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Editorial Brief

Editorial for ASEAN Journal of Engineering Education (AJEE)

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As the year draws to a close, we are thrilled to present the December 2024 edition of the ASEAN Journal of Engineering Education (AJEE), Volume 8, Issue 2. This issue is a testament to the diversity and depth of innovation shaping engineering education across the ASEAN region and beyond. Featuring 13 manuscripts, it encapsulates transformative ideas, research findings, and reflective practices aimed at advancing teaching methodologies, curriculum development, and technology integration in engineering education.

This edition begins with a focus on curriculum innovation and industry alignment. The opening paper investigates the application of Six Sigma's DMAIC methodology in refining TVET course syllabi in Pasir Gudang, Johor. This is complemented by a study from Indonesia, which highlights critical gaps between industrial engineering students' competencies and industry demands, urging institutions to reimagine curriculum design for better alignment with workforce expectations.

Technological advancements in engineering pedagogy emerge as another critical theme. Articles explore the potential of Google-based automation tools to streamline peer evaluations and attendance management, as well as the development of an Arduino-based photometer during the COVID-19 pandemic to enhance hands-on learning in resource-constrained environments. These contributions emphasize the role of accessible and innovative technology in fostering resilient and effective learning experiences.

The spotlight also falls on active and problem-based learning methodologies, with papers examining the impact of project-based learning on students' problem-solving abilities and the introduction of competency-based learning (CBL) in teaching thermodynamics. A reflective study provides a mid-program analysis of a chemical engineering undergraduate's learning journey, showcasing the significance of personalized educational experiences in shaping engineering identity.

Workshops and collaborative initiatives also feature prominently. A report on mechatronics workshops outlines strategies for equipping future engineers with multidisciplinary skills essential for addressing challenges in mobility, energy, and production engineering. Meanwhile, another study details the transformative potential of Technology-Enhanced Cooperative Problem-Based Learning (TE-CPBL) workshops in empowering educators to integrate student-centered approaches into their teaching.

Two insightful book reviews enrich this issue, shedding light on instructional scaffolding strategies and the evolving landscape of engineering education. Together, they underscore the necessity of adapting pedagogical frameworks to prepare students for complex global challenges.

Finally, this volume concludes with an evaluation of capstone design projects in chemical engineering, presenting evidence-based recommendations to enhance professional readiness and align academic outcomes with accreditation standards.

The research and perspectives showcased in this issue underscore the dynamism of engineering education as a field that is both forward-looking and deeply responsive to societal needs. As we look ahead to 2025, we invite educators, researchers, and practitioners to continue contributing to AJEE, fostering a vibrant discourse that bridges academia and industry.

We extend our deepest gratitude to our contributors, reviewers, and readers for their unwavering support in making AJEE a platform for advancing engineering education in the ASEAN region and beyond.

Assoc. Prof. Dr. Zaki Yamani Zakaria

Chief Editor,

ASEAN Journal of Engineering Education

Editorial Boards

Contents

Midpoint Reflection: Personalized Second- and Third-Year Experience of a Chemical Engineering Undergraduate

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Abstract
With ever-increasing worldwide challenges and the need for originality in their solutions, engineers from countless backgrounds are giving their full effort towards closing gaps and aiding sustainable development in almost every sector. Yet, during such times, it is also vital to not disregard another side of the engineering profession: the scholars pursuing and soon to complete their engineering education, training and degrees, most joining the workforce, where they too will be involved in the efforts aforementioned. In this circumstance, it becomes greatly important to view through a magnified "lens", the progress of students in their respective engineering and specific programs, which still lacks being often academically published for viewing by the larger populace. Interestingly, one such way is from hearing the students' perspective in the form of reflection, which is becoming more accessible via online channels in recent years. Similarly, this paper is an accumulation of the personalized Second and Third-Year experience, which together forms the middle year experience and midpoint reflection of a chemical engineering undergraduate. It briefly expresses personalized academic insights and lessons learnt from the student's viewpoint, by taking advantage of the available freedom of expressing the university learning process, where the Engineering Identity Development usually takes effect. Ultimately, this paper aims to give students a refreshed outlook, and more intently to those concentrating in engineering fields, on ways to explore their own interests and develop independent viewpoints, by pursuing their own reflective journeys and forms the framework for the paper to highlight the importance of reflective writing.

Keywords: Reflection, Second-Year Experience, Third-Year Experience, Engineering Identity, Engineering Education, Academic Learning, Undergraduate.

Introduction and Significance

Does reflection serve any significant purpose for the direct benefit of students during their higher-learning journeys at institutes globally? This paper aims to explore the importance of reflection and reflective writing as its main conceptual framework, primarily on the knowledge being gained and additionally on the engineering identity being developed by each individual scholar.

