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A CDIO FRAMEWORK FOR A DIPLOMA IN CIVIL ENGINEERING PROGRAM IN MALAYSIA

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Abstract:

The CDIO framework for Diploma in Civil Engineering at Universiti Teknologi MARA is designed by integrating the "Design-Implement Experiences" approach to create a dynamic, hands-on learning environment. The purpose of this paper is to examine the implementation and effectiveness of the "Design-Implement Experiences" approach within the CDIO framework in the Civil Engineering Design Project. A qualitative method by analyzing documents related to the CDIO framework for the diploma program focusing on the capstone project is conducted. The CDIO framework allows students to develop their knowledge and skills progressively from lower to higher semesters. A capstone project is introduced in the final year, where students apply the skills and knowledge learned from the previous semesters to complete a project incorporating design of reinforced concrete elements, project scheduling, structural modelling and project costing using CDIO approach. The average students' attainment for problem solving, investigation and communication learning outcomes are 77%, 62% and 71% respectively. On average, students' attainments for all learning outcomes meet the minimum threshold of 50%, demonstrating their ability to conduct necessary investigations, develop solutions that ensure construction feasibility, sustainability, and cost-effective design, and effectively present their findings both orally and in writing. The CDIO implementation promotes a student-centred learning approach. Future enhancements are encouraged to include sustainability and smart building features. The CDIO approach underscores the practical application of theoretical knowledge, equipping students with the skills necessary for real-world engineering tasks.

Keywords:

CDIO Framework, Capstone Project, Civil Engineering, Design-Implement Experiences

Introduction

Traditional education in engineering has long been characterized by lecture-based instruction, standardized testing, and a focus on theoretical knowledge dissemination. While this approach has been prevalent in educational systems worldwide, it has faced criticism for its limitations in adequately preparing engineering students for the complexities of modern professional practice. Passive - learning, limited practical application, and a lack of interdisciplinary integration are among the key challenges associated with traditional engineering education. Students in traditional engineering education frequently fail to bridge the theoretical-practical knowledge gap. The traditional classroom approach, which focuses mainly on textbook learning and theoretical concepts does not effectively equip students for dealing with real-world engineering challenges. This gap leads to graduates who have solid academic underpinnings but lack the hands-on experience required to effectively design, develop, and manage engineering projects. In response to these shortcomings, innovative pedagogical frameworks such as the Conceive-Design-Implement-Operate (CDIO) approach have emerged, aiming to revolutionize engineering education by prioritizing active learning, hands-on experience, interdisciplinary collaboration, and the development of professional skills. The CDIO approach seeks to bridge the gap between theoretical knowledge and practical skills by involving students in the entire lifecycle of engineering projects, from conception to design, implementation, and operation, resulting in graduates who are better prepared to meet the demands of the engineering industry.

CDIO is an innovative educational framework for producing the next generation of engineers developed by the Massachusetts Institute of Technology (MIT) around 1998 (Edström et al., 2012). The CDIO framework was developed with the goal of producing engineers who are not only technically proficient but also capable of innovating, collaborating, and adapting to rapidly evolving technologies and societal needs. The CDIO has been adopted by many universities around the world (Zhu et al., 2009; Yan, 2009; Kulkarni et al., 2020; Thiruvengadam et al., 2020; Hong et al., 2024; Qu et al., 2024) forming a best practices, resources, and experiences and constantly evolving the framework to stay up with breakthroughs in engineering and education.

The CDIO approach employs a structured method to integrate engineering education with practical experience via syllabus and standard. CDIO Syllabus is defined and classified desired traits of engineering graduates based on stakeholder feedback on what engineers should be able to perform as professional practitioners. The CDIO framework foster students with an engineering education in the context of Conceiving – Designing – Implementing – Operating real world systems and product. Students are taught about system integration, testing, troubleshooting, and life cycle management. The final phase generally brings about the application of the developed product or project.

