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PAPER

Experience of Project-Based Learning: Challenges, Assessment, and Analysis

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ABSTRACT

Though theoretical knowledge is essential, there is a growing belief that when teaching applied sciences, particularly engineering, a great emphasis should be placed on the development of students' practical skills. Therefore, some courses and curricula need to be revised to enhance the current state of education in this field. This can be achieved through the introduction of project-based learning (PBL). The PBL approach is ideal for teaching engineering disciplines because its framework promotes critical thinking and problem-solving skills, which are essential for a professional engineering career. This paper explains the implementation and comparative analysis of the PBL method in the departments of Electrical Engineering and Biomedical Engineering at King Faisal University. The challenges faced in this implementation include incorporating the PBL approach into the departments' overall instructional technique, defining the roles of PBL coordinators, and addressing the characteristics of the PBL problems that arise in the courses offered. Furthermore, the implementation of PBL projects is evaluated based on the common courses offered in both departments. It is taken as an example and assessed based on problem-solving, teamwork skills, and the outcomes of accreditation board for engineering and technology. The results of this implementation are reported in this paper. Furthermore, we actively shared our experience managing course projects remotely during the fall semester, which COVID-19 impacted. Recommendations for future work are discussed, emphasizing the importance of having sufficient resources and fostering collaboration with industry and researchers from diverse disciplines.

KEYWORDS

project-based learning (PBL), experiential learning, learning design, holistic, bio-medical, electrical engineering, COVID-19

1 INTRODUCTION

Engineering education has undergone a significant change, moving from traditional lecture-based teaching methods to more interactive and student-focused techniques. Project-based learning (PBL) has garnered significant attention from educators and

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scholars in this context. PBL is an educational approach that engages students in practical problem-solving activities, helping them acquire a thorough understanding of engineering principles while also fostering essential skills for future career success.

The motivation for this study arises from the increasing recognition of the potential of PBL to transform engineering education. The capacity of PBL to foster critical thinking, problem-solving, teamwork, and communication skills is in perfect harmony with the fundamental abilities desired by the industry. Furthermore, the emphasis of PBL on active learning and self-directed exploration aligns with the constructivist learning paradigm, which promotes better retention of knowledge and enhanced problem-solving skills.

The PBL model has been extensively implemented in numerous colleges, yielding positive outcomes. William Kilpatrick, in 1918, as documented in his paper "The Project Method" [1], was the first to explore the concept of PBL. PBL is an educational approach that involves applying academic knowledge and gaining practical experience through the completion of specific projects. The courses on electric circuits and digital logic can employ a similar pedagogical approach. Students are often required to participate in collaborative work within small groups during these courses. The primary concept underlying the utilization of PBL in education is that students, while working autonomously on proposed projects, acquire the ability to apply theoretical knowledge in practical situations and develop essential skills in the process [2]. Utilizing a PBL approach can offer significant advantages to engineering students due to multiple factors. This specialization requires hands-on experience and can be beneficial if a substantial part of it is gained during the educational program. PBL not only equips students with crucial practical skills but also improves their capacity to retain and comprehend information acquired during lectures. In contemporary times, there is a heightened expectation for engineers to engage in collaborative efforts. Hence, collaborating on projects with colleagues might be advantageous for the professional development of engineering graduates. Additionally, this form of learning has the potential to enhance students' motivation and interest in the subject matter by fostering greater engagement [3], [4].

This study aims to explore the complexities of implementing PBL in engineering education, with a focus on three key research topics. The initial investigation focuses on assessing the effectiveness of PBL in engineering education compared to the traditional lecture-based approach, with an emphasis on student outcomes. This analysis aims to measure the influence of PBL on student learning by evaluating its efficacy in cultivating critical thinking, problem-solving, teamwork, and communication abilities in comparison to conventional approaches.

The second topic discusses the navigation of challenges and opportunities in integrating PBL in engineering education. This issue explores the practical aspects of implementing PBL, addressing the challenges that teachers and students may face, and suggests strategies for overcoming them. Additionally, it aims to uncover the untapped potential of PBL, highlighting opportunities to improve its implementation to achieve the best possible student outcomes.

The third objective focuses on developing optimal methodologies for PBL in the field of engineering education. The purpose of this topic is to establish a framework for the successful implementation of PBL in engineering education. The objective is to provide instructors with practical guidance on effectively integrating PBL into their courses. This aims to establish a well-organized learning environment that boosts student engagement and facilitates the development of essential engineering skills.

This study aims to enhance the existing knowledge of PBL in engineering education by investigating these research questions. The objective is to provide essential knowledge to educators, curriculum designers, and policymakers, empowering them to make well-informed decisions about integrating PBL into engineering education programs. The main goal of this study is to make a valuable contribution to the improvement of engineering education. The aim is to develop a new generation of engineers who have the necessary skills and knowledge to effectively address the intricate issues of the 21st century.

2 RELATED WORKS

Extensive research has been conducted on the efficacy of PBL in engineering education. A substantial amount of evidence indicates that PBL has a beneficial effect on student outcomes. Research has demonstrated that PBL effectively enhances essential skills such as critical thinking, problem-solving, teamwork, and communication skills, all of which are vital proficiencies for engineers. Moreover, PBL has the potential to foster a deeper understanding of engineering principles and encourage dynamic engagement in the learning process.

Multiple studies have been conducted to compare the efficacy of PBL and standard lecture-based instruction in the field of engineering education. These studies consistently show that PBL leads to better student outcomes in terms of information acquisition, problem-solving skills, and overall engagement. While there is supportive evidence, the successful implementation of PBL in engineering education can pose challenges. Instructors may face challenges when creating and overseeing PBL projects, while students may struggle to adapt to the independent and cooperative aspects of this approach. In order to address these challenges, several optimal strategies for implementing PBL have been identified. These practices include providing clear project parameters, structuring student learning, facilitating efficient teamwork, and consistently providing feedback.