Chang (2019) suggests that by students conducting their own reflections, the part retaining information in our memory can be retrieved and expanded, to benefit lifelong learning from experience. Hence, this becomes even more significant for undergraduates in their second or third year of engineering degrees or programs, where the requirement of multidimensional thinking on various subject matters and fields can be stimulated further. Through reflecting, connections between pieces of information can be found, to better provide solutions to complex problems spread across the duration of their respective specializations and beyond.

Nevertheless, a challenge that exists is that a significant proportion of the population in most cases where task completion and work is involved, remain rather reluctant to reflect on their efforts and planning. Similarly, this transcends to students in higher-learning programs, efforts on their actions, academic or practical work and project completions for their courses are left not reflected upon.

A working paper by Harvard Business School (Di Stefano et al., 2023) carried out a series of studies, such as if the benefits of reflection were obvious, revealed that the "majority of participants decided to gain additional experience rather than take time to reflect on what they had learned from prior experience". This indicates that experiential learning is often preferred over reflective learning. Perhaps this was on a premise that participants were more inclined towards gaining additional experience as they believed it would lead to better performance and improvements as compared to engaging in direct articulation and contemplation. However, remarkably, results from the studies carried out showed the opposite effect, wherein participants asked to reflect on their past experiences showed to consistently outperform those opting towards additional practice.

In this manner, perhaps reflection also challenges university students to perceive their own actions and ethical dilemmas related to their academic pursuits, which could aid the better formation of a more developed and matured engineering identity. Such a scenario could be in the area of academic dishonesty, where preventive measures to directly deter any cheating by students may be ineffective in the long run as studied by Davis et al. (1992). Nevertheless, reflection by students on their own actions and methods towards learning or assessments could be a more effective approach to deterring ethical wrongdoings. Figure 1 shows just some of the benefits of reflecting, making it vital for the success of students in both "higher education and future professional practice" (Atira et al., 2019). Hence, the possibilities of applying reflection to daily life and academics are perhaps limitless.

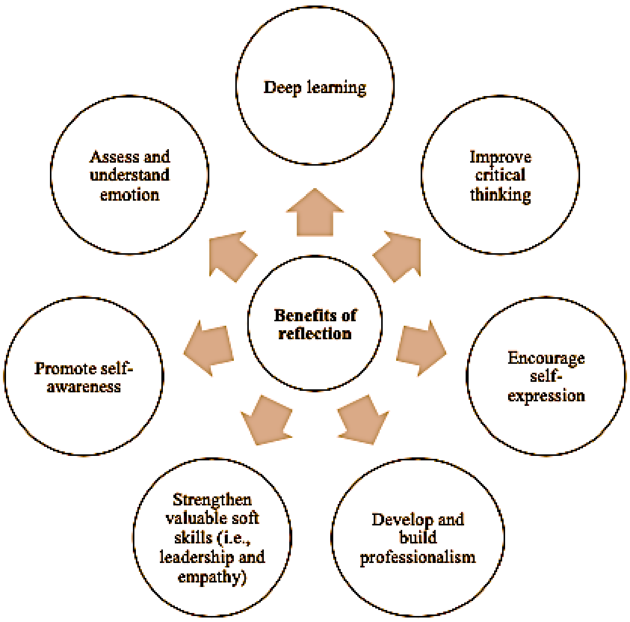

Figure 1: Benefits of reflection

Based on these trends and potential significance, this paper includes a brief, personalized reflection of my second- and third-year, which together forms the middle year experience and hence the midpoint reflection (Spence et al., 2022) in the Bachelor of Chemical Engineering (with Honours) program at the Faculty of Chemical & Energy Engineering (FCEE), Universiti Teknologi Malaysia (UTM). Overall, my journey over these semesters are described, meshed with different ideas from engineering education and other areas of both STEM and humanities, in order to give a brief sense and example of how reflections by undergraduate students may be crafted. Moreover, the paper aims to motivate students in higher-learning programs in order to shape their own engineering identity that best suits them through such reflections, and for the student to potentially excel in both their pursued subject, as well as diversify from it based on strengths and interests.

Methods

The fundamental method used for this paper is based on storytelling and lived experience of the author, via autoethnography (Ellis et al, 2010) combined with physical noting of experiences using reflective journals and notes (Zakaria et al., 2020) to obtain past information and articulations. As highlighted in the methodology of a past First-Year experience study (Ghoshal, 2022), written notes on experience throughout the semesters in the form of reflections as well as reflective writings were continually kept for use in future works such as this. To broadly represent the stages of the reflective writing process implemented, a model of the 4Rs as in Figure 2, aids in the understanding of the steps (Ryan & Ryan, 2012).