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In the context of the Civil Engineering Design Project offered in Semester 5 Year 4, Diploma in Civil Engineering, Civil Engineering Studies, Universiti Teknologi MARA, the CDIO initiative is being adopted to correspond with Outcome Based Education (OBE). The drive for adapting CDIO in teaching and learning is to assure knowledge and skill development, accreditation and professional growth, and a fully integrated curriculum with cross-disciplinary subjects and qualities. The primary purpose of adapting CDIO in teaching and learning is because traditional teaching methods in Civil Engineering Design Project focused heavily on lectures, textbooks, and examinations. Traditional methods emphasize the transmission of knowledge through passive learning, with limited opportunities for students to actively apply concepts to real-world situations. The traditional approaches fall short in preparing students for the complexities and multifaceted nature of engineering practice. Another significant challenge of traditional teaching is the limited scope for interdisciplinary learning and collaboration. Civil Engineering Design Projects require not only technical knowledge but also project management, teamwork, and communication skills. Traditional methods, however, often isolate subject areas, leaving students ill-prepared for the collaborative environment they will face in the industry. Thus, this paper provides the CDIO framework and the effectiveness in Civil Engineering Design Projects which prepares students for the complexities of professional practice by blending theoretical knowledge with practical application, fostering creativity, and emphasizing collaboration, ethics, and continuous learning.

Literature Review

The traditional teaching methods offer a solid foundation in theoretical knowledge, they are often inadequate in preparing students for the dynamic, interdisciplinary, and hands-on nature of civil engineering practice. The focus on individual work, exams, and isolated theory creates a gap between academic learning and professional practice, leaving students underprepared for the demands of modern civil engineering projects. This is where alternative approaches, like the CDIO framework, offer significant improvements by integrating practical, collaborative, and real-world learning experiences into the curriculum (Hong et al., 2024; Lin et al., 2024; Zelmiyanti et al., 2024).

CDIO-based education is an excellent option for students in four areas: improving positive learning and practice, developing ideas and solutions to issues and innovation, emphasizing conceptual learning, and improving feedback mechanisms in learning. Teaching with the CDIO technique includes taking into consideration the requirements of the students, allowing them to engage, and analysing the students' knowledge and skills to assign learning projects. The CDIO approach employs a structures method to integrate engineering education with practical experience with several key components. As for the curriculum integration, the curriculum is designed to integrate with CDIO framework throughout the educational program. Courses are aligned with the CDIO stages, ensuring that students' progress through conceiving, designing, implementing, and operating systems and products as they advance in their studies. Students can participate in active learning such as problem – based learning, project - based learning which engage students in hands – on activities and real - world challenges, enhancing their learning experience. Strong partnership with industries will ensure that the curriculum is relevant to the current engineering practices. The industrial expert may contribute to the course design, provide lectures and bringing the real – world project into the classroom. According to the Worldwide CDIO Initiative (2024), the framework of CDIO has been widely adopted by over than 200 universities from numerous regions such as Europe, North America, Asia, UK-Ireland, Latin America, Australia, New Zealand and Africa.