Numerous studies have been dedicated to the implementation of PBL in engineering education. For instance, project-based methods can be applied in electronic and computer engineering studies, especially in integrated circuit layout courses. For such tasks, students can be divided into small groups of four to five. Teck [5] suggested a detailed six-week plan comprising the following stages: "project clarification, investigation, processing of data, realization, and evaluation." In [6], the authors examined the benefits of applying PBL to teaching electrical power systems engineering. Using the example of a course in power system modeling as an illustration, they concluded that PBL can enhance students' professional skills. Although PBL practices have been widely used in higher-level courses, some research has suggested that they can also be successfully introduced in lower-level classes [7]. Hence, studying by completing projects can be done in various engineering fields at different educational levels. Engineering is a broad discipline with various specialized areas. Undergraduates typically pursue a bachelor's degree in Civil, Mechanical, Electrical, and Chemical Engineering. Graduates specialize in Structural Engineering, Aerospace Engineering, Environmental Engineering, Biomedical Engineering, and Systems Engineering. Doctoral students pursue advanced research in robotics and automation, nanotechnology, renewable energy engineering, artificial intelligence (AI), and machine learning (ML).

The article [8] examines the utilization of PBL as a pedagogical approach for teaching virtual design and construction (VDC) in a bachelor's-level civil engineering curriculum. The researchers discovered that PBL was successful in facilitating the acquisition of generic competences, such as problem-solving, communication, and teamwork, among students. Additionally, it was discovered that students who engaged in PBL had elevated levels of satisfaction with their educational experience. The study in [9] outlines the utilization of PBL as a means to enhance critical thinking and problem-solving abilities in geotechnical engineering courses. The researchers discovered that PBL proved to be effective in fostering the acquisition of these skills. Moreover, students who engaged in PBL exhibited higher levels of academic achievement. The study in [10] investigates students' perspectives on team learning strategies in project- or design-based learning (PDBL). According to the authors' findings, students highly appreciated the opportunity to study in teams and considered that PDBL was essential in cultivating crucial abilities such as communication, teamwork, and problem-solving. The authors in [11] explore the significance of creativity in the realm of engineering education. According to the authors, PBL is a valuable approach for nurturing students' creativity. The authors present an analysis of a project-based learning course in which students were assigned the task of designing and constructing a solar-powered vehicle. The study revealed that the project facilitated the enhancement of students' engineering skills and creativity. In general, the studies reviewed indicate that PBL is a beneficial method for engineering education. PBL facilitates the cultivation of vital skills in students, including problem-solving, communication, teamwork, and creativity.

There might be some alterations in how the work is organized in PBL courses. This approach may involve an unstructured project that usually implies only some general guidelines or a structured one that includes predetermined limitations. The former allows students to be more creative, while the latter enhances their resourcefulness and flexibility. Projects can be assessed when they are completed (summative method) or at different stages of their progress (formative assessment). The latter approach can help monitor students' work, motivating them to start early [5]. Giving timely feedback can improve the final outcome.

There are various approaches to implementing PBL methods, and numerous studies have utilized them in the field of electrical engineering (EE) education. A recent study claimed that the variety of projects assigned during different courses can be overwhelming; therefore, it suggested resorting to multi-course practice-based learning (MCPBL). The study conducted at Qatar University [12] showed that, in addition to equipping students with the necessary skills, MPL can enhance their awareness of sustainable development, a skill increasingly demanded in engineering graduate studies. Some researchers have suggested that combining the project-based approach with traditional teaching methods is the most beneficial approach [6]. Hence, educators who want to implement the PBL approach should consider delivering theoretical materials through lectures and exploring the advantages of creating a multi-course project.

Nonetheless, some challenges that may arise when resorting to PBL should also be mentioned. The major one among them is that it demands considerable time and effort from students and their teachers [5]. However, the educational value of this approach can outweigh the amount of work it demands. Some modifications might be necessary for general courses in which students have different backgrounds. For instance, in an engineering mechanics course, students from the mechanical department may have an unfair advantage over those from other departments [12]. While there is room for subjectivity in the evaluation process, designing a proper assessment rubric can help mitigate this challenge. Therefore, its benefits can mitigate some of the challenges associated with the project-based approach, while meticulous planning can resolve others. Recent studies have shown that PBL can be successfully used to teach various aspects of engineering. It can increase students' motivation, equip them with the necessary professional skills, improve their understanding of theoretical knowledge, and enhance their collaboration abilities. Although some challenges can be noted in PBL implementation, increasing research has indicated ways to overcome these difficulties.

Project-based learning is not exclusive to European and North American academic institutions. Some universities that have implemented PBL in their engineering curricula include the University of Manchester (UK), the University of British Columbia (Canada), and the University of Delaware (USA) [13–19]. Various approaches have been adopted to implement these methods. Examining its application in EE education, a recent study claimed that the variety of projects assigned during different courses can be overwhelming. Therefore, it suggested resorting to MCPBL. The study conducted at Qatar University showed that, in addition to equipping students with the necessary skills, MCPBL can raise their awareness of sustainable development, which is increasingly required in engineering graduate studies [12]. However, little is known about similar efforts within the Middle East and Asia, including Saudi Arabia.

