Conducting an International Med-IoT Project under the Innovation-Based Learning Model

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Abstract

This article describes a new trend in engineering education using the Innovation-Based Learning (IBL) model to deliver instruction in a biomedical engineering course and to evaluate student output in the form of value impacts. The University of North Dakota Biomedical Engineering (BME) Department has implemented the IBL approach to cultivating students' innovation, creativity, and problem-solving skills, surpassing traditional memorization-focused methods. IBL encourages active student engagement through exploration, questioning, and practical application of knowledge to address real-world challenges. It introduces a new pedagogy that is being used to deliver engineering fundamental concepts while providing students with the skills and experience necessary for success in future careers. Students engage in collaborative teamwork on an engineering innovation project and apply concepts learned in their classes. Project team members are students from different BME courses comprising of a combination of undergraduate, graduate, on campus, or remote students.

This article highlights the experience and outcomes of students participating in an international IBL design engineering project, conducted across multiple continents to design and develop a Medical Internet of Things (Med-IoT) biomedical device. International collaboration can experience several challenges, such as language barriers, local resource management, device setup, hardware and software integration, calibration variance across multiple test setups, and higher reliance on individual skill sets. In this case study paper, data is analyzed from feedback acquired through semi-structured interviews and an evaluation of the research impacts produced by a focus group participating in the IBL project. As a result, recommendations for best practices for students entering the IBL program are discussed on how various challenges can be addressed throughout the process.

Introduction to Innovation-Based Learning Model

The innovation-based learning (IBL) model is a new method of instruction that seeks to equip students with fundamental principles of concepts through a combination of autonomy, discovery, and hands-on experiences. IBL emphasizes hands-on, problem-solving, and creative project-based learning models. Fundamental principles are defined as condensed blocks of the key features of a topic of study. IBL is a form of discovery-learning that encourages learners to come to self-directed key conclusions with assisted guidance through various points of feedback, including the opportunity to teach the fundamental principles, receive collective group feedback regarding their understanding of the concept they taught, and by further applying the ideas discussed to a novel project that challenges students to solidify these concepts in practice. This active learning model is collectively using project-based, problem-based, gamification [1], peer instruction, and tokenized learning models. IBL is a multidimensional approach to developing knowledge, innovative thinking, problem-solving, and collaboration skills [2].

IBL courses are conducted virtually and on campus using Microsoft Teams Meetings. Students are encouraged to attend in-class meetings, and remote students can attend either synchronously over video call or asynchronously, by watching a recording of the class sessions.

Within the IBL program, students can take various courses ranging between subjects such as anatomy and physiology to engineering courses covering topics on sensors, instrumentation, wireless communication, and others. Along with the designated coursework associated with each class, students participate in a semester-long project. At the beginning of each semester, students taking courses within the Biomedical Engineering (BME) program are tasked with pitching innovation projects related to biomedical engineering and form project teams. These projects are presented to the entire program, including undergraduate and graduate students. Each student must join a team project as one of the IBL course requirements. Project team members comprise of 3-5 students. As a result, not all proposed projects submitted during this early stage will be worked on. In the most recent semester, about 20 different projects were worked. These groups have the freedom to be a mix of undergraduate, graduate, on campus, or remote students. Over the course of the semester, these project teams meet at least once per week with a project mentor to review project scope, action items, and deliverables for each project team. For further support, each student is assigned to a personal learning coach, with whom they meet weekly to review individual progress on projects and assignments and to assist in resolving challenges experienced by each student. Project mentors and learning coaches are experienced graduate students who have successfully completed previous IBL courses.

To demonstrate their understanding of core engineering concepts covered in class lectures, each student is required to submit individual coursework pieces – referred to as “blockchain tokens”- through an online education management system. Engineering concepts are based off the course that a student takes. For example, a biomedical engineering student taking a physiology course may need to create pillar tokens demonstrating an understanding of physiology concepts, such as how the circulatory system works in the body or the basics of diffusion and osmosis. A student taking a course on biomedical instrumentation may submit pillar tokens discussing analog to digital conversion sampling rate and its effect on signals. Pillar token content is dependent on the course and curriculum it is being submitted for.

