An Online Approach to Project-Based Learning in Engineering and Technology for Post-secondary Students

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Abstract. In this work, we present an active digital learning environment to support undergraduate research-based education in an online environment in the Biotechnology program, as part of the iThink program that is part of the PIVOT initiative. Specifically, the students were tasked to demonstrate an open-ended objective using the biosensor technology for organic sample detection. To do this in an online environment, students undertook the research and development of their experiments by learning the laboratory techniques using online lab exercises and evolving the research in a collaborative online environment. Their progress was recorded throughout the academic year via weekly assignments, review of the content relating to the weekly deliverables, online interactive lab simulations, and lab reports with detailed technical content relating to their experiments. As with the in-person format, the iThink project continues to teach the concepts to the students from the highest levels of the Bloom's taxonomy. An evaluation of the effectiveness of the iThink program in an online setting showed that the performance of the students in the online setting was similar to that of the students in the in-person format.

Keywords: Remote/online learning · Project-based learning · Engineering pedagogy · Biotechnology

1 Introduction

Transition from in-class delivery of academic content because of the pandemic restrictions was done on a global scale through university institutions worldwide [1–4]. Students across all universities around the globe had to adapt to this mode of learning. For a successful online delivery of the curriculum, pedagogical innovations were introduced to ensure that the education is uninterrupted, and students may graduate in a timely manner. Post-secondary engineering institutions' goal is to graduate competent engineers with real-world experiences and who can translate the technical concepts taught in the classroom into functional designs and innovations [5–7].

Among other pedagogical techniques, active learning [8–13], problem-based learning (PBL) [14–18] and project-based learning are widely used in academia [19–22]. Apart from these, an important pedagogical approach is the research-based

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education in which students are expected to explore and experiment to experience the essence of the discipline. As per the constructivist theory of learning, exposure to such rich and varied experiences will result in a good mental construction of the various concepts [23, 24]. By undertaking research, the students are exposed to the application of the concepts they learn, and this helps reinforce the principles of the discipline. It also encourages the students to become independent life-long learners who are confident graduates ready to join the industry or pursue graduate studies. The overall education experience is enriched since the students not only learn the fundamental concepts, but they also improve their problem-solving skills, learn the exploration and use of scientific literature, and develop their oral and written communication skills [25–27].

Hartmann [28] identified that students are aided in areas such as problem definition, technical abilities, decision making and critical thinking. An investigation by Seymour et al. [29] in four colleges found that an overwhelming majority of students (91%) perceived undergraduate research positively. Rodrick and Dickmeyer [30] found that capstone projects significantly benefit students and proposed an integration of capstone projects in the communication curriculum to provide more research opportunities for the students. Thus, in general, there is consensus in the literature that undergraduate research experience brings a positive transformation in students and prepares them better to apply the theoretical principles to solve complex real-world problems [31–35].

At the W Booth School of Engineering Practice and Technology, we recently introduced undergraduate research-based learning through the iThink program [36, 37], that is part of the PIVOT initiative launched by the Faculty of Engineering at McMaster University. Unlike the traditional curriculum in which students are guided through a training program that starts at the lower levels of the Bloom's taxonomy and gradually progresses to the upper levels, in iThink, students are introduced to an application (highest levels of Bloom's taxonomy) and are required to research and learn the skills to be able to design and develop the application. Thus, in iThink, students traverse the Bloom's taxonomy in the reverse order. Working in groups to undertake the complex design and development exercise, students are expected to develop a deeper understanding of the subject and the journey fosters critical thinking, collaboration skills, and other transferable skills that is critical for engineers in society [38, 39].

In this paper, we describe the details of students are subjected to the previously taught content of the iThink program through an online delivery method. The iThink program produces an outcome of implementation of a project-based and active learning digital component for students. This program offers a new innovative approach to the shift into online learning. Work in relation to this program has been drawn from the work done at MIT in the form of the NEET project [40]. Students involved in this project stem from the Biotechnology program offered at McMaster University which has come from the online education transformational initiative, PIVOT, led by the faculty of engineering at the led by the faculty of engineering at W Booth School of Engineering Practice and Technology. The assessment of the evaluation of the project and students involved are documented to discover the influence and transition from an in-class working environment to an online platform.