Level	Stage	Questions to get you started
1	**Reporting** and Responding	Report what happened or what the issue or incident involved. Why is it relevant? Respond to the incident or issue by making observations, expressing your opinion, or asking questions.
2	**Relating**	Relate or make a connection between the incident or issue and your own skills, professional experience, or discipline knowledge. Have I seen this before? Were the conditions the same or different? Do I have the skills and knowledge to deal with this? Explain.
3	**Reasoning**	Highlight in detail significant factors underlying the incident or issue. Explain and show why they are important to an understanding of the incident or issue. Refer to relevant theory and literature to support your reasoning. Consider different perspectives. How would a knowledgeable person perceive/handle this? What are the ethics involved?
4	**Reconstructing**	Reframe or reconstruct future practice or professional understanding. How would I deal with this next time? What might work and why? Are there different options? What might happen if...? Are my ideas supported by theory? Can I make changes to benefit others?

Figure 2: The 4Rs model of reflective thinking

This model was greatly instilled in the making of reflections for the use in describing my own experience for the Second and Third-Year of the engineering program as in this paper. Moreover, the concept of reporting by relating, reasoning and reconstructing made the reflection detailed and its filtering was, in turn required, to only highlight important parts and find connections to international studies and established concepts in the humanities and STEM fields. This meant only using reflections connected to feelings with limitation and focusing more on the overall development and knowledge gained (Zakaria, 2021). Hence, the Gibbs Reflective Cycle (Gibbs, 1988) was a concept also included in the methodology and framework, to better identify which parts of the reflective writing to use in the section it best suited. Figure 3 displays this cycle through 6 parts, adapted by the Western Sydney University School of Nursing and Midwifery (2016).

One common model is the **Gibbs Reflective Cycle**, which has 6 parts:

Describe	Describe what happened
Feelings	How did it make you feel?
Evaluate	What was good or bad?
Analyse	What sense can you make of the situation? (Include external issues)
Conclude	What general and specific conclusions can you draw?
Action	What next, or what will you do next time?

Figure 3: Gibbs Reflective Cycle

Findings and Discussion

Second Year Experience

The second year of my chemical engineering program was both demanding and stimulating. From the fundamentals of the first year, I encountered more advanced courses for the Second Year, first semester like thermodynamics and energy balance, as well as new conceptual subjects such as fluid mechanics, materials engineering and differential equations. Social science and language courses were also included, such as introduction to entrepreneurship and academic communication skills. Among these courses, the one that raised particular curiosity in me was materials engineering. For this course, I recall that the content was large but felt of great potential to me as I could visualize its direct applications across many scientific fields. For example, while going through lecture notes given to us for the materials science course, I could directly link it to the work being done at that time, breakthroughs in the field and stories shared by my physicist father from time to time.

The idea of a field that is perhaps never-ending, with continuous innovations in branches such biomaterials, nanomaterials and sustainable materials just intrigued me to delve into more news and research on the topic.

Whilst learning about the crystalline and different material structures in the course, I could also relate it to shapes, patterns and techniques used in the Japanese art of paper folding known as Origami, which is a regular hobby of mine since I was young. I was further excited on the correlation between materials engineering and origami and came across official research studies done by materials scientists, mathematicians, researchers as high as in the Soft Math Lab at Harvard University, and was completely mesmerized by the relations between the two, using mathematics as the common glue. In visualization, Figure 4 shows some of the beautiful figures on innovative studies done by such groups of researchers (Dias et al., 2012) and Figure 5 displays some of my own folded modular (multi-paper) origami that mirrors material structures possible to be synthesized in the lab from assorted chemicals and molecules which already exist in nature.

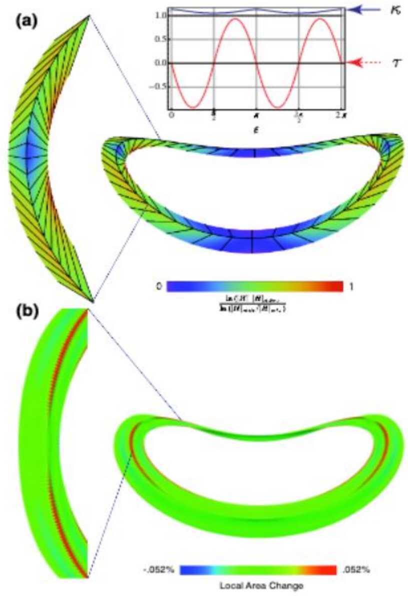

Figure 4: Simulated perturbative folds and curvatures

Figure 5: Modular origami pieces

Now that I reflect on that interest and the effort I gave towards finding more information on the course, I would advise future students to definitely pursue that curiosity for a subject that peaks their interest, but also to have a discipline of following through for other courses, in order to perform well across the semester which perhaps I myself slightly deterred from, for we are still students.