To the best of our knowledge, our initial attempt to implement PBL within an engineering syllabus in 2009 was the first of its kind in the Kingdom of Saudi Arabia. The College of Engineering at King Faisal University (KFU) mandated that the curricula for all four programs—electrical, mechanical, civil, and chemical engineering—be developed based on the PBL approach. All four programs were ABET-accredited in 2015. After the COVID-19 outbreak, teaching at KFU transitioned to online classes using the Blackboard platform. The Coles College of Business in the USA followed a similar approach by utilizing its Desire2Learn LMS platform [20], while universities in Georgia opted for the Google G-Suite solution [21].

The research methodology employed in this study aligns with the established body of knowledge on PBL in engineering education. The study will utilize a mixed-methods approach, integrating both quantitative and qualitative data gathering methods to obtain a comprehensive understanding of PBL implementation and its impact on student outcomes. The collection of quantitative data will involve administering pre- and post-tests to evaluate the extent to which students have acquired knowledge and developed problem-solving skills. The collection of qualitative data will involve administering surveys and conducting interviews to gather the perspectives of both students and instructors on their experiences with PBL. The research hypothesis suggests that PBL will lead to improved student outcomes in terms of information acquisition, problem-solving skills, and overall engagement compared to traditional lecture-based instruction. The study aims to evaluate this hypothesis by conducting a comparative analysis of the academic performance of students enrolled in PBL groups and lecture-based sections of an identical engineering course.

This paper discusses the implementation of the PBL system within the departments of EE and Biomedical Engineering at KFU. The challenges involved in integrating the PBL approach into the overall instructional strategies of the departments, appointing PBL coordinators, and addressing the issues related to PBL features in the courses offered. The paper also highlights the experience of implementing the PBL approach during the COVID-19 pandemic. The challenges faced and policy implementation are discussed in detail. Additionally, the ABET outcome assessment results are provided at the end of the paper.

3 OVERVIEW OF PBL ACTIVITY

The process initiated in PBL is shown in Figure 1.

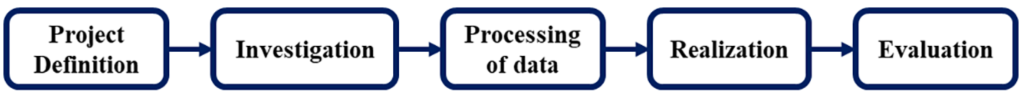

Fig. 1. PBL process

The project's specifications are defined and explained first. During the initial investigation, the tasks included identifying information, gathering data, evaluating the problem, and proceeding to find the solution. During the project activity period, the students worked as a team to analyze and interpret the gathered data, classify it, and prepare it for application. During the realization phase, the students had to conceptualize potential solutions and learn how to organize and manage their time to create a prototype or model. Project evaluation could be conducted independently or in groups through presentations, reports, self-reflection, peer reviews, or self-assessments. Finally, conclusions were drawn.

3.1 Integration of PBL in the coursework structure for the EE department

The EE program [22] at King Faisal University has implemented PBL with the belief that this approach can enhance the quality of education. By adopting PBL, the program aims to equip graduates with the necessary skills to pursue advanced studies, conduct research, and develop innovative solutions to electrical engineering problems. The program also emphasizes collaboration with industry and research centers to address national issues of importance. Students in each course are offered project tasks that they work on in teams. Program coordinators consistently evaluate students' technical proficiency as well as their interpersonal interactions and communication abilities. Typically, every project includes a design and/or analysis component, simulation, and verification through measurement. The majority of the time is dedicated to constructing a prototype.

Engineering programs ultimately prepare students for post-graduation life. Regardless of the age at which children are introduced to our society, it is imperative that they comprehend the connection between education and their future aspirations. Consequently, our department's upcoming strategies involve considering the use of PBL in collaboration with the industry. Course projects, such as those based on real-world industry problems, provide students with a valuable opportunity to collaborate with industry professionals and gain a deep understanding of the industrial environment.

At the first stage, the adoption of PBL presents several challenges, including the course instructor's difficulty in effectively selecting the specific topic or unit from the textbook to be taught using PBL. Subsequently, the esteemed faculty members of the department convene and engage in thoughtful discussions to determine the appropriate course of action to rectify the situation. The selection and planning of projects are mostly based on the learning outcomes and project briefs. Every course is equipped with specific learning objectives, and it is the responsibility of the course instructor to select course projects that effectively assess these objectives. The course consists of multiple sections and is instructed by various teachers. The course coordinator is responsible for selecting the learning objectives (LOs) to be assessed using the PBL technique.

To implement PBL, every course follows the following procedures: The process consists of five stages: 1) choosing a topic and proposing a project; 2) planning and designing the project; 3) monitoring the project activities and implementing them; 4) evaluating the project; and 5) presenting and reporting the project.

Project-based learning is a suitable method for improving the quality of engineering programs. It is integrated throughout the program, starting from the first-year (freshman) through the fourth-year (senior) courses. However, the PBL content in a first-year course should be minimal. This is because a first-year undergraduate in the program would only have completed preparatory courses, such as mathematics and physics. Therefore, the types of PBL problems they could be expected to solve using this level of mathematics and physics would be limited to simple problems.

Other fundamental EE subjects taught in the third and fourth-semester courses, such as Electric Circuits I and II, Electronics I, and Digital Logic Design, should continue to be taught using a traditional approach to build a strong foundation of theoretical knowledge in these areas. The PBL approach is implemented in the initial Electrical Circuits courses, EE 241 (Electric Circuits I) and EE 242 (Electric Circuits II), as well as in the core EE courses focusing on computer-related subjects, such as EE 231 (Digital Logic Design) and EE 233 (Microprocessor). It is also utilized in electronics-related courses such as EE 243 (Electronics I) and EE 244 (Electronics II).

