Multidisciplinary Problem-Based Learning (MPBL) Approach in Undergraduate Programs

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Abstract. In the 21st century, education is about training graduates with a variety of competencies and reducing the gap between the classroom and the real-world environment via professional practice and simulating a work environment in the curriculum. In this paper, the authors explore the pedagogical benefits of implementing multidisciplinary open-ended research-based projects in an undergraduate curriculum to improve students' understanding of the concepts and develop meta-skills. Specifically, this paper discusses how such projects could facilitate experiential learning by providing students with an opportunity to actively participate in real-world research projects that are multidisciplinary in nature. The proposed project is a typical real-world problem that draws on competencies from various disciplines. The authors' goal is to develop deep content knowledge, foster critical thinking, engage in collaboration, and promote creativity and communication skills. Such meta-skills are a crucial component to succeed in today's workplace. The other significant objective of this new teaching and learning methodology is to support collaborative and concurrent competency by involving students with various backgrounds working on multidisciplinary projects.

Keywords: Experiential learning · Engineering education · Problem-based learning · Multidisciplinary projects

1 Introduction

1.1 Experiential Learning

The experiential and collaborative learning paradigm has been known as a global best practice in engineering education across different disciplines as it facilitates active learning and provides an opportunity for students to engage in discussion and reflect on their experience and performance within the team [1]. According to Kolb, "*Experiential learning is a powerful and proven approach to teaching and learning that is based on one incontrovertible reality: people learn best through experience*" [2]. However, the experience could not automatically lead to learning [3] or in another words "*the richness of Dewey's concept of experience is lost if it is reduced to simply learning by*

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doing" [4]. Therefore, a structured reflection and practices of former understanding are required to promote the continuity of experiences which could eventually lead to learning [5–8]. Kolb's experiential learning theory, which is concerned with the learner's internal cognitive processes, suggests that learners transform the experience to knowledge by completing a four-stage learning cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation [9–11]. Although experience is central to Kolb's theory, the learning model requires the experience to be supported by reflection and analysis, and ultimately something to be generated from experience, as shown in Fig. 1.

Fig. 1. The four-stage learning cycle of Kolb's experiential learning theory.

Experiential learning has long been employed as part of engineering education in various forms, such as applied research projects [12–16], capstone projects [17, 18], interactive simulation, and explicit use of technology [19–22], case studies [23–25], labs [26, 27], and co-op and internships, which are also referred to as *work-integrated learning* according to the experiential learning guideline issued by the Ministry of Training, Colleges and Universities in September 2017 [28–30].

1.2 Collaborative and Multidisciplinary-Based Learning

Engineering education scholars have identified that collaborative education in various forms of problem-based learning [31–34], project-based learning [35], or research-based learning could promote critical thinking, especially in a small team environment [1, 36–39], and produces higher achievement and greater productivity [40]. In collaborative education, it is aimed that learners often work in groups to develop a solution for authentic or ill-structured problems. It is important to note that problem-based and project-based learning are two categories of experiential learning with slightly different definitions. In problem-based learning, the problems lack a well-defined answer, and learners typically work in groups and apply critical thinking to examine and solve the problems, fostering learners' metacognitive skills, while there is no one correct answer. In project-based learning, the goals are typically set, and through structured instructions, students learn by investigating complex and often authentic problems. To better differentiate various types of learning, which are used in this paper, Table 1 has been prepared.

Table 1. Definition of various learning pedagogical approaches.

Term	Definition	Reference
Experiential learning	*"the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience."*	[9]
Experiential education	*"a teaching philosophy that informs many methodologies in which educators purposely engage with learners in direct experience and focused reflection in order to increase knowledge, develop skills, clarify values, and develop people's capacity to contribute to their communities."*	[41]
Problem-based learning	*"The learning that results from the process of working toward the understanding or resolution of a problem."*	[42]
Project-based learning	*"a systematic teaching method that engages students in learning essential knowledge and life-enhancing skills through an extended, student-influenced inquiry process structured around complex, authentic questions and carefully designed products and tasks."* *"an instructional technique in which meaningful tasks, often in the form of problems, serve as the context and stimulus for knowledge-building and critical thinking."*	[43, 44]
Cased-based learning	*"a set of learning and teaching models that uses real or realistic events holding multifaceted issues and complexity as part of learning resources, which engages students in individual and/or group inquiry on the given events with other relevant information, and which promotes students' reflections on their own learning and problem solving"*	[45]
Collaborative learning	*"giving students an opportunity to engage in discussion, take responsibility for their own learning, and thus become critical thinkers"*	[46]

Brame (2019) has also identified collaborative learning, when it goes well, as one of the most effective teaching approaches in the classroom regardless of whether the instructors seek to enhance deep learning or meta-skills [47]. Researchers have also recognized that collaborative learning could go poorly due to the lack of student contribution, engagement, and motivation and several other factors often leading to arguments and failing to achieve the desired outcome [47]. As a result, several researchers have argued for the importance of explicitly teaching students how to work collaboratively at the undergraduate level and provide students with an opportunity to practice teamwork [48, 49].

