive statistics shown in Figure 8, indicate that for all the questions the answers ranged between 3 and 5 except for question 5 which got one student who rated it 0. Furthermore, the standard deviation of the questions show that the answers were almost in the same flow and very close to the mean except for question five which was affected by the answer described above. The results indicate a positive view of the students towards learning through projects or as termed project-based learning.

CONCLUSION

In this paper, a project-based learning (PBL) approach has been presented to enhance the teaching of an undergraduate level microprocessor-based embedded systems course. The goal was to expose engineering students during their education to real-world problems and give them the chance to apply what they learn in the classroom. This was achieved through requiring students taking the class to design and implement comprehensive system-level prototypes within predefined system requirements and realistic constraints. In this work, the guidelines of The Accreditation Board of Engineering and Technology (ABET) in accrediting engineering programs have been followed and the criteria has been considered. The paper has presented the course coverage, objectives and outcomes. It has described the design projects' requirements and deliverables. It is believed that this PBL method in teaching this course has helped bridging the gap between theoretical electrical engineering education and the real world. The feedback from students confirmed the effectiveness of the presented method in enhancing the understanding and the ability of students in applying embedded systems design concepts to solve real-world engineering problems.

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