Moreover, the PBL approach is integrated into many of the more advanced EE courses, such as EE 430 (Introduction to Control Systems), EE 332 (Introduction to Communications Systems), EE 335 (Introduction to Power Systems), EE 429 (Mechatronics), and EE 434 (Digital Signal Processing). In these courses, students are exposed to real engineering challenges, specifically drawn from various subdisciplines within EE. For example, engineers may be asked to design power systems, control systems, electronic circuits, microprocessor-based systems, communication systems, and other components.

The PBL approach is further enhanced by the nine hours of technical elective courses that students are required to take, including Power Systems (EE 481), Power Electronics (EE 482), Modern Control Systems (EE 483), and Digital Communication Systems (EE 486). In these courses, it is emphasized that a seemingly complicated design problem can be broken down into a set of sub-problems that can be solved by applying the foundational knowledge acquired in previous courses on various EE topics.

The PBL approach culminates in the senior design courses EE 495 and EE 496. This year-long sequence of the two senior design courses provides students with valuable experience in completing a design project, from its definition to its implementation. In addition, these design projects are invariably team-oriented, providing students with the opportunity to cultivate diverse teamwork experiences and a sense of engineering ethics. The KFU EE department's planned percentage of courses with PBL content is shown in Figure 2.

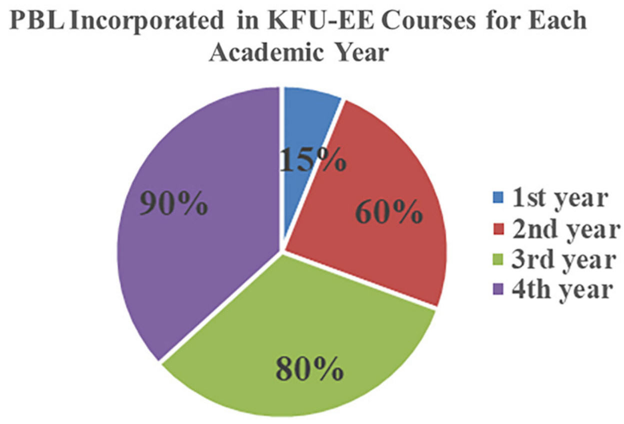

Fig. 2. Percentage of courses with PBL content for each academic year in the KFU EE department

3.2 Implementing PBL and formative assessment

In addition to laying the foundation for knowledge integration, the PBL approach enables faculty to implement teaching and learning methods that more directly engage students. In the next section, the authors present case studies of PBL activities conducted in various EE courses for each academic year.

4 CASE STUDIES

4.1 PBL in EE department course- EE 244: electronics II

Project presentation. Third-year course projects, such as those in Electronics II, are designed to enhance engineering students' skills to enable them to solve actual engineering problems. In the first week of the term, students are required to design and construct a prototype with specific functions based on a set of guidelines outlined in the project statement handout.

i) Challenge

Assuming they are working with a high-level state machine, the students must implement the state machine as a sensing, filtering, and control system.

ii) Overview

The goal of this project is for the students to gain hands-on experience in formulating, designing, and building a complex EE system that responds to real-time changes. Teamwork and project management are part of the experience gained.

iii) Project statement

The students are expected to design and build an optimized robot system that can perform the following tasks: The robot system should navigate through a predetermined field with randomly placed obstacles. The robot needs to overcome obstacles and move forward to its destination, which is one of the two garages located inside the field. The robot is expected to identify the designated garage and park inside it. Moreover, the robot should include, but not be limited to, the following electronic circuits: optical ultrasonic sensing, electromagnetic signal sensing, signal filtering noise reduction, and signal amplification.

iv) Rules and constraints

In this project, students must select the type of system and its functional circuits. Starting with the identification circuit, sensing circuit, filtering circuit, and decision-making circuit, students must solve numerous electronic problems and develop a design capable of performing the necessary functions.

v) Pre-work for PBL activity

To prepare for the project activity, students are required to submit 25% of their reports in the fifth week of the term. This submission should primarily focus on the literature review and initial design ideas. There are two advantages to giving students an early start. First, students are more likely to get involved in the project and develop a stronger interest instead of delaying it until the last weeks of the term, which are usually quite busy for them. Secondly, the students will learn how to search for solutions even when they do not possess all the necessary knowledge. We can assist them by providing tools and references to aid them in their searches.

Sample of the work of students. One example of the work done in a report can be provided from a Fall 2019 Electronics II class. First, as shown in Figure 3, the students created a block diagram of a circuit detailing the five main circuit blocks: transmitter, receiver, bandpass filter, control circuit, and action circuit.

