Project Based Learning during the COVID-19 Pandemic: Experiment Reports of Initiatives in Computer Engineering

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Abstract

The COVID-19 pandemic caused profound impacts arising from a traditional on-site teaching model rupture and demanded distance learning for Engineering students, who faced additional challenges and opportunities for practical activities with physical components such as Internet of Things projects. As an alternative to standardized synchronous tests, Project Based Learning (PBL) was employed in this context to engage students in the social distancing context. This paper presents experiment reports of PBL application for the Polytechnic School of the University of São Paulo's Computer Engineering curriculum in 2020: two undergraduate courses (third year's Digital Laboratory II, fifth year's Laboratory of Software Engineering II), scientific initiation (short-term research project of smart meter for third year student), and capstone project (one year project fifth year student regarding smart home monitoring). In all courses, at least a Master of Science student acted as co-advisor or graduate teaching assistant. When combined with remote labs, home labs and virtual labs, PBL could engage students and make practical activities happen during the pandemic. The students took an active part in the projects, working with stakeholders and raising demands for tools usage.

Keywords: PBL; Computer Engineering; Internet of Things; Remote Lab.

1 Introduction

Social distancing and the consequences for education are subjects for continuous reflections regarding the way we evolve techniques and methodologies for teaching. It holds true for Engineering students: they must learn concepts, exercise them, and discuss their applications in the context of a real-life scenario. The situation caused by the Covid-19 pandemic created many touching points in education themes, especially regarding virtual interactions. In this paper, we describe the following experiences in detail: the first one regards a digital circuits lab named "Laboratório Digital II" applied for third-year students; the second one describes a scientific initiation, a short-term research project for a beginner Engineering student; about the third report describes a Software Engineering Lab, named "Laboratório de Engenharia de Software II"; and the last study case regards a Engineering capstone project where technologies and methods are presented by advisors and co-advisors to let student teams obtain consistent technical and business orientations.

Some lines of thought were fundamental to develop these education study cases:

1. Line of Thought 1: Collaboration teams with professors, students, technicians, and staff teams discussing the importance of the traditional way to teach (Hayashi, Arakaki, 2020d);

2. Line of Thought 2: Real-time data and actions using electronic sensors, actuators and other digital tools to improve the virtual platform to immerse students in their activities inside the lab instruments. In this case, considering four roles: students in pairs, each in their home; professor to assist, help and monitor learning results; the lab pieces of equipment and components accessed remotely; and technicians for supporting all activities (Hayashi, 2020a), (Hayashi, 2020b)

3. Line of Thought 3: Similar to the previous item, the Internet of Things was fundamental here. Students created innovative projects using various types of sensors and actuators, Internet connections, cloud

processing resources to support smartphone applications as evidence of digital transformation results, and providing an experience resembling an augmented reality (Hayashi, 2020c);

4. Line of Thought 4: Application of remote lab for simple experiments would be helpful, but solving practical problems was the mainstream directive to engage teams. They were strongly oriented to search and get real situations of people in their day-by-day routines. This line of though is aligned to the Problem Based Learning method (Hayashi, 2020e);

5. Line of Thought 5: Value proposition was one of the main aspects of inspiring, creating, and executing learning activities. As a result, all projects had to show what and how to add value for people (Hayashi, 2020b).

Figure 1 presents a timeline of the learning initiatives presented. All Lines of Thought cited here created engagement from students. In the lab activities, they were motivated by using canvas to improve value proposition of their projects (Osterwalder, 2019). Significant results in terms of project quality by applying immersive activities using IoT in remote lab environment. In their final course work, innovative teams' awards are evidence of marks obtained by combining these lines of thought. The following items present more details.

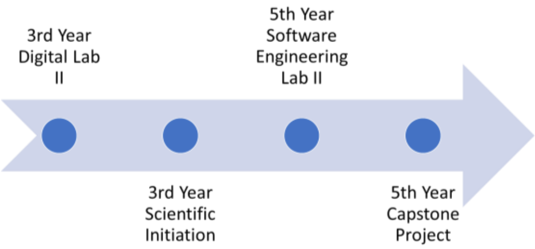

Figure 1. PBL initiatives during social distancing for Computer Engineering in 2020.

2 Prior Work

The knowledge associated with Internet of Things (IoT) technology which enabled remote monitoring and control in the social distancing context is a result of continuous efforts. In this section, prior work related to IoT is presented so that the reader is introduced to the infrastructure and tools employed in the 2020 PBL initiatives for Computer Engineering.