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The CDIO standards are a key part of the CDIO framework by defining the distinguishing features of a CDIO program, by serving as guidelines for educational reform, and by providing a tool for continuous improvement (Brodeur & Crawley, 2005; Crawley et al., 2001; Crawley et al., 2007; Crawley et al., 2014; Bennedsen et al., 2016). The CDIO Standards are a set of twelve best practices for implementing and continuously improving the CDIO strategy in engineering education. The standard comprises of (1) CDIO as context: Adoption of the principle that product and system lifecycle development and deployment of the framework containing conceiving – designing – implementing and operating. (2) CDIO Syllabus : Specific detailed learning outcomes for personal, interpersonal, and system building skills, consistent with program goals and validated by program stakeholders. (3) Integrated curriculum: A curriculum designed with mutually supporting interdisciplinary. (4) Introduction to engineering: An introductory course that provides the framework for engineering practice. (5) Design – Implement Experiences: Hands – on project at both basic and advanced levels in the curriculum. (6) Engineering workspaces: Laboratories and workspaces that support hands – on learning. (7) Integrated learning experiences: Experiences that combine learning disciplinary knowledge with practical skills. (8) Active Learning: Teaching methods that engage students actively in their learning process. (9) Enhancement of faculty skills competence: Program to develop faculty skills in personal, interpersonal. (10) Enhancement of faculty teaching competence: Support for faculty to improve their teaching methods. (11) Learning assessment: Methods to assess students' skills and knowledge. (12) Program evaluation: Continuous improvement through regular review and evaluation of the program. These standards are divided into five major categories: (1) Context, curriculum, workplaces, teaching and learning, and assessment and evaluation. They emphasize the necessity of using the CDIO framework as the foundation for engineering education, gradually incorporating CDIO skills across the curriculum, and providing adequate physical venues for hands-on learning. The criteria also promote active and experiential learning techniques, faculty development, and rigorous assessment and evaluation mechanisms for ensuring educational success.

Modern engineering education programs aim to provide students with a broad range of knowledge, skills, and attitudes required to become effective young engineers (Yellowley et al., 2005; Gu et al., 2006). For example, a design – directed curriculum was introduced by Xiong & Lu (2007) for the College of Engineering at Shantou University in Shantou, China to prepare students in a design environment, allowing them to study engineering science, technology, and non-engineering skills as needed. The curriculum was improvised from course – directed to the design – directed as in CDIO Standard that been offered in Year 2 until Year 3 of civil engineering program. The same approach has also been adopted by Cheah (2009) in reengineer a curriculum revamp for the Diploma in Chemical Engineering at Singapore Polytechnic. Several courses were revised and removed to ensure that CDIO Syllabus infused in the curriculum.

Engineering education institutions have been particularly active in establishing curriculum and implementing novel teaching and learning techniques in response to fast technological advancement. CDIO approach commonly been adopted in the capstone course offers in the final year of the program (Somerville et al., 2023; Gal et al., 2022). The capstone course requires students to integrate the theoretical and practical knowledge acquired in the previous semester. Knowledge and skills are provided to the students in the development of the product using the CDIO module set up by the faculty. For the conceive and design phase, the initial review of the project was initiated. Students are required to create new ideas or modify the

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preliminary conceptual design according to the new knowledge learnt in the course. Through the implementation and operation phase, software and simulation are used to establish the ideas and build the product.

Methodology

This research utilizes a qualitative method by analysing documents related to the CDIO framework for Diploma in Civil Engineering Program (CEEC110) in Universiti Teknologi MARA, focusing on the capstone project. As the current Diploma in Civil Engineering Program is adopting the Outcome based Education (OBE) framework as specified by Malaysian Qualification Framework, the integration of CDIO is made by embedding CDIO based activities within selected individual courses, without interfering the existing OBE framework. For the selected courses, projects and case studies are conducted following CDIO process, i.e. conceive the problem, design the solution, implement the solution and operate the system. Active and experiential learning approaches are used as teaching and learning strategies in the CDIO projects and case studies. Faculty lecturers encourage students' active participation in the CDIO projects where students go through the CDIO process while achieving OBE outcomes. A CDIO-aligned capstone project is incorporated in the CDIO framework, where students are required to design a civil engineering project. To ensure that the CDIO framework is implemented accordingly, the faculty lecturers attended workshops on active learning, CDIO methodology and how to align CDIO activities with OBE learning outcomes. Industry partners are invited to contribute real-world challenges for the projects and participate as panellists for the capstone, offering insights into the implementation of the CDIO framework and providing constructive feedback.

Development of CDIO Framework for Diploma in Civil Engineering Program

In designing a CDIO framework for the diploma in civil engineering program, the CDIO Standard 5 (i.e., Design-Implement Experiences) is implemented. The CDIO Standard 5 emphasizes on introducing design-implement projects and activities at the early semesters of the program and the complexity of the projects and activities increases as students' progress to higher semesters. This allows students to develop their knowledge and skills progressively. The main CDIO projects in the Diploma in Civil Engineering Program is listed in Table 1.