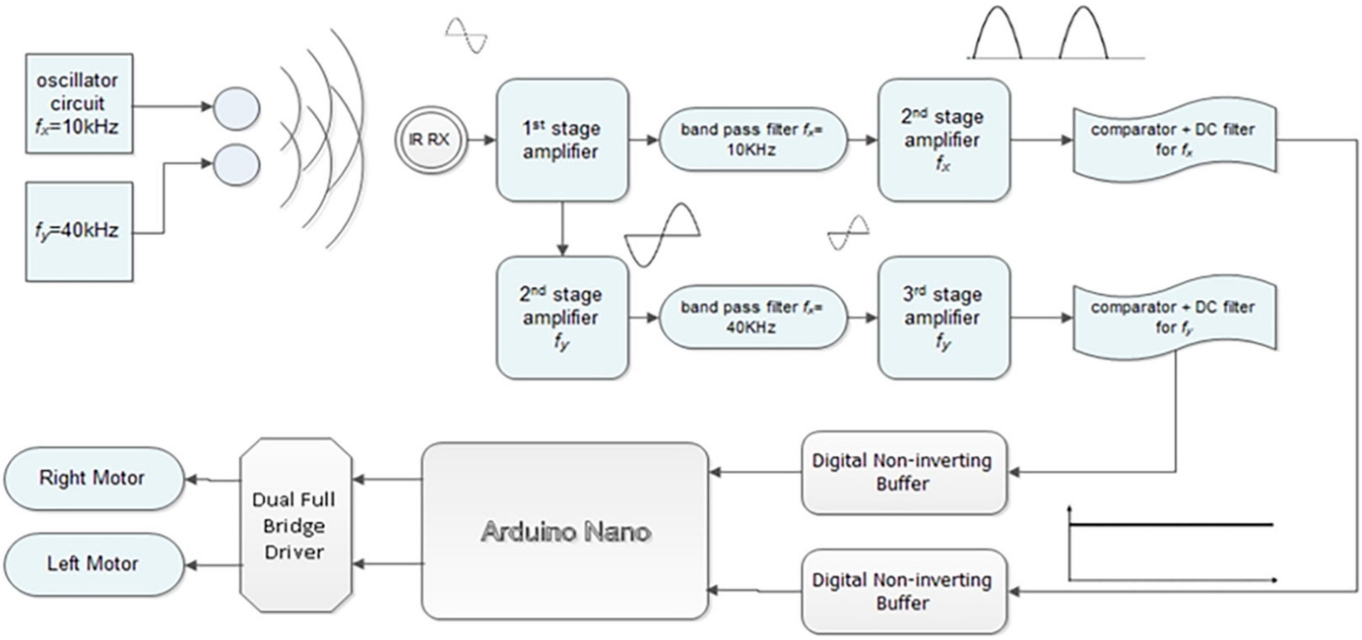

Fig. 3. Block diagram of the project circuit

These were mainly servomotors. In their report, the students began by designing and simulating each circuit individually. Subsequently, they proceeded to solve all theoretical problems associated with the circuit in order to accurately determine its intended function. Figure 4 illustrates an example of a circuit the students designed: a simulated bandpass filter circuit. To check the filter bandwidth, the students used NI Multisim 14.1 software, which allowed them to simulate the circuit's behavior using the AC sweep function, as illustrated in Figure 5.

Figure 6 shows the final circuit design for all circuits involved in the project. The figure depicts two circuits with distinct responses (indicated by the yellow light) based on the input received from the sensor. After the simulation, the students begin implementing their design in a working prototype. They start by building each circuit individually and then testing it using the available testing tools. Figure 7 shows an example of circuits that were built and tested.

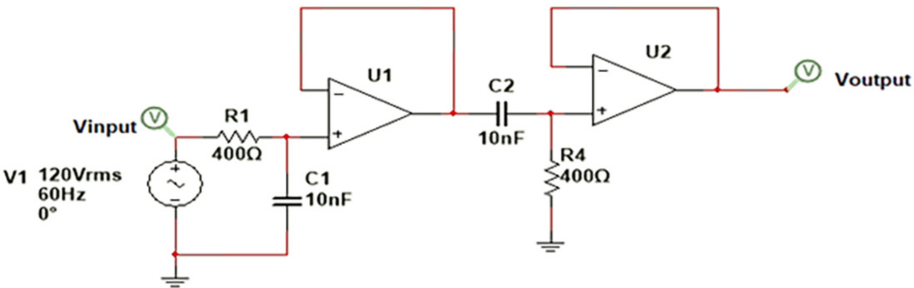

Fig. 4. Active bandpass filter one-stage circuit

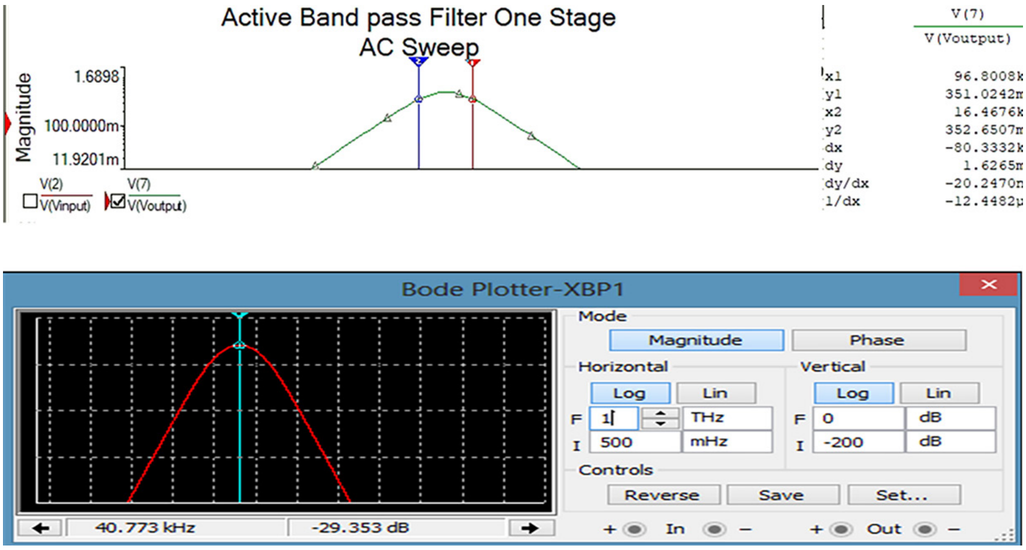

Fig. 5. Simulation of the active bandpass filter using AC Sweep of MultiSim software