Students submit both pillar and project tokens to Massive Open Online Courses for IBL (MOOCIBL) platform [3,4] built on a blockchain architecture and serves as a repository for pillar tokens, milestone tokens, and project tokens that are submitted by students [5]. Figure 1 provides a visual diagram of tokens that must be submitted by each student for each class. To pass an IBL course, the following grading structure is used for final grading:
A = All Pillar Tokens approved and 3 Milestone Tokens approved
B = All Pillar Tokens approved and 2 Milestone Tokens approved
C = All Pillar Tokens approved and 1 Milestone Token approved
D = Incomplete Pillar Tokens with some Project/Milestone Tokens approved
F = Few or no Pillar, Project, and Milestone Tokens approved

Pillar tokens are short video presentations in which each student demonstrates their understanding of the fundamental principle of each weekly topic. Each token must be reviewed at least two (2) times by peer students prior to instructor review and is evaluated based on short and concise presentation length and clear evidence that the student understands the concept they are presenting. Instructors will ensure any peer review comments have been addressed and the video presentation shall show the understanding of the topic. Once instructors have approved the token, it is officially tokenized and submitted for credit in MOOCIBL [3]. If tokens are not approved, they are sent back to the submitter with constructive feedback to identify areas in which the student's understanding of the concept is partial or incorrect. MOOCIBL is also used as a management tool to capture student effort data for grading and quality improvement. This process can help students learn, improve, remember, and apply knowledge to their projects.

The IBL project is divided into three phases: Gap (Survey to Define), Solution (Explore to Solve), and Impact (Draft to Share). IBL projects are intended to emphasize research and are extrapolated from orthodox project-based learning in that proposed projects are intended to address a real gap in the world and propose new solutions to address these challenges. Students submit Gap, Solution, and Impact milestone tokens for their research projects to receive the maximum credit for each class. The Gap milestone report is a summary of research into market gaps and/or technical gaps for the IBL project. It includes a problem statement that identifies the current state of the problem, key stakeholders, and how addressing the identified gap could lead to improved outcomes. The Solution milestone report describes the result of efforts to design, build, and test the proposed solution. This milestone token represents the actionable work performed to address the identified gap. The Impact milestone report is a summary of the value generated from the semester's work and provided how the IBL project resulted in the benefit of the community and abroad. Examples of impact include provisional patents, manuscript submissions to related journals, abstract or poster presentation to related conferences, or some other evidence of value.

In MOOCIBL, project tokens are submitted as discrete work activities performed by students that demonstrate individual contributions documenting the work and efforts towards respective milestone tokens and are categorized into supporting attachments, as shown in Figure 1. These project tokens include literature review summaries, preparation of project presentations, design processes/drawings, test results, and any new tools or programs utilized. This documentation supports the assessment of student contributions and the overall project development.