As for the second semester of Year 2, courses like electrical technology, chemical engineering thermodynamics, transport processes, numerical methods & optimization, fluid mechanics laboratory were the designated chemical engineering courses and were all of great value given their complex thinking and learning outcomes. Humanity and co-curriculum courses like appreciation of ethics & civilizations and table tennis were also part of the session and allowed to explore the nature of philosophical scenarios and questions while also helping me balance the workload with a healthy routine of sports and recreation. I was fortunate to have interesting lecturers for all the courses I had taken so far, up to my second year, who urged us to study beyond what was done inside the classroom and this really aided in learning and connecting dots as we discussed in groups or wandered to the internet for answers to our questions of curiosity and desire of knowledge. Figure 6 is an example of the equipment, in this case a refrigeration system during our thermodynamics laboratory, that raised so many questions which helped reach a better understanding of the working principles behind it, and its wider applications in industry and common life.

Figure 6: Lab refrigeration system in operation

Third Year Experience

In Year 3, for my first semester, I took courses like chemical reaction engineering, separation processes, pollution control engineering, occupational safety and health in industry, pollution control and reaction laboratory, analytical chemistry for engineering, analytical chemistry practical and science & technology thinking.

Looking back, I recall that I thoroughly enjoyed my time in all of these classes; however, my favorites among these courses seemed to be analytical chemistry and pollution control engineering. Both courses raised a level of enthusiasm in me that renewed my motivation to learn and focus on the tasks being assigned. For analytical chemistry, the concept behind the different techniques and instruments sparked my interest in its diverse applications.

My truly favorite moment was working on an individual assignment where we were tasked with finding a recent research article or breakthrough study on the application of analytical chemistry to environmental monitoring such as in analysis of amount of heavy metals present in freshwater sources. I could then directly link this subject matter to the pollution control engineering course, which looked at the treatment and monitoring of supply of water in treatment plants as one of its subtopics. In reflection, I can remember the moment I realized that most people are unware of the treatment process behind the water we use every day, and what a gift it is to find out about the inner workings of it all by being chemical engineering students. In recollection, I also realize that I was regularly one of the active students in these classes in terms of approaching the lecturers when I needed verification or affirmation on a concept. This was perhaps due to my enthusiasm and focused passion in the courses, which can equally be directed to other topics and modules by students wanting to find interest in a particular area of their program.

Another tool that can build on this confidence and interest is reflection itself, and aid in achieving the goals a student sets for him/herself, leading to a higher learning rate (Di Stefano et al., 2023). To present this aspect using further literature, Bandisatisan et al. (2019) also displayed through findings that most students lacked clear reflection of a large part of subject-content learnt and skills needed. Hence, the need to raise awareness on the importance of reflection via workshops, classes or training on reflective thinking may elevate their intellectual and conceptual thinking over the long-term, in order for them to contribute to society by surpassing their expected abilities.

Personally, reflection has helped in more ways than I can write about, and perhaps there are not enough pages to write on! Yet, by the end of the first semester of my third year, I had a somewhat good visual sense of the areas and fields I had grown interested in, as well as those that closely suited my interest, if I am to be successful as a student and engineering scholar. Nevertheless, a long road lies ahead in my own academic and reflective journey, and I shall stay optimistic for what is to come. Presently, I am in the second semester of my third year and remain hopeful to document and reflect on highlights of the one and half year which remains (including the required industrial training that would last around three months).

Conclusion

In summary, it appears that in both instilling knowledge via engineering education and in training the next generation of adaptable and versatile engineers, the student perspective would hold great potential and value for both educators and scholars. Furthermore, as the students would progress in academic or applied institutions, their personal insights would benefit learners and their direct educators, who wish to implement effective courses or programs for the future. Hence, this paper is a way of channeling the opportunity undergraduates and all other students have, towards formulating ways they can learn and gain the most out of their university life.

It is hoped that it eventually allows the creation of more dynamic and adaptable engineers who would pursue the path of a lifelong learner, with an ability to discover career paths both within and outside core engineering roles. Ultimately, such reflections and ones better to come, may serve the purpose of aligning effective learning methods, for future engineers to contribute their utmost, using the skills and caliber at their disposal.

Acknowledgement

The creation of this paper was greatly made possible by the ideas, inspiring words and continuous support given to me by the lecturers of the Faculty of Chemical & Energy Engineering (FCEE), Universiti Teknologi Malaysia (UTM). I would like to give my sincere and special thanks to Associate Professor Ir. Dr. Zaki Yamani Zakaria for his unrelenting motivation and optimistic guidance which allowed me to accumulate all the ideas for the paper. I am also deeply thankful for the knowledge and enlightenment instilled within me by my parents, family, and friends; whom have also kindly shared their own stories which continue to influence my own journey through studies and life. I am ultimately grateful to all the people I have crossed paths with, and who have left a positive mark or a memorable story for my use and contemplation.

