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FOSTERING ARTIFICIAL INTELLIGENCE COMPETENCIES THROUGH PROJECT-BASED LEARNING: A CAPSTONE APPROACH

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ABSTRACT
In today's quickly evolving technological landscape, engineering graduates must be able to understand the fundamentals of cutting-edge technologies. Under this perspective both students and faculty must explore the digital world and Artificial Intelligence (AI) as allies in technological innovation. As the demand for AI expertise continues to rise, equipping students with essential AI competencies has become imperative. For their final capstone projects, engineering students were asked to come up with an innovative system, under the supervision of four faculty members. This paper presents the student's learning experience while designing AI based systems in real-world scenarios and resulted in fostering hands-on experience in novel technologies.

Keywords: Higher education, educational innovation, artificial intelligence

1 INTRODUCTION
Artificial Intelligence (AI) literacy has become a necessity of the modern world, especially for engineering undergraduate students, not only computer scientists [1]. Defined as the ability to understand the basic techniques and concepts underpinning AI across various products and services [2], AI literacy is emerging as a pivotal skill sought after by industries driving the current and future labour market [3] [4]. Despite its undeniable significance, the formal integration of AI education has been lagging compared to other areas such as medicine and applied science [5].
The critical need for AI literacy in formal education emphasises the role of students not merely as end users but potential problem-solvers capable of employing AI technologies across diverse scenarios to propose ideas and create solutions [6].
The development of AI skills among final year undergraduate students from Tecnologico de Monterrey was accomplished drawing on the Technological, Pedagogical, and Content Knowledge (TPACK) framework [7] [8] integrated with Project-Based Learning (PBL) technique. The educational model of the Tecnologico de Monterrey is centred on a challenged based model, where students are engaged and work collaboratively to develop disciplinary and transdisciplinary skills [9].

2 ENGINEERING DESIGN
At Tecnologico de Monterrey, final-year students majoring in Mechatronics Engineering must complete a compulsory capstone project. This capstone project follows the PBL technique to develop disciplinary competences in all the four main areas of Mechatronics Engineering, namely: control, electronic, mechanical, and software systems. AI technology is not a compulsory topic in the current curricula. Nonetheless, including AI in their project design allows for the students to develop technological innovation.
The incorporation of PBL within the framework of capstone projects serves as a pedagogical strategy of paramount significance in higher education. In the context of capstone projects, where the emphasis lies on culminating academic knowledge and skills, PBL provides a both structure and hands-on methodology. The integration of project-based learning in capstone projects aligns with the overarching goal of preparing students for the challenges of their respective fields by instilling a sense of self-directed inquiry and promoting a deeper understanding of the subject matter and engineering project design.

During the academic semester February-June 2023, 39 students participated in the capstone projects. The students were divided into teams with a maximum of 5 members. Each team was formed autonomously according to their member's interests.

3 IMPLEMENTATIONS

The teams had a choice to either select a project proposed by faculty members or to submit their own. With the objective of developing AI competences among the students, various capstone projects incorporated prerequisites that demanded the utilisation of AI technology. In all cases, the capstone project had to comply with several requirements as listed below:

- Must apply technological tools for the design of mechatronic systems.
- Include at least three areas of the mechatronics engineering.
- Define the product's system-level design.
- Detail design for a physical product.
- Must resolve or alleviate a technological need.
- Must evaluate technical and economic feasibility.

During the detailed design implementation, each team defined the user needs and product attributes to establish the target specifications, schematics, drawings, design alternatives, and production details for each phase, allowing the opportunity to create innovative technological design.

Three projects utilising AI technology were chosen, each one developed by a different group of students. These projects are described as:

1. Collaborative Robot Applications in Assembly Task project, herein referred to as CORAL project, integrates a collaborative robot (cobot) and Deep Learning to assist users in assembly tasks; particularly during part handover and storage.
2. Gesture Detection System for Collaborative Robot Control project, or Sign-a-bot, aims to design a system capable of controlling a collaborative robot through hand gestures.
3. Smart Traffic Light system project, or Visual Road, identifies pedestrians in a crossroad hence selecting the timing of the traffic lights to assign priorities.