2 The iThink Program

The iThink program was introduced to W Booth School of Engineering Practice and Technology to foster a cross-disciplinary research-based curriculum in the undergraduate programs. Students from the Biotechnology, Automation Engineering Technology, Automotive and Vehicle Engineering Technology, and the Software Engineering Technology programs participate in the iThink program [36, 37]. In these inter-disciplinary projects, students are required to develop a prototype for applications such as biosensor design to detect proteins in a sample. Thus, the education starts with a definition at the highest levels of the Bloom's taxonomy. To develop the prototype that meets a certain prescribed benchmark, the students undertake a literature review, and propose a design of experiments. A key aspect of this work involves collaborating with students from other disciplines. Faculty members from these streams engage with the students in an advisory role, guiding the students in the explorations.

As an outcome of the first batch of the graduates from the iThink program, a novel, open-source, electrochemical biosensor device was developed by the students using an *IO Rodeostat* potentiostat made from the *IO Rodeo Smart Lab Technology* for detection of organic material. The potentiostat was capable of measuring voltage and current, programmed to conduct Cyclic Voltammetry (CV) and Differential Pulse Voltammetry (DPV) tests of organic samples on screen-printed electrodes. The initial project was used to detect hybridization events of complimentary DNA strands on the electrode surfaces in order to identify the presence of target biomarkers for Prostate Cancer in humans. The computer program made to run the tests on the potentiostat biosensor device was programmed using the Python GUI application by a student from the Deaprtment of Electrical Engineering. The data acquired by the device was stored in an online database and made accessible to the faculty and students involved in future projects. The graphs acquired from the GUI application were programmed into Excel spreadsheets with corresponding data set values and used to compare the different stages of hybridization events occurring throughout various experiments. Further innovation of the novel, open source biosensing device involved the addition of a Raspberry Pi computer for processing.

The iThink projects were embedded into the curriculum and offered as an option for the students. More precisely, students could opt to take this research-based learning option instead of the traditional lab-based learning. Further, the students were given the opportunity to choose their own research topic and develop their own experimental protocol to develop the biosensor. In an active learning environment, the instructor engages with the students, discussing about the specific skills and the experiments that the students have planned. Following this discussion, students make amendments and adjustments to their experimental plan, if needed, and continue performing the experiments and analyzing the results. Throughout the entire process, the students would research and design their own experimental procedure, all while learning the necessary lab techniques provided in the original lab curricula. Assessment of the progress was done through regular short presentations/video reports and discussion of the weekly findings. Thus, by creating a discussion-based environment during the presentations, an active learning environment was maintained to help develop the groups work skills.

3 The Online Version of iThink – Procedures and Outcomes

The online version of iThink initiative was launched in Biotechnology Program at W Booth School of Engineering Practice and Technology in academic year 2020–2021 to improve the project-based learning in two biotechnology courses BIOTECH 2M03-Molecular Biology and BIOTECH 2BC3-Biochemistry. Despite the time constraints and the challenges associated with the COVID-19 pandemic, our goals were to provide a teaching and learning experience that was as close as possible to the in-person version of iThink initiative in terms of creative teaching and learning strategies, student engagement, and active learning.