2.1 OKIoT – Open Knowledge Internet of Things Project

The Open Knowledge Internet of Things Project (OKIoT) is an open-source initiative for capstone projects based on IoT technologies. OKIoT aims to make IoT accelerators built in capstone projects freely available and highlights how Software Engineering methods could be used to specify and model IoT systems.

The timeline in Figure 2 presents 10 projects from 2016 to 2019:

1. CerveJá (2016): brewery automation project with mobile application and cloud-centric IoT architecture to automate brewery process at home. Group of three undergraduate students for microprocessors course. Communication based on HTTP requests and cloud monolithic architecture.
2. ElderAid (2016): elderly monitoring project with IoT modules with alert functionalities deployed locally and in the mobile device (via cloud communication) for gas leakage detection and SOS button. Group of four undergraduate students for Software Engineering II course. Communication based on HTTP requests and cloud monolithic architecture.
3. Hedwig (2017): smart home project with lightning, access control, kitchen and aquarium automation, with a fault-tolerant architecture with web interface, local and cloud back-end services. Group of four undergraduate students for capstone project. Communication based on HTTP requests, MQTT, and a fault-tolerant architecture.

4. Smart Home (2018): integration with commercial sensors and controls with radio frequency communication of 433 MHz, integration with Google Home and Alexa conversational interfaces in smart speaker devices. Communication based on HTTP requests with a fault-tolerant architecture.
5. Shared Garage (2019): with the lack of parking spaces in large urban centers, the proposed solution was to enable residential garage sharing with mobile application integrated to access control IoT module. Group of two students for capstone project.
6. Thermal Comfort (2019): motivated by the increase in the elderly population in Brazil, the project aimed to provide thermal comfort with an intelligent shower customized to each user. Group of two students for capstone project.
7. Anomaly Detection (2019): detection of outliers based on data streams from IoT sensors deployed in a smart home. The objective was to enhance residents' safety. Group of two students for capstone project.
8. Smart Home for Elderly (2019): automated reminders of medications for elderly, and proposal of open smart speaker architecture to enhance performance of conversational interfaces for smart TV usability enhancement, integrated with mobile application and open-source smart speaker based on Raspberry Pi. Group of three students for capstone project.
9. Energy Awareness (2019): voice assistant integrated with IoT devices for real-time monitoring and control, with suggestions from prediction algorithms to increase energy awareness at home. Integration with conversational interfaces and smart TV dashboard. Group of two students for capstone project.
10. Access Control for Airbnb (2019): access control module to increase usability of home sharing with fault-tolerant architecture.

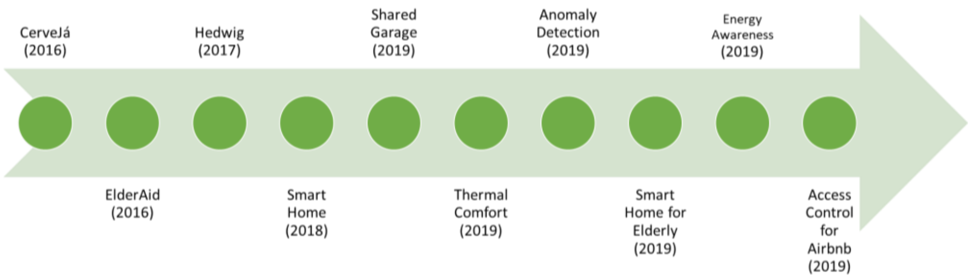

Figure 2. OKIoT Projects Timeline from 2016 to 2020.

For detailed description of available resources and projects up to 2019, please refer to (Hayashi, 2020a).

Some investigations on Software Engineering methods applicability to enhance quality attributes of IoT architectures can be found in (Hayashi, 2020b).

2.2 LabEAD – Remote Lab for Engineering

LabEAD is a series of initiatives to make remote teaching of laboratory subjects feasible for Engineering courses. In this paper, we present the LabEAD in the context of a Digital Laboratory course. Figure 3 presents a high-level concept of the LabEAD concept. Each student in their own residence can access the lab benches by connecting with an IoT platform, using their own smartphones and computers.

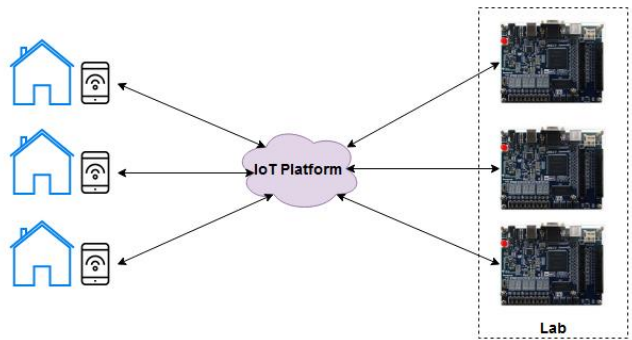

Figure 3. LabEAD high-level concept.