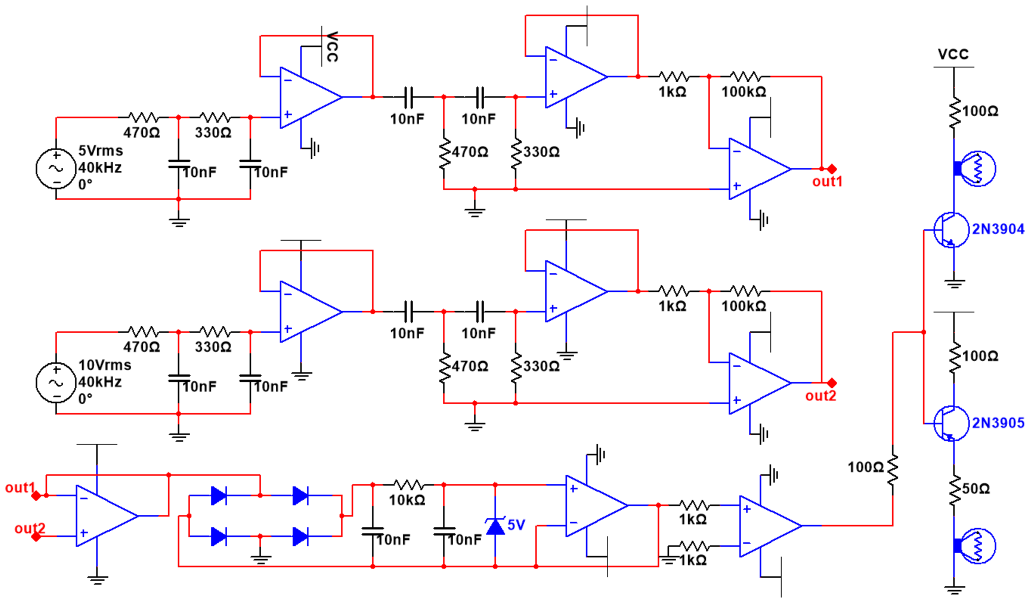

Fig. 6. Final circuit design with all circuits involved in the project using MultiSim software

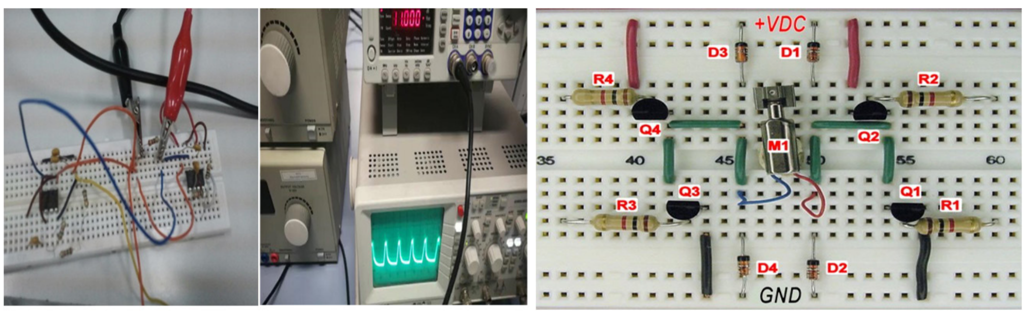

Fig. 7. Experimental testing of the bandpass filter designed at a central frequency of 40 kHz and the motor control circuit

The students utilize a function generator to produce an AC signal with adjustable frequencies and an oscilloscope to observe the input and output of the constructed filter. Following the provided steps, the students build and test each circuit to achieve the final goal of constructing the entire system. Figure 8 shows the final implemented system.

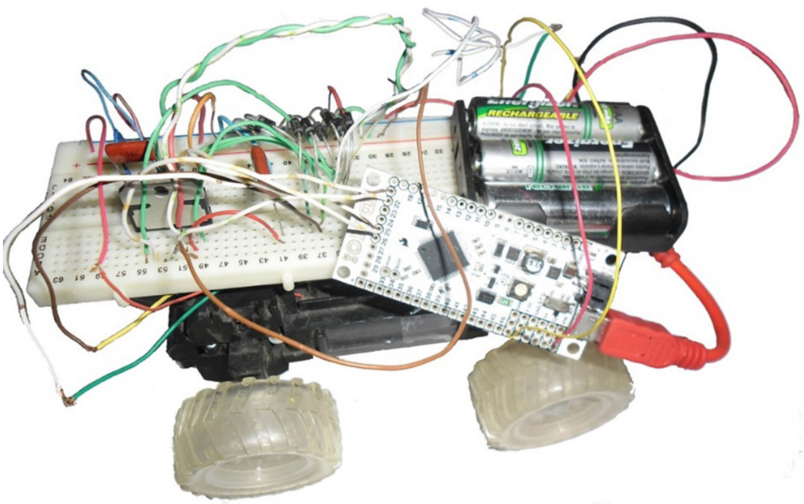

Fig. 8. Implemented system, with the final built robot system

4.2 PBL in bio-medical engineering department – second year course – EE 243: electronics I

In this section, we share our experience of implementing PBL in a junior-level engineering course. The Electronics I (EE243) course syllabus and assessment components are the same in both the EE and Biomedical Engineering departments, although it is referred to as Bio-Electronics (BME310) in the BME department.