In both courses, to maintain a realistic approach, the iThink students were provided a list of topics, expectations, and resource availability from the program to ensure a feasible target. Typical examples of the projects undertaken by the students in the two courses include the characterization of nucleus DNA from breast cancer cells; the development of biosensor technique to detect biomarker protein in breast cancer cells; the purification and biosensing of lipids from Gram-positive bacteria; and isothermal amplification of viral DNAs for disease diagnosis. The students undertook the research initiative over a duration of 13 weeks. In both courses, the class met twice a week for a duration of 1.5 h in each meeting. While the first class in the week was devoted to outlining the technical principles and discussions, the second class focused on the lab experiments, the challenges faced by the students, and discussion to help them move their project forward. All the course content was shared on McMaster's learning management system, Avenue to Learn. Student work (including assignment, presentation, and final report) was submitted, marked, and analyzed on Avenue to Learn course shell. Comments were provided back to students one week after the submission. During the academic year of 2020–2021, all the students who enrolled in both the courses (BIOTECH 2M03 and BIOTECH 2BC3) participated in iThink Program. The numbers of students who participated in the iThink Program during the two courses are summarized in Table 1.

Table 1. The number of students who participated iThink Program in BIOTECH 2M03 and BIOTECH 2BC3 during the academic year of 2020–2021.

Course Code	The number of students who participated in iThink Program
BIOTECH 2M03 molecular biology	60
BIOTECH 2BC3 biochemistry	57

An extensive and entrenched participation, and assuming responsibility was the focus in the initial stages of the course. Students were required to form teams of 3–4 students per group, and the assessments were conducted on the group. The stages of online iThink program presented in this study include the following: 1) planning and determination of the idea of making simple biosensor tools, 2) design of biosensors, 3) reporting the progress on biosensor design through Avenue to Learn course shell, and making amendments based on the professor's feedback, 4) implementing functional tools through self-designed experiments, 5) recording and submitting the videos that demonstrate the design and functionality of the tools, and 6) a final presentation of the project undertaken by the students through a recorded video. The students were evaluated based on the outcome of these different steps and were assigned a final grade. Project assignments were collected in the form of project work schedules, photos of equipment designed by the students, practicum photographs carried out individually by students, and the simulation-based proof-of-concept experiments due to the online course during the COVID-19 pandemic. Throughout the iThink Program, students were required to submit the biweekly assignments that describe the progress report on the project, including the description of the project to the various research steps undertaken by the students in the consecutive weeks. Specifically, these assignments present the project viability, lists of materials, and the designs of the various protocols. Since students were unable to perform any experiments in the lab during the pandemic, concepts such as DNA/RNA extraction, PCR analysis, molecular cloning, protein synthesis, and viral gene therapy were covered in the simulated experiments. These experiments were delivered through the online lab simulation program known as *Labster*. Students were provided some data from these experiments to process/analyze and submit a commentary on the findings in the form of a report. Thus, through this collection of experiments, by the end of the semester, students were exposed to a suite of competencies needed for developing a design of experiments for their respective research projects. A final report was due at the end of the semester which included all the previous work completed by the students. To ensure continued progress throughout the term, intermittent assessments were done as follows: 5-min group presentations on the progression of the projects were required every 2–3 weeks. In this, the instructors and students would engage in detailed discussions, conducting simulated experiments on theoretical concepts taught within the course that directly coincided with the knowledge needed for their research topic.

The effectiveness of iThink Program measured in the form of the average student performance in BIOTECH 2M03 and BIOTECH 2BC3 is shown in Fig. 1**.** To measure the learning in students we compared the performance of the students who undertook the iThink projects with those who did not participate in iThink in these two courses and instead took the traditional labs to learn the skills during 2019–2020 academic year. As seen in this figure, in both courses, students who participated in the iThink projects scored nearly 16% higher than the students who did not participate in iThink. Similarly, in BIOTECH 2BC3, the students who participated in the iThink projects scored approximately 5% higher than the students who did not participate in iThink. This is not surprising because with more exposure to literature via research and reading, the students in iThink had a better understanding of the various concepts and performed much better during the assessments. This is mainly due to the development of their critical thinking, project planning and troubleshooting, communication, and soft skills, that are honed while working in groups.