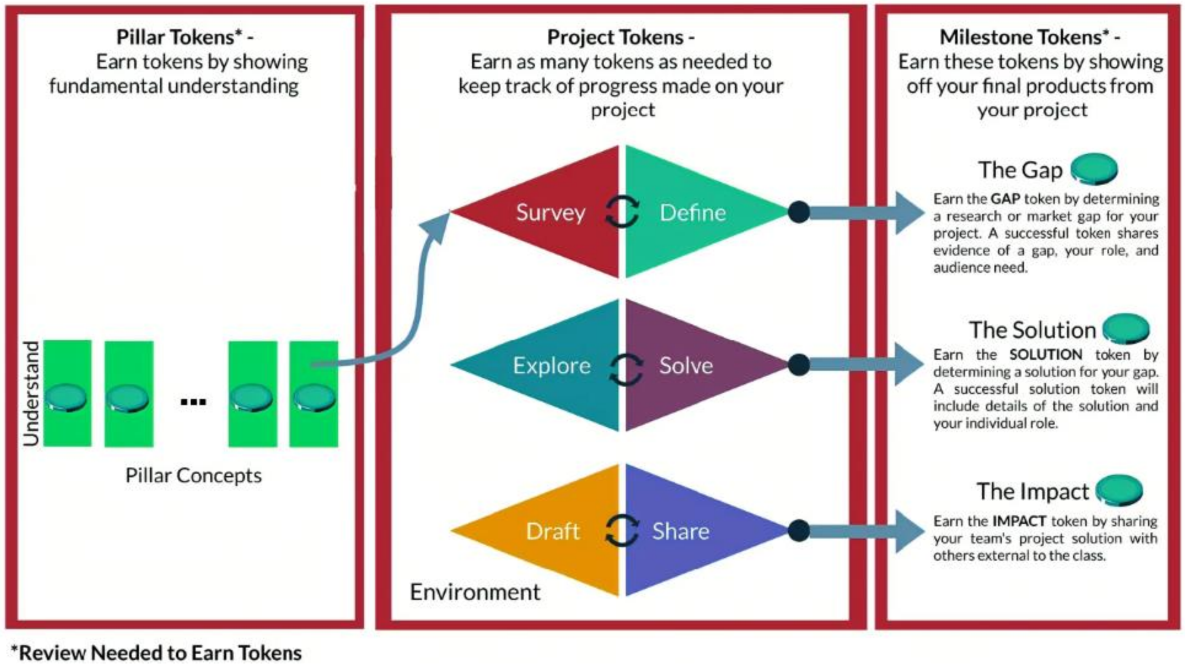

Figure 1: IBL Model [2]. For example, the survey token opens up from left to right on Project Tokens in the middle, representing divergent thinking from the 10-12 pillar tokens and more research results on the left Pillar Tokens. As the defining triangle gets smaller from left to right, this means convergent thinking to the Gap, Solution, and Impact on the right Milestone Tokens.

There are challenges in evaluating pillar tokens and especially project milestone tokens within the IBL model. Project milestone tokens, which are more comprehensive and subjective for reviewers, pose significant difficulties. Innovation projects, by nature, involve higher risks, and their outcomes may not always be successful. However, within the IBL framework, the learning process and project execution hold substantial value. Project tokens can serve as evidence of individual contributions to project progress. The IBL education model is significantly different from traditional methods of evaluating students using examinations and quizzes. Undergraduate students entering IBL courses may struggle initiating work that requires a foundational understanding of underlying concepts. New students in the program may feel uncomfortable with making videos and/or presenting their projects on a weekly basis. Aspects of self-learning, time-management, and the ability to work on an interdisciplinary project are important considerations for student success in IBL.

To better understand how a successful IBL project can be executed with these challenges, a student focus group and their project outcomes within the BME IBL program was examined.

Biomedical Instrumentation Course by IBL

At the time of this study, fifteen (15) courses have implemented IBL in the BME department. The biomedical instrumentation course is one of the core course requirements for BME graduate or undergraduate students. The purpose of this course is to introduce design principles and characteristics of Medical Internet of Things (Med-IoT) concepts. Med-IoT refers to a growing number of IoT uses in the medical industry [6, 7]. Med-IoT provides sensors and applications for remote healthcare monitoring, telemedicine consultation, and delivery. This sixteen-week course featured twelve (12) fundamental principles and core concepts, as shown in Table 1: Pillars and Fundamental Principles. This 3-credit course comprised of one class discussion session and one project presentation and review session per week. Students were expected to work on their own individual projects that implement Med-IoT concepts discussed in the class. Students also had lab assignments using hardware materials such as Arduino Starter Kit. As requested, research lab assistant was available to the students if they needed to schedule online live laboratory demonstrations via Teams.

Table 1: Pillars and Fundamental Principles. For example, the Biomedical Instrumentation course is tokenized into 12 fundamental principles for each week.