Several industrial surveys and reports have argued for the need for graduates with more experience in a multidisciplinary team environment. At the same time, engineering education literature has recognized the need for engineering curriculums with multidisciplinary capabilities to address industry requirements and increase graduates' employability. In the end, "*it is sometimes forgotten that industry is an important customer of engineering education*" [50]. Brassler and Dettmers have also indicated that problem- and project-based learning are two of the most suitable pedagogical approaches that could enhance learners' interdisciplinary competence [37]. Multidisciplinary research projects allow learners to understand better the relationships between various disciplines, which encourages a higher level of thinking and innovation, leading to solving complex real-life problems [37].

This paper adds to experiential learning literature and provides an overview of problem-based learning in second-year and third-year Automation Engineering Technology and Biotechnology programs. The overall goal is to transform a traditional deterministic lab-based setting into an open-ended active learning environment. This paper builds on a pilot project started in Fall 2019 involving second-year students designing their biosensing platform to detect an analyte/biomarker of their choice [15, 16].

2 Framework

Students from two programs (*Biotechnology* program, thorough the 3rd year Bioprocess Control and Dynamics course, and *Automotive and Vehicle Engineering Technology* program, through the 2nd-year Fluid Mechanics course) collaborate to design robotic endoscopic capsules with closed-loop drug delivery systems, including the design and fabrication of capsule robots and the development of the closed-loop system (sensors, actuators, and microcontrollers) for drug delivery systems. The students from the Automotive stream focused on the design and dynamic modeling of capsule robots, including practicing fluid mechanics principles such as external fluid analysis, computational fluid dynamics (CFD) study, and fluid similitude for experimental tests. The biotechnology stream students collaborate closely with automotive stream students and emphasize designing and modeling a closed-loop drug delivery system integrated with capsule robots. This includes practicing sensors and actuators selection and dynamic modeling, closed-loop response analysis, and control logic analysis.

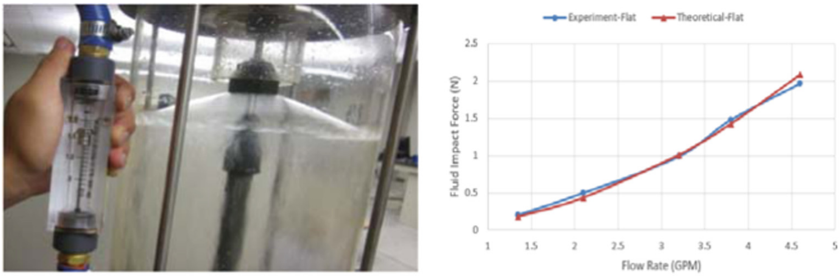
Students' activities comprise both self-study and in-class activities. Due to the open-end nature of the project, students are motivated to complete self-study activities. These activities are aligned with weekly in-class laboratory session activities. Students are required to perform a minimum of 3-h lab work every other week. In the first few weeks, the students undertake a literature review to design their protocol. Students present their progress every four weeks in addition to a detailed midterm and final report. Students also reflect on their learning experience in the final report. The students' activities were designed based on the four-stage learning cycle of Kolb's experiential learning theory. The implementation details of the MPBL in Automotive and Biotechnology stream courses are outlined in the ensuing paragraphs.

Implementation of Kolb's Experiential Learning

In this subsection, we present the details on the planning of laboratory sessions employing the four stages of Kolb's Experiential Learning Theory in the Fluid Mechanics course. From the course design perspective with the MPBL approach, the learning activities need to be aligned with a course learning outcome. The learning outcomes (LO) for the fluid mechanic course are:

- LO1: Relate real-world components in fluid systems with theoretical and numerical models
- LO2: Evaluate and analyze fluid systems performance
- LO3: Optimize fluid system performance with numerical and experimental methodologies
- LO4: Design and build fluid systems to achieve the required system performance

The first activity is Kolb's concrete experience. The fluid mechanic course has six classic laboratory experiments that include fluid statics, fluid dynamics, internal and external flow, and turbomachines. These six laboratory experiments, two hours laboratory sessions for each experiment, provide concrete experiences on the application of the theoretical concepts of fluid mechanics. As an example, Fig. 2 demonstrates the experimental measurement of fluid impact force on a flat surface. The second activity is Kolb's reflective observation; students in groups of two discuss their observations from the experiment and compare the experimental measurement with the theoretical calculations using the principles of fluid mechanics' (Fig. 2B shows one such sample analysis done by students).



(A) (B)

Fig. 2. A) Fluid impact force measurement experiment. B) Comparison of experimental data with theoretical calculations, as a reflective observation.

The third activity is Kolb's abstract conceptualization; students are involved in thinking and using fluid mechanics principles in a real-world and multidisciplinary project. The final project is defined as the design of robotic endoscopic capsules with controlled drug delivery. The Automotive stream students need to determine the specifications of a robotic endoscopic capsule, including the dimension, speed, propulsion system, and the drug dispensing mechanism. Automotive students use the principle of fluid mechanics to approximate the required force for the motion of the endoscopic capsule robot (Fig. 3).