4 METHODOLOGIES

The capstone project course runs for a 10-week period. The initial phase in the pedagogical process involved teams comprehending the requirements and deliverables for their respective projects, concurrently discerning both theoretical and practical needs. Through their analysis, it became evident that the incorporation of AI was imperative. Notably, none of the students engaged in the AI capstone projects possessed prior experience in AI technology; nevertheless, they were proficient in numerical, analytical, and programming skills.

The teams internally segmented into specialised areas based on the project requirements. Broadly, they established three domains: mechanical, electronic and software systems. Mechanical system's students were on charge of the design and construction of any physical element that the final product may require. Those in charge of the software system were responsible for any task that requires coding, e.g., AI algorithms, digital user interface, among others. Finally, the electronic system sub team was responsible for the selection and integration of the mechanical and electronics systems.

The students exercised full control over the project's development, with faculty members assuming roles more akin to project advisors rather than traditional lecturers. Once the teams recognised the advantages AI posed for the solution of their projects, they requested an AI tutorial focusing on vision identification and speech recognition.

To address their concerns, Introductory short courses were conducted by the lectures employing platforms such as Edge Impulse [10] and Teachable Machine [11]. Additionally, frameworks like TensorFlow [12] and TinyML [13] were reviewed. Owing to the unique nature of each project, the AI courses served only as an initial guide for the teams to explore tailored solutions pertinent to their respective projects.

To keep track on their development, a weekly meeting was convened wherein each team presented their progress and disclosed any challenges they may have encountered.

5 RESULTS

All three projects integrated hardware and software into their design according to their requirements. However, due to their nature, each project followed a distinctive path towards its completion.

CORAL. Its objective was to evaluate the feasibility of the interaction human-cobot by means of voice commands on assembly tasks. The team had previous experience with cobot technology. However, they identified that a more complete collaboration between the human user and the cobot could be possible if the system was responsive to voice commands and perceptive to visual cues.

Voice commands recognition was achieved by integrating a Convolutional Neural Network (CNN). It recognises four commands ("bring", "take", "go", "cancel") and seven numbers ("one", "two", "three", "four", "five", "six", "seven"). A pretrained hand-tracking CNN system identifies the user-hand position from RBG-D data to hand over or collect the assembly part. Finally, another CNN uses a camera to classify the parts received from the user and place them in a store area. Figure 1 and figure 2 shows the system functionality.

The system developed by the CORAL team allowed the user a more natural interaction experience compared to that of a standard cobot. The final prototype demonstrated the capability to respond to voice commands, track the user's hand movements, and autonomously execute certain simple tasks such as sorting.

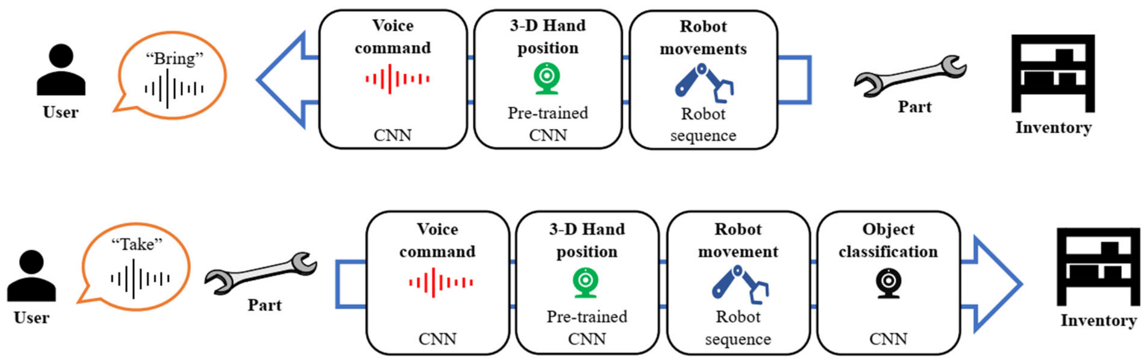


Figure 1. This diagram shows the functionality achieved by the CORAL project. Taken from [14]