Table 1: Main Projects in Diploma in Civil Engineering Program

Course	Stage	Project Description	Teaching Methodology
Introduction to Civil Engineering	Year 1, Semester 1	Students propose a township with various township systems, focused on sustainability and energy efficiency aspects.	Experiential learning
Civil Engineering Drawing	Year 1, Semester 1	Students are tasked to select a suitable architectural drawing for a reinforced concrete building and convert it into a structural key plan using the foundational knowledge acquired in the course.	Active learning

Solid Mechanics	Year 1, Semester 2	Students utilize the project from the Civil Engineering Drawing course to determine the beam types (such as simply supported beam or continuous beam) based on the prior structural key plan. Additionally, they will create a free body diagram for a simply supported beam and analyse the forces of the beam.	Active learning
Fluid Mechanics	Year 2, Semester 3	Students refer to the cornerstone project and apply suitable concept if the building is moved from land to sea or river. Based on new knowledge in this course, student will design foundation of the building in ensuring the building is stable and floating.	Experiential learning
Surveying	Year 2, Semester 3	Students learn to calculate soil volume based on given soil cross sections and longitudinal sections.	Active learning
Basic Structural Analysis	Year 2, Semester 3	Students apply the same project from Solid Mechanics and amend their structural layout using newly acquired knowledge from the course. The intended task involves conceptualizing the continuous beams and analyse continuous beam using structural analysis methods learned in the course.	Active learning
Project And Construction Management	Year 2, Semester 4	Students suggest suitable activities and work progress for a construction project, and then work out a construction plan and schedule using Microsoft project.	Active learning
Structural Concrete and Steel Design	Year 2, Semester 4	Students learn reinforced concrete design of structural elements based on Eurocode Standards.	Active learning
Soil Engineering	Year 3, Semester 5	Students learn to calculate soil bearing capacity based on given soil investigation report.	Active learning

Civil Engineering Design Project	Year 3, Semester 5	Students work on a construction project for 2 storey reinforced concrete building that integrate prior knowledge in courses from year 1 until year 3.	Experiential learning

Pedagogical Foundations in CDIO Framework

The pedagogical foundations in the CDIO framework includes active learning and experiential learning approaches. Active learning allows students to actively participate in the learning process through project-based learning, problem-based learning and flipped classroom. Experiential learning involves learning through experience, allowing students to gain knowledge and practical skills through hands-on activities such as field studies and design-implement projects. The framework is designed in a way that students have a continuity of learning knowledge from lower semesters courses to execute and design the capstone project.

Progression of knowledge in CDIO Framework

The CDIO framework is structured to ensure a continuous progression of knowledge from the lower semesters to the higher semesters via interlinking of the program as shown in Figure 1. In the first semester, students are introduced to the CDIO approach, construction materials (ECM256) and importance of sustainability and renewal sources in civil engineering in the Introduction to Civil Engineering (ECM157) course. In this course, students are given a project to propose a township incorporating sustainability and energy efficiency considerations. In the same semester, students learn drawing skills by drawing architecture and structural drawings with AutoCAD software. Students are required to draw a structural key plan for an architecture drawing of a simple reinforced concrete building. In the second semester, students learn to analyse forces of a simply supported beam in the Solid Mechanics (ECS226) course. Students are asked to refer to their structural key plans from the cornerstone project and identify whether the beams are simply supported or continuous. They will create a free body diagram for a chosen simply supported beam and analyse the forces for the beam using the knowledge learnt from the Solid Mechanics course.