The Biotechnology students are responsible for researching a closed-loop drug delivery system that could be integrated with the capsule robot. This requires the students from both programs (biotechnology and automation) to work in close collaboration to understand the design limitations. While automotive students need to perform an extensive literature review to determine the required performance for a robotic capsule robot, the biotechnology students need to focus on the disease or the disorder of interests that could be regulated using a closed-loop drug delivery system. For this, students identify the associated biomarker, select a biosensor to detect the biomarker, select a drug, determine the controlled and manipulated variables and potential disturbances, and eventually propose a mechanism of the closed-loop delivery system (self-regulated administration), including the control diagram.

Some of the projects that biotechnology students selected for this open-end research project included a *milrinone drug delivery system* to treat congestive heart failure, *regulation of heparin and thrombin* to control blood coagulation, and a *closed-loop drug delivery system regulating the cortisol levels* associated with depressive disorder.

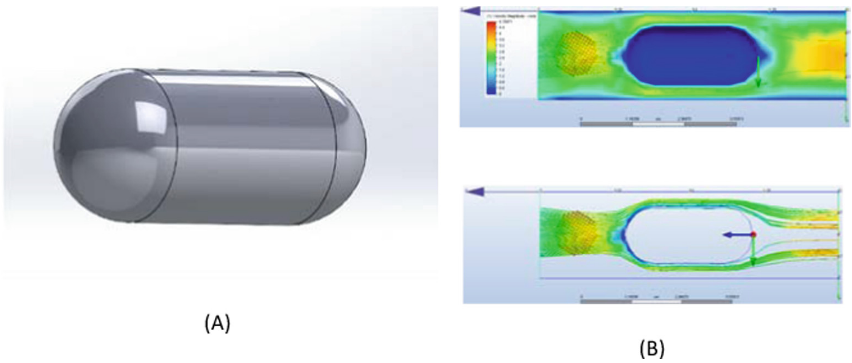


Fig. 3. A) endoscopic capsule robot designed by one group of students, B) Using CFD to estimate the fluid velocity, pressure, and forces acting on capsule robot.

The biotechnology students are responsible for developing a dynamic model (by writing transient mass balance equations based on the drug release, and drug uptake and metabolism knowing the drug's pharmacokinetics) to model and predict the concentration of the drug in the body. It is important to note that the biotechnology students learn how to formulate a steady-state and dynamic process in two different courses of Chemical Engineering Concepts (BIOTECH 2EC3) and Bioprocess Control and Dynamics (BIOTECH 3BC3). Using a first-order dynamic model for the actuator and the sensor, students develop a block diagram based on their proposed closed-loop delivery system and obtain the transfer functions of each block using Laplace Transform. Biotechnology students are then asked to solve the block diagram and analyze the stability of their closed-loop system using different types of controllers. Students are asked not only to perform hand calculations but also to set up a Simulink model in MATLAB, and compare their results. Using the developed and verified Simulink model, students will now be able to 1) shift their focus on analyzing and comprehending the transient response when, for example, there is a change in the setpoint value or if there is any disturbance, and 2) better reflect on their understanding of the theoretical concepts.

The fourth activity is Kolb's active experimentation: In this, students actively deal with a real-world problem. Since testing of the endoscopic capsule in an actual situation is beyond the scope of an undergraduate-level course, in vitro experiments can be performed. The students can use 3D printer technology, print the scaled model, use wind tunnel measurement to validate their theoretical calculations and numerical simulation, build the control loop hardware (mechanical and electrical), and obtain drug release profiles using spectrophotometry methods. Table 2 has been prepared as a summary that demonstrates the mapping of the students' activities and alignment with Kolb's experiential learning cycle and course learning outcomes.

As mentioned earlier, to support student learning based on Kolb's theory, each group (from both programs) is asked to present their progress every four weeks in addition to a detailed midterm and final report. The latter includes a section in which students reflect on their learning experience.

Table 2. Implementation of Kolb's experiential learning in the MPBL.

Learning outcome	Mapping to Kolb's cycle	Activities
LO2, LO3	Concrete experimentation, Reflective observation	Six classic laboratory sessions, result analysis with theoretical concepts
LO1, LO4	Abstract conceptualization	Apply knowledge to a real-world problem, collaborate with biotechnology students, literature review, preliminary design, and analysis
LO3, LO4	Active experimentation	Build and test, model the experimentation, optimize the design

3 Limitations

While this pilot study explores the importance of multidisciplinary problem-based learning (MPBL) in undergraute education, future studies are required to evaluate the success of such a learning strategy. In the future studies, questionnaires will be provided to students, and their feedback will be collected and analyzed to better understand student's perceptions around MPBL. To validate the success of MPBL, learning objective criteria will be defined in the future studies and a comparison with a control group using a different learning method will be made.

4 Conclusions

This paper sheds light on best practices around simulating the real-world environment in the undergraduate curriculum using multidisciplinary open-end problems, based on a four-stage Kolb's experiential learning theory. Specifically, we present the details on a multidisciplinary research-based curriculum across two programs that enables students from two very different backgrounds to collaborate on a research project of real relevance. Using this pedagogical approach, the authors seek to foster long-term retention of content and improve students' interest, engagement, and motivation in learning technical concepts and soft skills.

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