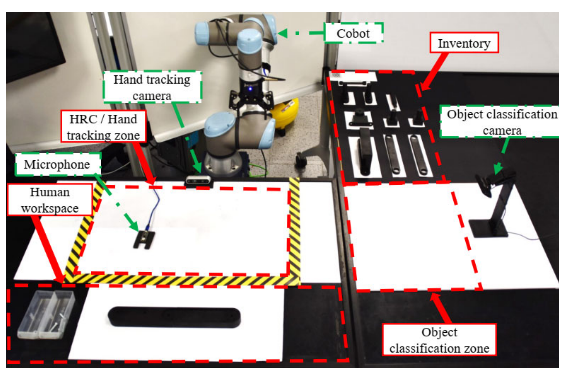
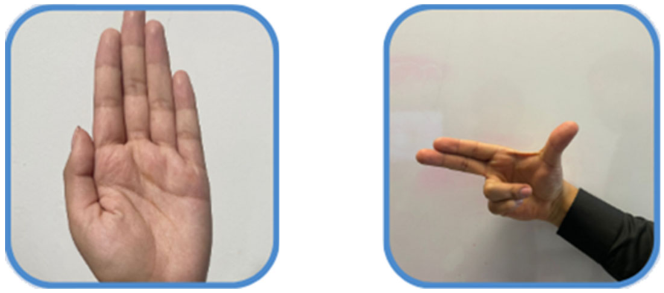


Figure 2. Testing setup used by CORAL. Taken from[14]

Sign-a-bot. Its aim was to create a more natural interaction between the user and the cobot in settings where verbal communication is neither feasible nor preferable, utilising a set of 18 customised sign language gestures.

A CNN was trained to identify gestures captured through a webcam. Subsequently, the system utilises these recognised gestures to command the operations of the cobot. Figure 3 shows some of the set of gestures recognised. Figure 4 presents the assembled system consisting of a camera, lighting, OLED display and microcontroller board for gesture recognition.

The implemented system enables the user to manipulate the cobot along three linear axes (X, Y, Z), three rotational axes (U, V, W), execute predefined movements or routines, and utilise a pneumatic gripper. This array of options gives the user the ability to work with complete spatial freedom within a specific workspace.



a) Move Up b) Open gripper

Figure 3. Hand gesture used by Sign-a-bot to interact with a cobot

Figure 4. Sign-a-bot assembly system

Visual Road. The objective was to control the signal phasing of the traffic lights at a pedestrian crossing through the detection of pedestrians and vehicles. The AI model was created using Roboflow [15], where feature extraction and training were performed. Finally, the model was executed using YOLOv5 [16]. Figure 5 shows a real validation of the performance of the system.

a) People b) Car

Figure 5. Road crossing identification performed by Visual Road

6 CONCLUSIONS

This paper presented a successful integration of AI competencies into the final-year students in Mechatronics Engineering at Tecnologico de Monterrey. The initiative, guided by the Technological, Pedagogical, and Content Knowledge (TPACK) framework and implemented through Project-Based Learning (PBL), aimed to address the growing importance of AI literacy in technological innovation.

The implementation phase involving 39 students in capstone projects revealed the effectiveness of Project-Based Learning in developing AI skills. The selected AI projects—CORAL, Sign-a-bot, and

Visual Road—illustrate the practical applications of AI in diverse domains, ranging from human-cobot interaction to sign language recognition and intelligent traffic control.

The methodology employed during the 10-week capstone project course allowed students to comprehend and fulfil the project requirements, even in the absence of prior experience in AI technology. Faculty members served as advisors, guiding the teams through challenges, and facilitating the exploration of tailored AI solutions.

The results of the projects showcase tangible outcomes where hardware and software were seamlessly integrated. The CORAL project demonstrated the feasibility of human-cobot interaction through voice commands and visual cues, employing advanced technologies such as Convolutional Neural Networks (CNN). Sign-a-bot introduced a natural interaction between users and cobots through customised sign language gestures, detected and interpreted by a trained CNN. Visual Road, addressing traffic management, employed Roboflow for feature extraction and training, and YOLOv5 for execution.

The written feedback provided by students at the end of the course highlight the importance of acquiring AI competencies at the undergraduate level. They expressed their enthusiasm on the potential and opportunities of AI utilisation, and the enriching experience gained from integrating AI into their projects as the sole viable technology capable of delivering possible solutions within the established timeframe.

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