In semester three (3), students learn buoyancy concept in the Fluid Mechanics (ECW231) course. The CDIO project given is to design for the foundation for the prior cornerstone project by applying buoyancy concept. In this project, students will create a model of the building foundation if the building is to be constructed on the sea water using the CDIO approach. The project allows students to brainstorm and propose a suitable shape of a floating building foundation. At the same semester, students learn survey skills and calculate soil volume based on given cross sections and longitudinal soil sections in the Surveying (ECG345) course. Apart from that, students also learn analysis of continuous beam and frame in the Basic Structural Analysis (ECS268) course. In this course, students do active learning in identifying continuous beams of a real building (Figure 2). At the same semester, students are required to participate in CDIO competitions such as tower design and bridge design competition (Figure 3). In the fourth semester, students learn project scheduling in the Project and Construction Management (ECM366) course. In this course, students are asked to propose suitable construction activities and submit a project plan and schedule using Microsoft Project software. In the same semester, students learn reinforced concrete design according to Eurocode 2 in the Structural Concrete and Steel Design (ECS338) course, where students learn the design procedures to design the reinforcements for reinforced concrete beam, slab, column and pad footing.

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In semester five (5), students learn how to calculate soil bearing capacity from soil investigation reports in the Soil Engineering (ECG344) course. In the same semester, students are given a capstone project in the Civil Engineering Design Project (ECS358) course. In the capstone project, students will apply the skills and knowledge learned from the previous semesters to complete a project incorporating design of reinforced concrete elements, project scheduling, structural modelling and project costing.

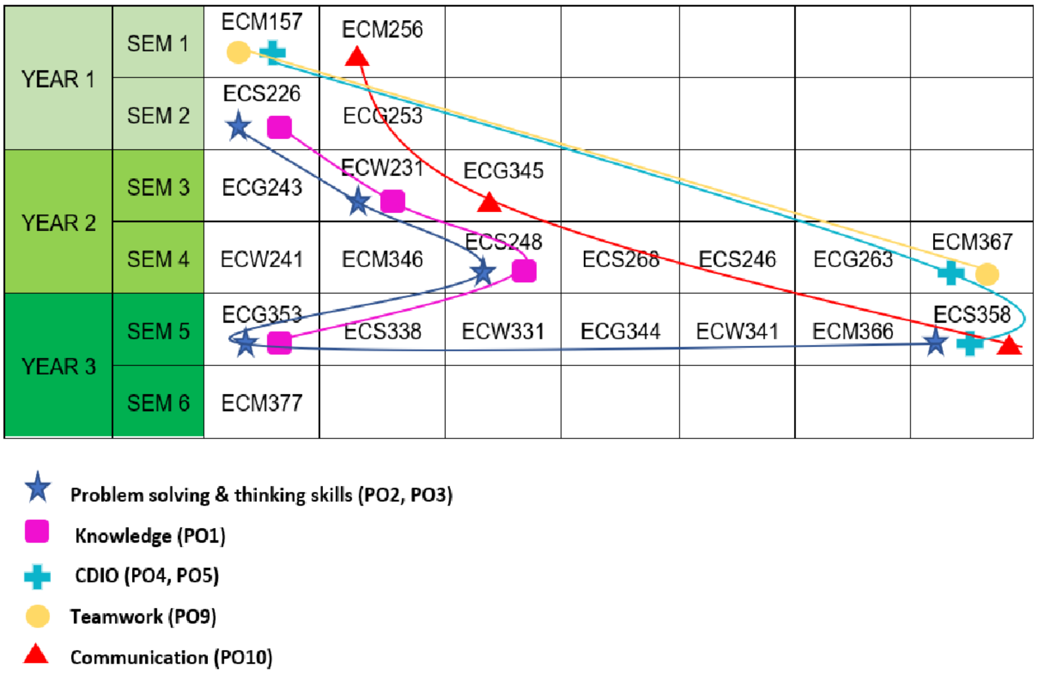

Figure 1: Interlinking CDIO Course

Figure 2: Students Identifying Continuous Beam (Active Learning)