Pillars	Fundamental Principles	Week
1	Med-IoT Cycle	1
2	Measurand and Associated Sensor	2
3	Arduino Hardware/Software/MATLAB and Simulink	3
4	Signal Conditioning I – Wheatstone Bridge	4
5	Signal Conditioning II – Instrumentation Amplifier	5
6	Signal Conditioning III – Filtering Considerations	6
8	Analog to Digital Conversion – Binary Systems	8
9	Analog to Digital Conversion – Amplitude Considerations	9
10	Analog to Digital Conversion – Time/Frequency Considerations	10
11	Static and Dynamic Calibration	11
12	Uncertainty Analysis	12

These fundamental principles were applied to the IBL project in this case study, in which students individually participated in the IBL model and created pillar tokens in accordance with the weekly schedule of the course. For example, students were required to submit Pillar 4 – Wheatstone Bridge (WB) after the class. The video presentation should include the explanation and demonstration of:

- What is Wheatstone Bridge?
- Explain WB circuit diagrams and formulars
- Build a WB circuit using Arduino UNO
- Show how to balance the circuit and find the unknow resistance using the WB

Conducting an International Engineering Project

A group of biomedical engineering graduate students, which include the authors, participated in the biomedical instrumentation course. The participants featured diverse interdisciplinary academic and professional backgrounds and formed a team in this research project. Students were remotely distributed with three students based in California, US, one based in Minnesota, US, and one based in Hong Kong, China [8, 9, 10]. Each student attended class lectures online. The student based in Minnesota had the ability to drive to the university and be on campus to conduct hands-on project activities, as needed. The first challenge noted here is that all team members were not physically together to build the prototype. Team members were also in three different time zones. The team had sixteen weeks to complete the IBL project, placing a time constraint on the group. The IBL project that the group worked on was the development of a continuous pressure-sensing and remote-monitoring device for aneurysm leak detection. This device is intended to be integrated with stent grafts for endovascular aneurysm repair and treatment of abdominal aortic aneurysms (AAA). The team built a working prototype device to validate the Med-IoT. In alignment with IBL, the project was managed in three milestone phases: Gap, Solution, and Impact as shown in Figure 2.

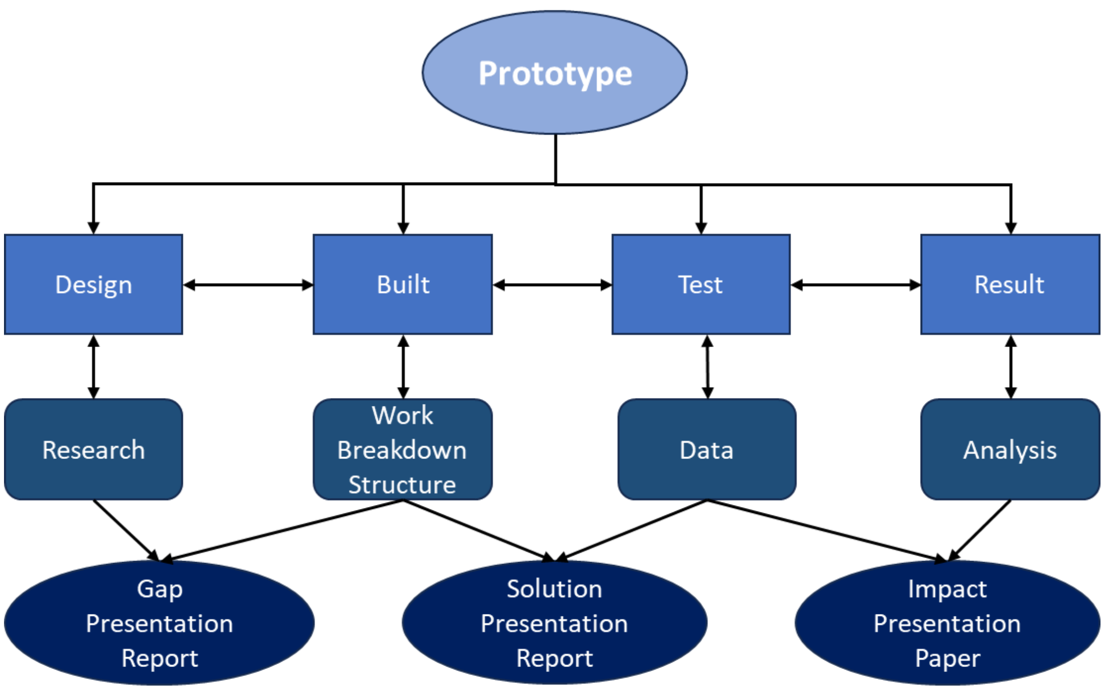

Figure 2: Prototype Design-Built-Test model flow chart. This flow chart represents the typical prototype design, built, and test phases. It also shows the project is divided into three milestones: Gap, Solution, and Impact.