Conflict of Interest

The author declares no conflict of interest.

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Workshop Development for New Frontier of Mechatronics for Mobility, Energy, and Production Engineering

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Abstract

Mechatronics is a multidisciplinary engineering field that integrates mechanics, electronics, control theory, computer science, communications, power, and production manufacturing, reflecting the trend toward deep cross-disciplinary collaboration. With applications in e-mobility, connected and autonomous vehicles (CAV), robotics, and unmanned aerial vehicles (UAV), the expanding mechatronics industry demands a workforce with broad, multidisciplinary training. This paper details the activities and outcomes of an NSF-funded ECR: PEER (EHR Core Research: Production Engineering Education and Research) project, which organized two workshops at Wayne State University (WSU) and California State University Long Beach (CSULB). These workshops aimed to gather insights from experts across academia, industry, and non-profit sectors to shape the future of mechatronics education and production. Over two days, professionals addressed challenges in workforce development for production engineering in mechatronics, covering educational pathways, advancements in teaching methods, and the social impacts of mechatronics technology. The workshops had distinct focuses: WSU concentrated on ground mobility technologies, while CSULB emphasized aerospace applications. A survey conducted at the end of the workshops evaluated their effectiveness, with the results informing future improvements in mechatronics workforce education.

Keywords: Mechatronics, Workforce development, Production Engineering, Workshop.

Introduction

Mechatronics is a multidisciplinary field of engineering that seamlessly integrates mechanics, electronics, control theory, computer science, telecommunications, power, and manufacturing production. The concept of convergence research [NSF 2017] emphasizes not only the inclusion of multiple disciplines but also their deep integration, forming new frameworks that catalyse scientific discovery and innovation. Mechatronics aligns perfectly with this trend of convergence engineering, facilitating deep cross-disciplinary integration. It is driven by the active pursuit of addressing specific societal challenges and opportunities. Developing a robust mechatronics industry requires a highly skilled workforce equipped with multidisciplinary knowledge and practical training.

This paper reports the outcomes of an NSF-funded project in USA aimed at advancing workforce development in mechatronics and its applications in production engineering through the organization of workshops. The project was a collaborative effort between two institutions: The Division of Engineering Technology at Wayne State University (WSU) and the Departments of Chemical Engineering and Mechanical & Aerospace Engineering at California State University, Long Beach (CSULB). The workshops explored educational systems and pathways for workforce development in mechatronics, including pedagogies, tools, and assessment methods; technological advancements in mechatronics; and the societal impacts, such as workforce diversity. A post-workshop survey was conducted to assess the effectiveness of these workshops.

Figure 1 illustrates the elements that comprise mechatronics, which includes knowledge from electrical/electronic engineering, mechanical engineering, control theory, and computer science. A mechatronics system is a complex device powered by electrical and/or mechanical sources, equipped with sensors that detect environmental changes. These sensors send signals to microcontrollers or computers through transducers, which then trigger actuators and mechanical parts to perform one or more tasks automatically using control theories. Mechatronics has wide-ranging applications, including automotive, aerospace, medical, manufacturing, defense, and consumer products. A cyber-physical system is a type of mechatronics system that is computer-controlled and tightly integrated with the internet, with its physical and software components deeply intertwined. In the automotive industry, the latest applications include electric vehicles (EV) and connected and autonomous vehicles (CAV). In manufacturing, robotics and smart factories are prominent, while in aerospace, drones, unmanned aerial vehicles (UAV), and advanced avionics are key applications.

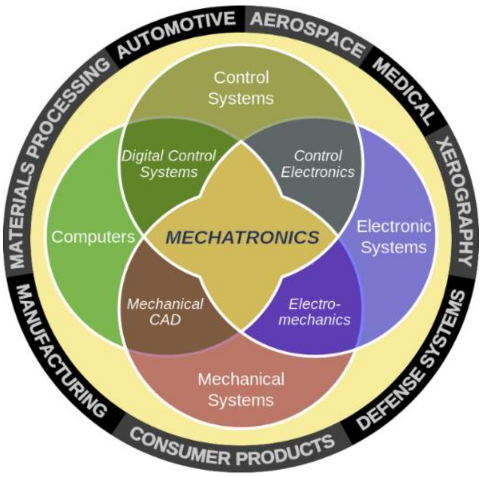

Figure 1. A Euler diagram by K. Craig from RPI's website describes the fields making up mechatronics.