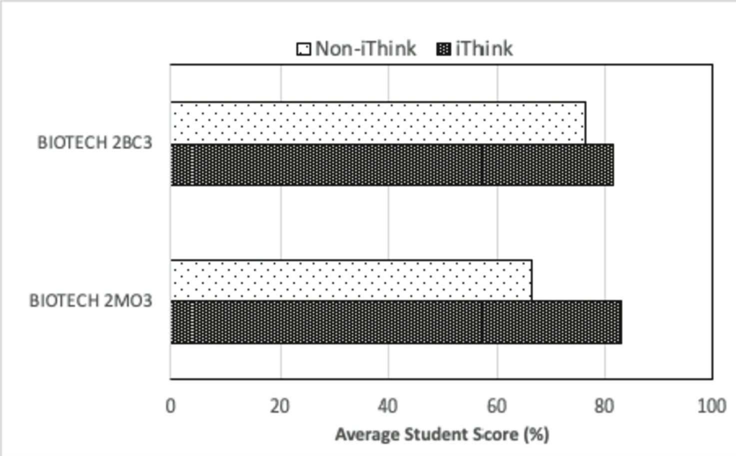

Fig. 1. Comparison of academic performance of students who enrolled in the iThink program during the academic year 2020–2021 with those who took the traditional lab format of learning (non-iThink) during the academic year of 2019–2020, in BIOTECH 2M03 and BIOTECH 2BC3.

4 Future Plan for the iThink Program

The COVID-19 pandemic posed a serious challenge to the format of several courses that require the presence of students and professors in laboratory for training purposes. Prior to the pandemic the students were also required to attend theoretical lectures in person. As an evolution from the pandemic, starting from Fall 2021, we plan to adopt a blended learning approach in which the theoretical lectures will be held online while the laboratory experiments will be conducted in person.

With respect to the laboratory experiments, based on the current virtual iThink structure described in this work, we would explore the following two options: In the first option, the students will use a combination of online labs as well as in-person labs to conduct their iThink project. Specifically, online labs could be used to obtain the skills and in person labs could be used to employ these skills to the specific iThink project. This online and in-person lab could be scheduled in a manner to accommodate for social distancing norms, as well as student preferences, give an added flexibility in the learning environment. In the second option, students will develop their laboratory skills and apply them to solve their iThink project by undertaking experiments in the laboratory in an in-person environment. With either option, the theoretical lectures as well as group discussions on the project and the experiments could be done in a virtual setting introducing a significantly flexible learning environment for future students. Thus, we can foster a collaborative learning environment not only in the laboratory during the experiments but also in the online environment. In other words, the future format of iThink will be a creative and an efficient blended learning environment for the learners in the iThink program.

There are some challenges to be mindful of in pursuing these options. For instance, it is also important to investigate how students engage virtually in iThink activities and compare this engagement levels with the in-person format. This while recognizing that engaging synchronously through virtual meeting platforms has been a particular challenge. There are also student-wellbeing issues that we should be mindful of when adopting a virtual format of instruction. In summary, reflecting on our experiences, we have identified several important steps for using technology as a tool through which creative active learning strategies can be implemented in virtual contexts.

5 Conclusion

As an educational evolution in response to the pandemic there has been a shift in the delivery of post-secondary education, and this has resulted in the adaptation of online/mobile learning for engineering and technology students. In this work, we present the transition from in-class to an online environment for the iThink program. Specifically, the previously established theme of research-based education, the iThink program, has been successfully implemented in an online format at McMaster University's W Booth School of Engineering Practice and Technology. In this, the students use online simulated labs to solve a research problem of their interest. The problem is solved in a collaborative and investigative setting and students learn the necessary skills via an inquiry-based learning. The iThink project addresses these teaching concepts and delivers them using a top-down approach to Bloom's Taxonomy. More precisely, in trying to solve a research problem, students determine the techniques and skills required to finish the necessary tasks, thereby picking up the skills as well as knowing how these skills are relevant in a real-world setting by employing them to solve a larger research project. An evaluation of the effectiveness of the iThink program showed that the students performed equally well in the in person as well as the online format of iThink. More importantly, the students in the iThink program tend to outperform students who learnt the concepts and skills via traditional lab exercises.

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