In the Electronics I course taught to junior biomedical engineering students, we designed DC power supply and audio amplifier circuits to meet specific specifications, such as the output DC level, ripple level, and amplifier output power. The developed DC power supply was also expected to be used to provide DC bias to the audio amplifier. The amplifier had to be tested by taking the input from a microphone and connecting the output to a 4 Ω speaker. This project involved group work, and the maximum number of students per group was five.

i) Pre-work for PBL activity

To prepare for the project, students are asked to study the fundamental functional building blocks of biomedical instrumentation devices and chapters 2–4 of the course. Moreover, the students are asked to identify the DC power supply and amplifier blocks of the instrumentation devices and classify them according to the theoretical background taught in this course.

ii) Hands-on component of the PBL activity

Two design examples are included in the project assignment to guide students through the design procedures. The design examples are depicted in Figures 9 and 10. Video tutorials are available to students to assist them in the design, implementation, and testing phases of the project.

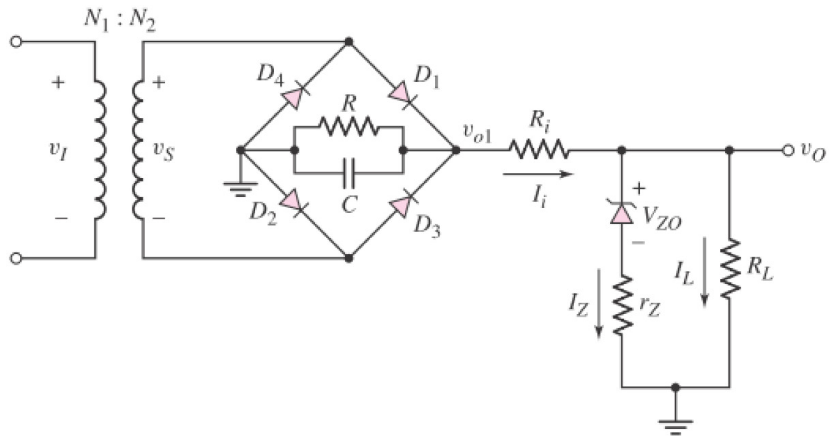

Fig. 9. Full-wave rectifier-based DC power supply circuit

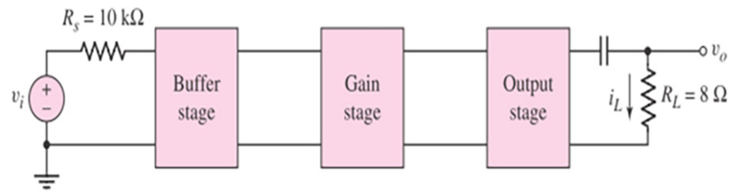

Fig. 10. Generalized multistage amplifier

iii) Standard design problem

The students are expected to design the DC power supply and amplifier circuits using the concepts learned in this course and following the examples provided. In solving the design problem, students should use standard values for circuit components, such as resistors, capacitors, and transistors. They must not use the same values as the examples provide because the project circuits have different specifications, as shown below:

- DC power supply specifications: The output load current is expected to vary between 25 and 50 mA, while the output voltage should fail within the 10–10.2V range.
- Audio amplifier specifications: An audio amplifier is required to deliver an average power of 0.1 W to a 4 **Ω** speaker from a microphone that generates a 10-mV peak sinusoidal signal and has a source resistance of 10 k**Ω**.

iv) Impact of design variations

Both the DC supply and amplifier circuits have a significant number of design variations. First, students can use circuits that differ from the example circuits provided in the hands-on material. Such an approach requires the students to be aware of various circuits in order to meet the design specifications. Furthermore, the example circuits do not include specific part numbers or device parameters, leading to a variety of design solutions. Such an approach imitates real engineering design problems in which the specifications are abstracted.

5 RESULTS AND DISCUSSION

This section will present the results of the ABET quality assessment of the courses discussed in these case studies. The authors will also highlight the challenges in the PBL process, specifically those caused by the COVID-19 pandemic.

5.1 ABET outcomes assessment results

The latest ABET edition covers 7 main student outcomes (SO) listed in Table1.

Table 1. ABET student outcomes

SO1	Ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
SO2	Ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
SO3	Ability to communicate effectively with a range of audiences
SO4	Ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
SO5	Ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
SO6	Ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
SO7	Ability to acquire and apply new knowledge as needed, using appropriate learning strategies

The ABET SO direct assessment is based on the students' grades in each of the course's SOs. The indirect assessment is conducted by the students, who provide feedback on how well they achieve specific student outcomes.

Depending on the course, a project can address many of these outcomes. For instance, the EE244 course covers four SOs, and its course project addresses SOs 1, 2, and 5.

The students exhibit great satisfaction upon completing the course requirements (EE 244) and implementing the project. Their course evaluation exceeds 90% of all expectations based on ABET standard values of 70%, most of the time, as indicated in Figure 11.

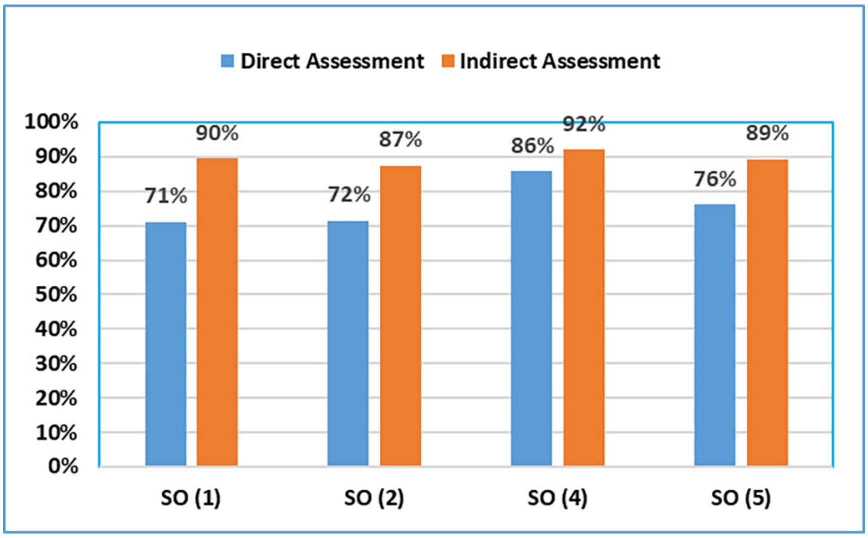

Fig. 11. ABET SO assessment results for the EE244 course

For the BME310 Bio-Electronics course, the number of students enrolled in the fall 2019 semester was 75. A summary of the results for direct and indirect SO assessment is provided in Figure 12.