We decided to use Blynk IoT as the IoT cloud platform, but any other platform could be used, if the required changes are made in the source code. Each student needs to download the Blynk app in the Google Play/App Store and then use it to send commands to the lab bench. An IoT architecture is built in the lab using the FPGA board, which is the core of the Digital Laboratory course, an ESP8266 component, which has a Wi-Fi module included and some input/output expansion devices. The physical assembly is presented in Figure 4.

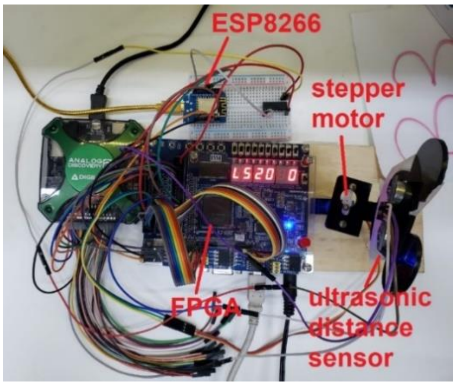

Figure 4. LabEAD physical assembly.

The project source code is available in: https://github.com/vthayashi/labead-labdig.

The first results were presented and published in (Hayashi, 2020d) and (Hayashi, 2020e).

3 Experiment Report A – Undergraduate Courses

3.1 Digital Laboratory II

The Digital Laboratory II it is a discipline offered to the third-year students. The students work in groups with a full hardware development cycle using a hardware description language (HDL) and a FPGA board.

The cycle starts with the project specification, where they need to identify which hardware components are required to implement the requested circuit, like logic gates, registers, multiplexers, and other components. After the specification, they need to write the project source code with the HDL than test the code using simulation tools like the ModelSim. This first half of the cycle the students need to make prior to the class, submitting a report to the professor with results. In the class they continue the cycle, compiling the code using the FPGA board development proprietary software, generating an output file called bitstream, then the bitstream is loaded in the FPGA board, making the FPGA behave like the circuit described. For the last part, the students need to test the circuit, sending different input signals to the FPGA and checking if the output signals are correct. If any inconsistence is verified, they need to debug the project, which can take a large portion of the class time.

In the 2020 offering, we had to adapt the course to use the LabEAD, allowing the students to interact with the FPGA board and other components, such as sensors and actuators, while respecting the social distancing protocols (due to the COVID-19 pandemic). That was possible with teachers, MSc students as monitors, course students, who all acted as stakeholders and the lab technical personnel. In addition, we used Google Meet as the videoconference tool and AnyDesk as the remote access tool to permit the students remote access to the lab computer machines.

The last half of the course classes is always dedicated to a project. The groups freely choose ideas related to the course concepts. The LabEAD allowed the students to integrate components in their residences with the FPGA board in the lab, giving more variability and possibilities to the projects. Table 1 presents 7 projects of Digital Laboratory II in the 2020 offering with 14 students. The detailed students and teacher's perceptions regarding the discipline offering were presented in (Almeida, 2021).

Table 1. Digital Laboratory II Projects.

Project Name	Description	Students
Lixeira inteligente	An IoT integrated bin, capable to communicate with a command central and track the empty fraction of its volume	2
Dispensador digital de álcool em gel	Automatic alcohol gel dispenser with a web control panel, where the owner can check the alcohol quantity inside the dispenser	2
Smart Home, detecção e ação contra incêndio	IoT platform to detect fire inside houses and act against it	2
Sonar mouse	Mouse developed with ultrasonic sensors, which receives hand movement input to move the cursor	2
Machine Learning FPGA	Neural network implemented inside the FPGA to predict stock market behaviour	2
Projeto Moisés	Garbage collection to be used inside rivers	2
Rega de plantas inteligente	An IoT platform to measure Earth humidity and automatically water plants	2

3.2 Laboratory of Software Engineering II

The Laboratory of Software Engineering II was designed to resemble a professional environment, with Master of Science student and Professor as Coordinators, and students grouped in squads, and each group has the freedom to choose a topic of interest to apply Software Engineering methods in the specification and documentation of such projects. The students are in the last year (fifth), and most of them work in entry-level positions in software companies.