The expanding mechatronics industry demands a high-quality workforce with multidisciplinary knowledge and training. This workforce can be sourced from recent graduates of colleges and universities or from workers displaced by automation and robotics in manufacturing. These displaced workers can re-enter the workforce through conventional pathways such as community colleges or through new pathways like industry-provided training programs, academic institutions, or other professional development organizations. The curricula at two-year colleges and four-year universities should be reviewed and updated to meet the emerging challenges of mechatronics in manufacturing. Graduate schools also play a crucial role in preparing higher-level workforces capable of conducting fundamental research and exploring new technologies in mechatronics. K-12 schools are vital in fostering the future workforce for all STEM areas. To effectively analyze workforce needs and organize educational resources, data and information from labor statistics agencies are essential. WSU and CSULB are gathering information from the Workforce Development Agency of Michigan [Michigan n.d.] and The State of California Labor & Workforce Development Agency (LWDA) [California n.d.]. WSU has a long-standing collaboration with the Workforce Intelligence Network for Southeast Michigan (WIN) [Workforce Intelligence Network n.d.] on workforce development in the greater Detroit area and consults the Michigan STEM education network [MiSTEM n.d.] for K-12 STEM education. Plans are in place to further collaborate with federal statistics agencies to collect longitudinal data on factors influencing career pathways, particularly for women, underrepresented minorities, veterans, and individuals with disabilities.

The advancement of mechatronics technologies has also enhanced the tools used to teach the subject. In recent years, affordable microcontrollers, along with peripherals such as sensors and actuators, have become popular in STEM education. Devices like Arduinos, Raspberry Pi, and LEGO controllers enable students to create projects by wiring electrical devices and writing code to control them [Mynderse & Shelton 2014, Reck & Sreenivas 2016]. These microcontrollers are cost-effective yet perform industry-level functions, making them suitable for prototyping or even commercial products. With wireless communication modules, these devices can be integrated with smart systems and controlled via apps, facilitating the development of advanced systems such as cyber-physical systems and the Internet of Things (IoT). The proliferation of desktop 3D printers - another example of mechatronic systems - has further simplified the creation of customized parts for building other mechatronic systems. In the workshops, WSU and CSULB collaborated with educational tool suppliers such as Quanser [Quanser n.d.]. Additionally, virtual reality (VR) has emerged as a promising technology in STEM education and workforce training, providing a platform for remote education. Various pioneers have explored the use of extended reality (XR) in teaching [Hafner et al. 2013, Piguet et al. 2001, Müller & Ferreira 2003] and professional training, including initiatives by Bosch [Bosch Media Service 2018].

Supported by the NSF ECR: PEER program and the Boeing Company, two workshops were organized to discuss the educational systems and pathways for workforce development in mechatronics; pedagogies, tools, and assessment methods for learning; technological progress in mechatronics; and societal impacts, such as workforce diversity. The first workshop was held on September 16-17, 2021, in the Detroit, Michigan area, organized by the WSU team. The second workshop took place on September 17-18, 2021, in Long Beach, California, organized by the CSULB team. Each workshop spanned two days, covering topics such as the current workforce situation in the industry, existing pathways for workforce development, traditional college and university training programs, and K-12 STEM education preparation in mechatronics. The workshop themes varied slightly based on the regional focus of the two institutions. In Detroit, the discussions centered around mechatronics technologies for alternative energy and ground mobility, reflecting Detroit's status as the hub of the automotive industry and its supply chain. In Long Beach, the focus was on aerospace, alternative energy, and related applications. The preparation for these workshops was presented at the 2020 ASEE conference [Chen et al. 2020]. This paper presents the motivation, vision, and outcomes of these workshops. The agendas included the speakers, their affiliations, and presentation titles. The survey results were analyzed and discussed to evaluate the effectiveness of the workshops, with lessons learned to be applied to future similar activities.

Background and Motivation

The primary motivation to conduct the workshop was based on the need to understand and bridge the gaps between education and industry related to the preparation of the workforce [Alboaouh 2018]. Several studies have shown that there is a significant disconnect between the educational outcomes of university and college programs and the needs of the industry [Bucak 2007, Brunhaver 2017]. This disconnect has been identified by both industry as well as professional organizations as a significant barrier to ensuring competitiveness in the marketplace [Siemens 2024, National Academies of Engineering 2019, Barton 2023, Sellery 2024]. The skills that industries expect from practicing engineers are not taught in typical undergraduate and graduate programs [Trevelyan 2019, Bilgin 2023]. Some of this is related to the rapid evolution of technology within the industry which is not matched by the evolution of the academic programs [Li 2023]. This is especially true in interdisciplinary STEM areas such as Mechatronics where the rapid evolution in AI, materials and electronics has provided an opportunity for development of novel automated systems. However, the students in traditional STEM degree programs may not be prepared to design or analyze these systems when they join the workforce. One of the solutions that has been proposed is to bring together personnel from industry and academia to identify and bridge these training gaps [Zeidan 2020]. This has been accomplished using several mechanisms including surveys [Fletcher 2017] and workshops [MIT 2021]. Our goal was to conduct the workshop specifically to address the gaps in the interdisciplinary field of mechatronics education.