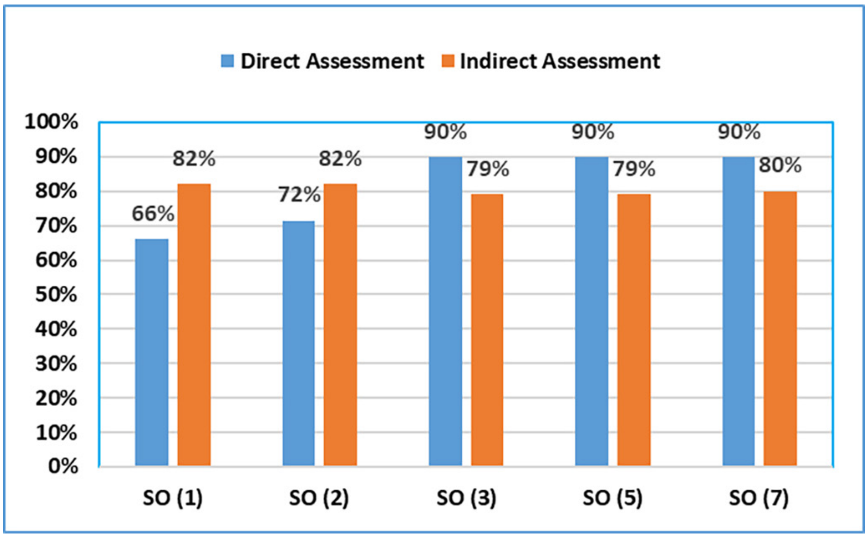

Fig. 12. ABET SO assessment results for the BME310 course

The project activity was assessed using SOs (2, 3, 5, and 7), with the achievement of SOs 3, 5, and 7 surpassing expectations.

5.2 COVID-19- impact in PBL

During the initial stages of the COVID-19 outbreak, a nationwide lockdown was implemented. As a result, schools and universities transitioned to online teaching to maintain the continuity of education. Senior design projects were no exception to this; however, the way they were conducted had to be adjusted to the situation. The course advisor met with their students online to discuss the progress of the work and inquire about any issues they had encountered. The main challenges encountered were faced by groups working on building a prototype. During the lockdown, this process slowed down significantly because students were unable to come to the college to utilize its facilities. During the initial stages of the COVID-19 outbreak, the shipment and import of the electronic components necessary for the project were disrupted as factories and transportation services ceased operations, resulting in a worldwide economic standstill.

To address these shortcomings, the instructors constructed the prototype themselves. They base it on the students' instructions, ensuring that all calculations are accurate and that the current specifications are safe for building and testing. For projects where the necessary components were unavailable due to logistical issues, the physical prototype was substituted with simulation software.

The course project presentation was held online. Prior to the presentation, logistics preparation was conducted for both students and instructors to ensure that the presentation would be carried out under optimal conditions without adversely affecting the regular course project presentation experience. The preparations included the following:

- Sending targeted emails to the students, their advisors, and the panel members to remind them to attend the presentation on time.
- Recording the presentation for the purpose of providing evidence to be included in quality portfolios, such as ABET.
- Collecting the evaluation electronically.

In the fall 2020 semester, following a decrease in the infection rate in the KSA and the resumption of normal activities, students were able to attend campus for laboratory work, exams, etc., while lecture courses continued to be conducted online. Students working on their senior design project could also meet with their course advisor and work in the project lab on their prototype. The department issued the following safety precautions to be used in the labs to eliminate the risk of COVID-19 infection:

- All students will have their temperature checked and their sense of smell tested in each lab.
- Wearing a face shield, in addition to a face mask, was mandatory.
- Students were required to bring pocket hand sanitizers and use them regularly.
- The equipment was spread out across the lab to increase the distance between the students.

These rules applied to all situations where a student entered the campus, including project activities. The semester ended well, with no outbreaks originating from labs or project meetings.

For the EE244 course, the ABET SO2 direct assessment reached 86% for Fall 2020, an increase from 72% in Fall 2019 [23]. This shows that, despite facing initial obstacles, sufficient preparation and adaptation enabled students to overcome challenges posed by COVID-19 and improve their theoretical and practical skills.

6 CONCLUSION

This paper demonstrates that PBL can be effectively utilized in teaching various aspects of engineering. It can increase students' motivation, equip them with the necessary professional skills, improve their understanding of theoretical knowledge, and enhance their collaboration abilities. This paper discusses the implementation of the PBL system within the departments of EE and Biomedical Engineering at KFU. The challenges faced in PBL implementation included integrating the PBL approach into the overall instructional strategies of the department, appointing PBL coordinators, and addressing the issues related to PBL features in the courses offered. In addition, the implementation of PBL projects was evaluated across different levels of EE courses. A specific program was selected as an example and assessed based on problem-solving abilities, teamwork skills, and performance on ABET tests. Recommendations were then made for future studies, emphasizing the importance of adequate funding and collaboration with industry and researchers from various disciplines. Finally, a detailed discussion on the impact of the pandemic on PBL implementation took place.

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