The course consists of 15 weeks, with initial presentations of 15-25 minutes regarding theoretical concepts and references, and 15 minutes meeting with each group. While one group was in a meeting, the other ones could work in the project. This work method enhanced students' autonomy and proactiveness and could be applied in face-to-face and remote alternatives.

Additional integration challenges emerging in the physical distancing context could be solved with software engineering methods such as architecture specification, simulations and mock-ups, unit tests, and integration tests. A key aspect after the course turned remote was communication, which was facilitated due to videoconference and project management tools (e.g., Google Meet, Trello, Jira, GitHub). The students operated fully remote from their residences, and integrated mobile applications and cloud back-end services with agile methods in an iterative manner: each week presented a functional project deliverable.

The classes were organized as follows:

1. Digital Transformation and technology trends for project motivation, expected results of projects, Osterwalder Value Proposition Canvas for project definition.
2. Software specification concepts (e.g., non-functional requisites), Collaborative development (e.g., Trello, Git).
3. Software architecture concepts and modelling.
4. Software architecture tactics for quality metrics trade-off analysis.
5. Study cases of software architectures.
6. First project documentation deliverable.
7. Microservices architecture.
8. Serverless computing.
9. Agile methods.

10. Project sprint mapping.
11. Tests and Quality metrics.
12. Software system evaluation.
13. Project implementation.
14. Project implementation.
15. Final project demonstration using Google Meet, with documentation in a GitHub repository.

Table 2 presents the 5 projects of Laboratory of Software Engineering II in the 2020 offering with 13 students.

Table 2. Laboratory of Software Engineering II Projects.

Project Name	**Description**	**Students**
Estágio_PCS	Internship system that facilitates job search, with integrated chatbot and automated digital signature to enhance usability in the remote work context.	3
EVacina	Vaccine platform to reduce manual labor by digitalizing vaccine information. The mobile application scans codes present in the vaccine and matches location information before registration in the database. It also notifies users of ongoing vaccine campaigns.	2
Ipet	Animal monitoring platform that uses IoT camera to monitor animals (e.g., cats and dogs) at home, designed as a social network for pets.	3
NLP	Use of Natural Language Processing models to cluster and classify product feedback opinions.	1
Petfinder	Animal finding mobile application that uses image recognition algorithms to ease lost animal search. Users can look up for their lost pets, and register found pets in the platform.	4

4 Experiment Report B – Scientific Initiation

A Scientific Initiation is a short-term research project whose objective is to enable undergraduate students learn and practice the scientific method, guided by advisors.

In this case, the advisor was a Professor and the co-advisor was a Master of Science student. The advisor was responsible by providing research guidelines, and the co-advisor assisted the third-year undergraduate student in practical matters such as Arduino programming and serial communication.

The scientific initiation occurred in four months (from April to July 2020), and was comprised of:

1. Study of existing smart meter based on one-hour interview with specialist from Federal University of ABC, and papers found in the literature (Amaral, 2014; Hayashi, 2020c).
2. Familiarization with tools required for the project: Fritzing (Knörig, 2009) for hardware module design and Arduino IDE (Fezari, 2018) for Arduino Mega programming.
3. Development of low-cost smart meter with Arduino Mega. Tests in home environment with fan and light bulbs. Data registration in csv file.

The resulting prototype is presented in Figure 5.

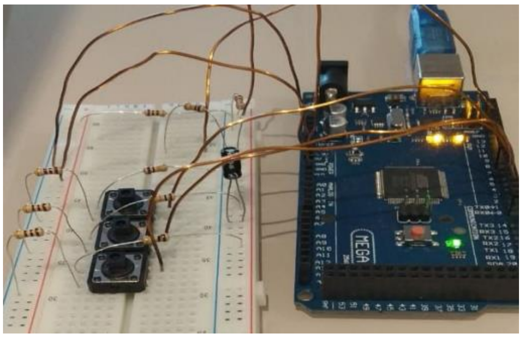

Figure 5. Low-cost smart meter prototype with Arduino Mega proposed in the scientific initiation.

The whole process was performed in a remote manner. The main challenges regard communication and physical device debugging. In some videoconferences with the undergraduate student, the co-advisor used remote access to desktop present in the undergraduate student home, and video streaming to verify if the prototype was connected properly. Additional project overhead was also added due to material delivery.

As a supervisor, some comments about this practice learning work: the student has done an excellent job: hardware circuits, local programming modules, and Internet connection supported considerable practical experience. Resilience was a soft skill capability developed by the student while facing challenges. The results presented in a workshop to students working as interns in companies received a good impression from the academic staff team that supports academic-industry relations.