In the Gap phase, the team conducted a literature survey to determine the market impact and novelty of the proposed project. Due to the differences in time zone, an availability calendar was used to identify time slots for a weekly meeting that could accommodate all members of the team. Work tasks were assigned to each member based on prior experience and access to equipment and resources.

To coordinate the work being performed, a Gantt chart and work breakdown structure was created to ensure that clear action items were assigned to each member. In order to complete the project in sixteen weeks, the team developed one standard design and divided the assembly of the device and testing elements into modules that could be worked on independently by each member. The system functional block flow diagram is shown in Figure 3.

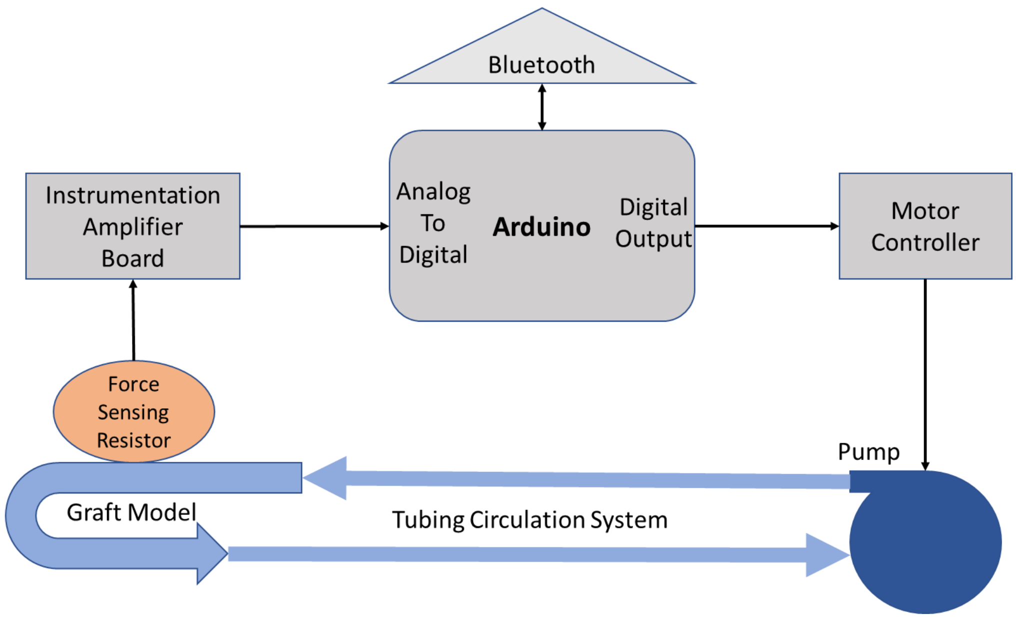

Figure 3: Prototype functional block flow diagram. This diagram shows the prototype is broken down into functional blocks.

In the Solution phase, the team designed a sensor and mock-circulatory test system, addressing the gap identified through literature review. The device consisted of a close loop hydraulic flow test bench with pump, silicone tubing, and a 3D-printed AAA model. Accessible force sensing resistor sensors were chosen to measure graft pressure and connected to an Arduino UNO that transmitted data using an HC-05 Bluetooth module to communicate with an Android cell phone. MIT App Inventor was used to design and develop an Android phone application that can connect with the Arduino UNO via Bluetooth.

The student members from California worked together to build a working test bench and design the pump controller to simulate mock-circulatory loop waveforms. The student in Hong Kong built simulation device to attach the prototype pressure sensor and developed the phone application for the device. The student member based in Minnesota had access to university equipment and 3D printers needed to generate AAA models and connect the modules together.