Mechatronics and Workforce Development

Mechatronics is both a multidisciplinary and interdisciplinary science [Habib 2007] that integrates knowledge from fields such as electronics, mechanics, control theory, robotics, computer science, and even biomedical and chemical engineering. Typically, a mechatronics system involves the automation of electrical and mechanical devices to perform specific tasks. The demand for more complex tasks drives the development of new mechatronics technologies, which, in turn, inspire innovative applications. Traditionally, workforces in the production industry only needed expertise in a specific area of their training. However, as manufacturing systems become increasingly complex due to the integration of mechatronics technologies, workers now face the challenge of communicating effectively with colleagues across different disciplines.

Most of today’s workforce has been educated through conventional systems, starting at two-year colleges, progressing to four-year universities, and, for some, continuing to graduate schools. These educational paths typically begin with fundamental STEM courses (mathematics, physics, and chemistry) before focusing on specialized courses in particular professional fields. This approach often leaves little room for incorporating multidisciplinary topics into the curriculum. There is a critical need to emphasize and address interdisciplinary approaches in engineering education [Allen 2006]. The lack of interdisciplinary education and its importance to workforce development have been highlighted by [Mayer-Krahmer 1997]. Mechatronic innovations are often stimulated by an integrated discipline approach [Cintra Faria & Barbalho 2023], and the full potential of interdisciplinary solutions results from bridging the gap between product technologies and engineering disciplines [Mayer-Krahmer 1997, Wikander & Torngren 1998].

To enhance college-level mechatronics workforce education, two approaches can be adopted: First, creating new pathways outside traditional schools, such as training programs provided by industries and social service organizations, which focus on practical, hands-on training. Second, reforming the curricula in conventional schools to incorporate interdisciplinary learning, aligning with the current needs of the mechatronics workforce. Integrating STEM education into K-12 education to develop a STEM-capable workforce has already been explored [Honey et al. 2014]. Mechatronics is a crucial component in preparing K-12 students for STEM careers, necessitating the development of new teaching methods and additional resources for both students and teachers. Ultimately, the design of education and workforce development pathways must align with industry needs, which was a central theme in the workshops.

In addition to modifying and integrating educational systems and strengthening the relationship between schools and industries for STEM workforce development, it is essential to address the technical elements used in both introducing the latest mechatronics technologies and in teaching methodologies and tools. During the workshops, industry professionals revealed current challenges and future trends in both the markets and technologies of mechatronics, while university faculty and researchers introduced the latest inventions and research in the field. Faculty members from engineering education programs at colleges and universities, along with K-12 teachers, shared their experiences and ideas for new teaching methods and tools, particularly those involving innovative technologies like apps, design software, microcontrollers, and virtual reality. Furthermore, experts discussed the social and economic impacts associated with the development of mechatronics technologies and the growing workforce in the production industries.

Workshop Goal and Objectives

The objectives of the workshop on STEM workforce development in mechatronics for production engineering can be summarized into two key areas: workforce analysis and training methodologies, and technology development and its impacts. The planned topics related to workforce education included:

- New providers and pathways of education and training.
- Inquiring the needs of industry employers.
- Examining college and graduate level education and their impacts on STEM workforce readiness.
- Prepare K-12 education for the farther future workforce needs.

The themes for targeting new and prospective mechatronics technology developments are:

- The trend of mechatronics applications
- New research and technologies in mechatronics
- New education technologies for mechatronics
- Social impacts of new mechatronic technologies

Workshop Organization

Advisory Committee

The successful development and implementation of all proposed activities necessitates a coordinated system for the exchange of information and resources, as well as the effective utilization of institutional strengths. To achieve this, collaboration among faculty, administrators, and industrial partners from both institutions was formalized through the establishment of an advisory committee. Members of the Joint Industry Advisory Boards from both institutions, particularly those from industry, were invited to serve on and advise the committee. The committee members met regularly via online meetings and teleconferences to plan, execute, and monitor the project progress.

Schedule and Location

Two workshops were organized to support mechatronics workforce development in production manufacturing. These workshops targeted university and college faculty, K-12 teachers, graduate students, and researchers in mechatronics-related fields, as well as technical, administrative, professional development, and human resource personnel from industry. The first workshop, managed by the WSU team, took place in the Detroit area and focused on mechatronics applications in ground mobility and alternative energy. The second workshop, managed by the CSULB team, was held in the Long Beach area and centered on mechatronics applications in aerospace. Each workshop spanned two days: the first day concentrated on mechatronics workforce education systems and pedagogies, while the second day was dedicated to current and emerging mechatronics developments and technologies that can be applied to workforce education. The workshops were recorded and live-streamed to the general public via YouTube and other social media platforms. During the Q&A sessions, the live stream was converted into a webinar format to enable in-depth interactions between local and remote participants. The workshop schedule and topics are shown in Table 1 and Table 2, respectively, where the details can be found at [ECR Workshop, 2021].