Figure 3: Photos From CDIO Competitions

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Capstone Project

The capstone project utilizes the design-implement approach, requiring students to obtain architectural drawings for a two-story reinforced concrete building that complies with Uniform Building By-Laws (UBBL) standards. Students are tasked with performing structural design for selected building components, presenting their findings, and producing a technical report that addresses construction feasibility, sustainability, and cost-effective design. Students are required to implement a comprehensive CDIO approach in the capstone project as follows:

1) **Conceive Stage**: Students start by defining the problem statement and stakeholders. After gathering stakeholder requirements, which encompass local authority by-laws and design standards, they will search for a set of architecture drawings for a double storey reinforced concrete building that fulfils the stakeholder requirements. The architectural drawings must provide comprehensive information, including floor plans, elevations, sections, and detailed descriptions of the roof, floors, staircases, and partition dimensions and materials. Students will decide appropriate construction materials for their building by specifying the grades of concrete and reinforcements. They then consolidate all gathered information and design parameters into the introductory section of their report.

2) **Design Stage**: Students develop structural plans for the building, detailing the placement of slabs, beams, and columns on each floor. They assess permanent and variable loads on these components, estimate initial dimensions, calculate forces, conduct structural analysis, and perform design calculations according to Eurocode 2 design standard.

3) **Implement Stage**: Students utilize design software such as Prokon and Esteem to create a structural model of their building. They iteratively adjust sizes of structural elements and reinforcements to address issues flagged by the software, optimizing the design to make sure that their design is cost effective, energy efficient and design compliance. Figure 4 shows a 3D generated building model and a 3D beam with moment and shear reinforcements from Esteem and Prokon design software respectively. The design software provides better visuality of the building layout and steel arrangement in the structural elements and helps students to have better understanding of the building structure.

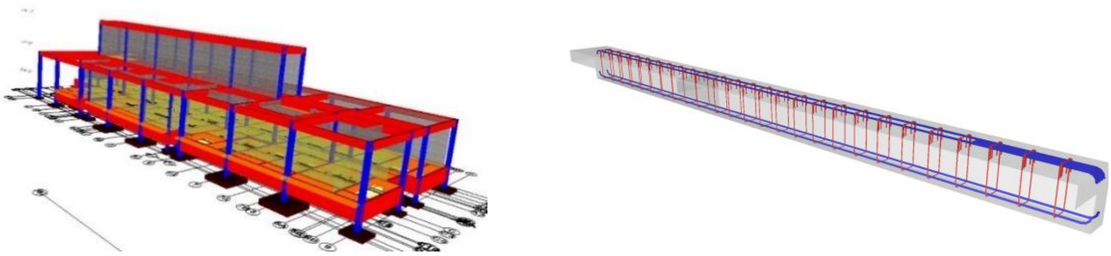

Figure 4: 3D Figures from Design Software

4) **Operate Stage**: The finalized design parameters, element sizes, reinforcements and structural plans are used to generate detailed construction drawings. Students organize

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construction phases, develop schedules using Microsoft Project, and prepare budgets for the project. They compile their work into a report and present their findings to industry panels at the end of the semester. Figure 5 shows a student presenting to industry and faculty panels.

Figure 5: A Student Presenting Project Findings to Panels

Results and Discussion

In the capstone project, students were assessed using evaluation rubrics. Evaluation of students' presentation and technical reports are based on problem solving, investigation skills and communication skills in completing and presenting the project. Feedback from students and industry panels were gathered to emphasize the benefits of the project implementation and identify areas for future enhancement. Industry panels unanimously endorsed the project's implementation, expressing satisfaction with the students' engagement in understanding building by-laws and using relevant software in the project. This exposure is expected to greatly improve students' proficiency in essential practical skills required by the industry. The participation of industry panels provides students with additional industry exposure and valuable experience sharing. Additionally, students conveyed enthusiasm about the opportunity to use design software in the project. The 3D rendered drawings generated from the design software provided invaluable practical experience, aiding them in visualizing the structural framework of the building and the placement of reinforcements within the structural elements. The average attainment of 60 students for problem solving, investigation and communication learning outcomes in the October 2023 – February 2024 academic semester are 77%, 62% and 71% respectively. The average attainment of students' learning outcomes are depicted in Figure 6. Average students' attainments for all learning outcomes achieve the minimum attainment of 50%, indicating that students can conduct necessary investigation to carry out the project, provide a solution that fulfils construction feasibility, sustainability, and cost-effective design, and present their findings both orally and in writing.