Project Outcomes

The team, working fully remote, with members based in the United States and in China, was able to apply key ideas acquired from teaching fundamental principles and providing feedback to peers, which better supported both peer and the reviewer in understanding core concepts further. These fundamental principles were applied in practice to the system development project and were within the scope of the IBL model. Two major impacts were accomplished. A provisional patent is in the process of being filed for the mock-circulatory loop test bench developed as a result of this project. A poster titled "Medical IoT Device for Leak Detection & Monitoring Post Endovascular Aneurysm Repair" was presented at the poster session of the Biomedical Engineering Society annual conference in October 2023.

To address the challenges of conducting an innovation design project with a remotely distributed team, project management strategies and collaborative efforts such as dividing the system into discrete and independent modules proved to be a successful strategy in the completion of the IBL project. This strategy has the potential to be transferable and repeatable. The constraint of differing time zones and locations was mitigated through the clear communication of action items and deliverables discussed weekly in team meetings. Each student was able to contribute to the project. This project also demonstrated the application of fundamental principles and shared the design concept of the IBL model. This IBL project was successfully conducted remotely involving parties in different countries.

Semi-Structured Interview

To further investigate group dynamics and challenges in IBL project teams, a semi-structured interview was conducted with existing IBL students about their projects. This survey was reviewed and approved by the university's Institutional Review Board (IRB protocol number 0006441). This study adheres to the ethical standards required for research involving human subjects. This online interview lasted approximately 30 minutes, involved volunteer participants from the IBL program. It consisted of ten (10) open-ended questions focused on the team project experience, based on a validated Self-Efficacy Survey [11]. The questions are listed in Figure 4.

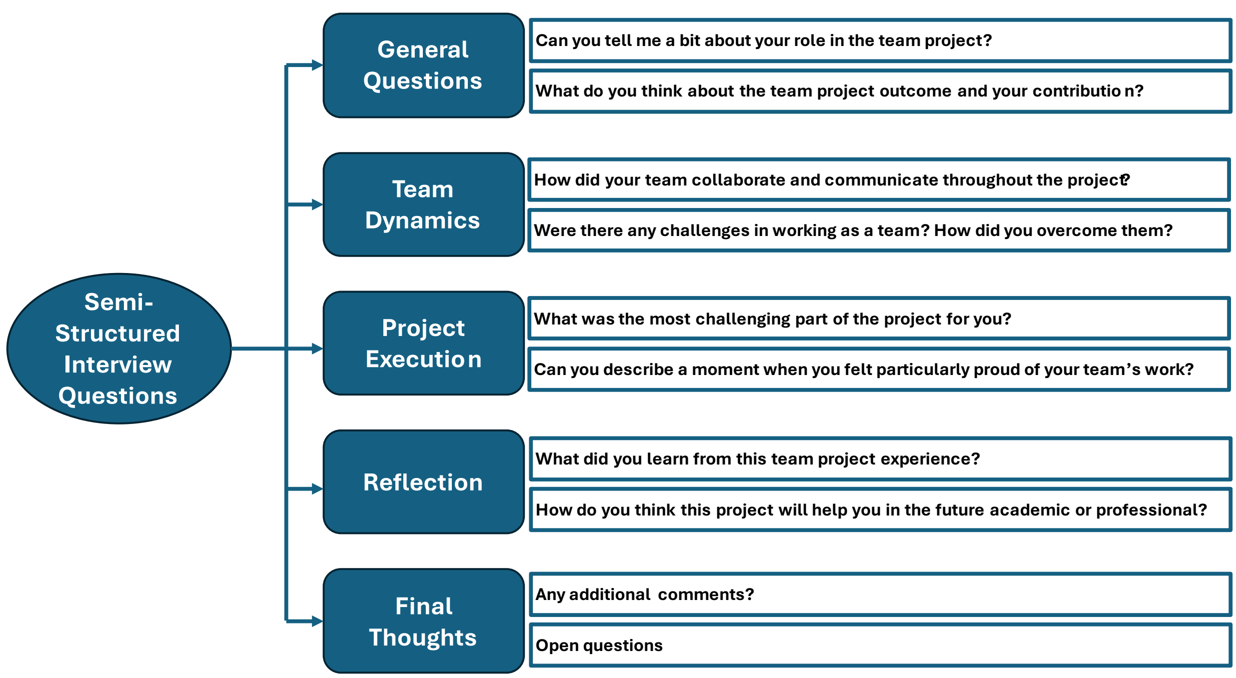

Figure 4: A flow chart list of the semi-structured interview questions that the researcher would ask the IBL students.