5 Experiment Report C – Capstone Project

A capstone project was performed from February 2020 to December 2020, with a Professor as the advisor, and the Master of Science student as a co-advisor. The fifth-year undergraduate student was responsible for project specification, implementation, and documentation.

One of the project objectives was to build a smart home monitoring infrastructure based on Arduino, Raspberry Pi and ESP8266 IoT module with built-in filesystem and Wi-Fi communication. The ESP8266 with datalogger capabilities used was a result of previous capstone project of the co-advisor and was used in this project as an accelerator. The fifth-year undergraduate student implemented the Arduino Mega interfaces with sound, motion, ultrasonic, and temperature sensors, and the middleware deployed in a Raspberry Pi device, which transferred data in real time from the testbed to a cloud back-end.

An ultrasonic sensor deployed in the smart home, and the prototype with sensing module (Arduino Mega) and datalogger module (ESP8266) are presented in Figure 6.

The data collected in the smart home testbed was integrated with the cloud by the middleware deployed in a Raspberry Pi 3.

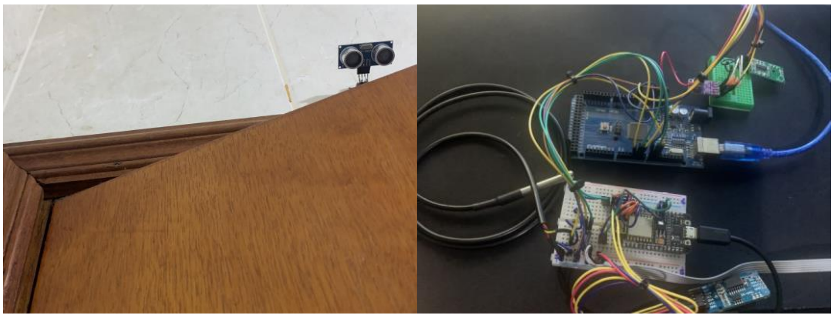

Figure 6. Ultrasonic sensor installed in smart home (left), and prototype (right) of capstone project.

Due to the COVID-19 pandemic, the capstone project was performed remotely from March to December 2020. Only initial presential meetings could be performed in February 2020. The main challenges regard testbed prototype debugging. Remote access was performed by co-advisor in the undergraduate student desktop connected with ESP8266 and Arduino devices.

The use of previous results from a capstone project (i.e., the ESP8266 datalogger module) showed the opportunity of a Master of Science co-advisor supporting future capstone projects. The deployment in a real smart home environment could be performed even in the social distancing context.

As a supervisor, some comments about this project: thinking and applying digital solutions to health in a capstone project were relate to immense opportunities. The Internet of things, cloud computing, and real-time monitoring combined to add value to people with special needs related to diabetes. The student involved constructed a tremendous professional portfolio, for sure.

6 Conclusion

The present paper described how remote practical activities were conducted in the COVID-19 pandemic scenario for the Computer Engineering at Polytechnic School of University of São Paulo in Brazil.

Internet of Things knowledge and expertise from Master of Science student (co-advisor and teaching assistant) and professor acquired from 10 projects from 2016 to 2019 were used to propose Project Based Learning (PBL) approaches in two undergraduate courses, one scientific initiation, and one capstone project in 2020.

In 2020, a total of 14 projects were executed by 29 students: 7 projects from third year´s Digital Laboratory II, 5 projects from fifth year´s Laboratory of Software Engineering II, 1 project in scientific initiation, and 1 capstone project. The PBL could engage Computer Engineering students in the social distancing context by presenting themes such as Sustainability, Healthcare, Smart Home (Safety and Automation), and Remote Work. Some students went beyond, and integrated emerging technologies such as Machine Learning, Cloud Computing, Mobile, Internet of Things and Natural Language Processing in some projects.

It demands considerable work to build new projects with innovative applications and high technical quality based on knowledge obtained in previous projects. However, we hope that by sharing how it was accomplished in the Computer Engineering using Internet of Things technologies, this idea can be expanded. The Project Based Learning approach showcased in the 14 projects executed in 2020 might be the conceptual basis for such future work.

The COVID-19 presented challenges to Engineering Education, but also opportunities to innovate in remote learning. Considering the efforts presented in this paper, the authors advocate that when combined with remote labs, home labs and virtual labs, the Project Based Learning can engage students by letting them integrate emerging technologies into their projects and choose themes of interest. The projects could create the situations and challenges necessary for practical knowledge, initially threatened by the limitations of physical access to labs during the pandemic in 2020.

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