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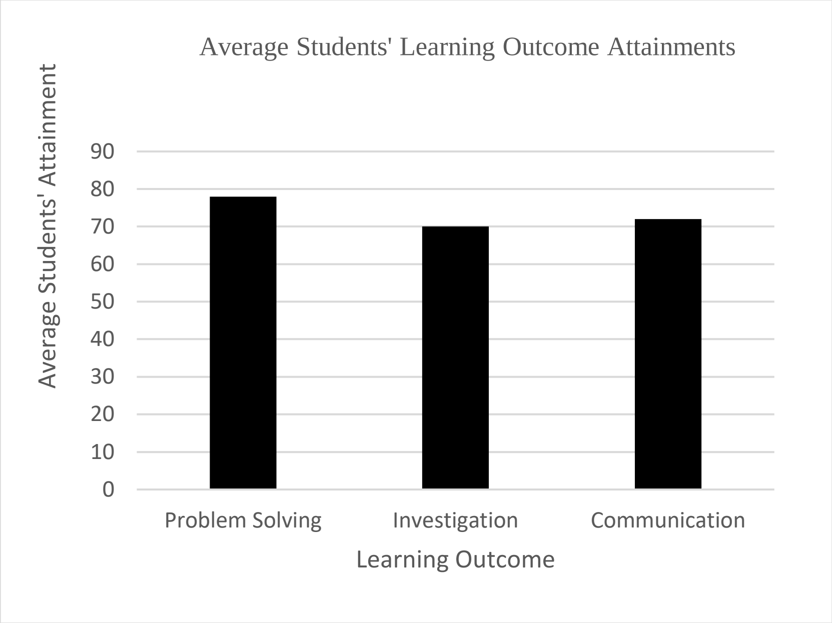

Figure 6: Average Students' Learning Outcome Attainments for Capstone Project

Lecturers' feedback highlights that students demonstrate greater capability and confidence in completing their capstone projects, having acquired essential skills in earlier semesters, particularly in identifying structural components of buildings and using software like AutoCAD and Microsoft Project. The consistent development of knowledge and skills from lower to higher semesters effectively equips students for success in their capstone projects. The capstone project enables students to apply integrated learning by addressing stakeholder requirements, conducting structural analysis and design, assessing cost-effectiveness, and developing project schedules, as mentioned by the study by Tao et al. (2009). The project elevates students' abilities from single-skill proficiency to the application of multidisciplinary knowledge and skills, enhancing their understanding of the engineer's role and responsibilities within both engineering and societal contexts (Yang et al., 2012).

Conclusion and Recommendations

This paper outlines the CDIO framework for the Diploma in Civil Engineering Program at MARA University of Technology, where active and experiential learning projects are integrated into the lower semesters to progressively develop students' knowledge and skills, culminating in the capstone project assessment. Students can complete their projects with minimal supervision, demonstrating that the CDIO approach enhances their investigative and problem-solving skills. While it may not directly improve students' learning outcome attainments, it fosters a more student-centred approach to learning. The implementation of CDIO bridges the gap between theoretical knowledge and practical application by integrating hands-on learning, project-based activities, and real-world engineering challenges. Students are better prepared to apply their knowledge in practical scenarios, which enhances their technical and problem-solving skills. Graduates of a CDIO-based program are better equipped to enter the workforce, as they have been exposed to real-world engineering challenges and problem-solving scenarios. The implementation of CDIO aims to enhance students' learning experience by incorporating multidisciplinary and innovative approaches in projects. For future improvement, it is recommended to incorporate sustainability and smart building features to the CDIO projects in the framework.

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