Interim Findings: IBL Team Project Evaluation

Participants:
The study involved five (5) students representing diverse backgrounds and learning modalities:

- Undergraduate International (Online)
- Undergraduate International (On-Campus)
- Undergraduate Domestic (Online)
- Graduate Domestic (Online)
- Graduate Domestic (On-Campus)

Each student contributed to a variety of projects, encompassing design, construction, and leadership roles. Participants were from different BME classes but under same IBL model. Participants were from different project teams and none of them were from the Med-IoT project in this case study to examine different project teams.

Key Findings:

1. Student Contributions
   - Most participants played significant roles in their respective projects, particularly in design and construction.
   - Leadership opportunities were effectively utilized by one student, highlighting the potential for skill development in team management.
2. Collaboration and Communication
   - Communication posed no significant challenges for the group.
   - Only one student perceived collaboration as problematic, suggesting a generally cohesive team dynamic.
3. Challenges
   - Technical Issues: The most significant challenge identified by participants was in lack of technical skills required to complete the project.
   - Time Management: Some students also found this aspect challenging.
   - Other Factors: Being online or international was not considered a barrier by any participant.
4. Achievements and Outcomes
   - All students expressed pride in submitting their abstracts to conferences.
   - They unanimously agreed that the project enhanced their collaboration skills, regardless of team members' locations.
5. Future Guidance
   - Participants recommended more guidance for students unfamiliar with IBL methodologies.
   - Such support could enhance the onboarding process and improve outcomes for new participants.
6. Satisfaction
   - All students were highly satisfied with the IBL team project experience.
   - They noted the value of this experience in preparing for future professional environments.

One of the students quoted:

> *"Communication may be inconvenient as an international student but there is no issue with team collaboration. I think the overall team collaboration and communication are good."*

Another student expressed:

"*I enjoy and am proud of the presentation of my project. After the presentation, I have learnt a lot from the valuable comments and suggestions from other students and instructors.*"

The results of the interim survey indicated that the IBL team project was highly successful in fostering collaboration, problem-solving, and professional growth among participants. Despite technical and time-management challenges, students felt empowered and proud of their achievements, particularly in their opportunity to present at conferences. Enhancements in guidance for first-time IBL participants may further strengthen the program's impact.

Discussion

IBL has proven to be feasible for implementation in design innovation projects spanning multiple time zones. The success of collaboration seems to depend on individual commitment to assigned tasks, access to resources, clear communication of deliverables among group members, and strong ownership of work. This suggests that IBL projects rely on students' ability to be self-motivate and self-direct. This case study examined a group of graduate students. Conducting an innovative project in a sixteen-week timeframe presents both technical and time management challenges as validated by the semi-structured interview conducted. Additional assessments of other combinations of student profiles would be beneficial insights into group dynamics within IBL and provide insights on methods to enhance group project success.

While this IBL model can provide more freedom to develop critical thinking, problem-solving, and teamwork skills for innovation, several challenges and problems remain. Based on the semi-structured interview conducted, a key finding and opportunity for improvement is the onboarding of students new to IBL. Students who are unfamiliar with the process and methodology often struggle with unclear guidance on navigating MOOCIBL and initiating innovation projects. Additionally, maintaining the program requires more resources. Various tools are utilized, including Microsoft Teams, MOOCIBL, other software, and demand significant administrative support. Depending on the size of the program, IBL may require increased assistance from learning coaches, project mentors, and instructors. The scalability of this IBL model is challenging but it can be extended to other departments and other institutions.

The semi-structured interview survey identified the primary challenge as a lack of the required technical skills to conduct the project. Team communication and collaboration are not considered as a major challenge, even in the context of an international collaborative engineering project within this IBL model. Additional focus groups and surveys are needed to further assess necessary updates and optimize the program. These efforts would help improve and enhance the quality of the IBL framework and ensure its continued success.

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