Workshop Evaluations

An online survey using the Quatrics software on both university websites was given to the participants to evaluate the workshop. The survey had three main categories, regarding the participants' backgrounds (question 1 and 2), their opinions to the workshop setups (question 3 and 4), and their evaluations of the workshop effectiveness (questions 5 - 8). There were a few sub-questions using the five-point Likert scale with 5 being Strongly Agree and 1 being Strongly Disagree [Spooren et al. 2007].

Question 1 investigated the current jobs/positions the participants were. We found the results basically included all the targeted groups. Although there was no industry professional checked in the WSU survey, we believe the two "others" can be counted in this catalog. One of the "others" of CSULB was a CSULB College of Engineering staff member. Question 2 explored the professional specializations of the participants. The CSULB result was very diverse, while the backgrounds of the WSU participants were more concentrated in the electrical and mechanical areas. The 11 CSULB aerospace background and the 2 WSU automotive background participants demonstrated the targeted groups based on the workshop themes. The questions and the results are listed in Table 3.

Table 1. The two-day workshop agenda of WSU[1]

Session Title	Affiliation
Accelerated Mechatronics Program	Macomb Community College
Mechatronics and Model Based Development for EV's and ADAS applications	Siemens Digital Industries Software Engineering & Consulting Services
Modular Educational Certification for Advancing Training Online through Industry Collaboration (MECHATRONIC)	Oregon State University
Online Session: Mechatronics Education Tools	Quanser
Apprenticeship overview Baker College Training Business/Company view Panel Discussion	Mega Session Michigan Department of Labor and Economic Opportunity
Inspiring Tomorrow's STEM Workforce through Project-based Learning	Michigan Square One Education Network
Smart Sensors for Mobility Energy and Production Applications	University of Alabama

Table 2. The two-day workshop agenda of CSULB[1]

Session Title	Affiliation
Multidisciplinary Environment for Research and Education on Increased Autonomy of UAVs	Department of Aerospace Engineering, UAV Lab Director, Cal Poly Pomona
Mechatronics for Automated Test Equipment Development	Boeing Defense Systems
The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) Integration and Test Campaign	JPL MOXIE
Starting High School Students on the Path to Careers in STEM	Sato Academy of Mathematics and Science
A Taxonomy of Modern Mechatronics: Classification and Dissection of Autonomous Electromechanical Systems for Scaffolded Skills-Based	Quanser
Learning Experiences, Mechatronic Systems Design – A Pedagogy	California State University, Long Beach
A Journey in Curiosity: The Lego Pieces of an Engineering Career	Northrop Grumman Corporation
Continuously Evolving Mechatronics Education Challenges for GNC, Mechatronics and Autonomy	The Aerospace Corporation
Exploring the CAVE Collaborative Autonomous Vehicle Ecosystem	The Aerospace Corporation
Talent Development for Workforce of the Future through Skill-based Training	Cypress College

Table 3. Question 1 and 2 and the response frequencies of WSU and CSULB.

Question 1. Are you a:							
	4y university faculty	2y college faculty	K-12 teacher	4y university student	2y college student	Industry professional	Other
WSU	2	1	1	9	3	0	2
CSULB	6	1	1	22	5	2	1

Question 2. Please indicate your top area of specialization using the list below:										
	Electrical	Mechanical	Computer	Control	Robotics	Chemical	Automotive	Aerospace	Biomedical	Other
WSU	9	2	0	0	1	0	2	0	1	3
CSULB	5	12	6	1	1	1	0	11	0	1

[1] See the full schedule in [ECR Workshop, 2021].

Question 3 asked about the length of the workshop. All of the WSU participants and most of the CSULB participants thought they had right lengths. Question 4 found that most of the participants of both WSU and CSULB felt the workshops had intermediate level of topics and materials. The questions and the results are listed in Table 4.

Table 1. Question 3 and 4 and the response frequencies of WSU and CSULB.

Question 3. Given the topic, was this workshop:			
	Too short	Right length	Too long
WSU	0	18	0
CSULB	1	28	9
Question 4. In your opinion, was this workshop:			
	Introductory	Intermediate	Advanced
WSU	6	10	2
CSULB	9	26	3

The detailed descriptions of Question 5 to 7 are listed in Table 5. Question 5 inquired the workshop contents and materials. Both WSU and CSULB obtained generally good feedbacks (means larger than 4). Only the item "The content was as described in publicity materials" of CSULB survey had a lower score. Question 6 showed the ratings for the speakers. Both WSU and CSULB obtained generally good feedbacks (means larger than 4). Question 7 was for the ratings for attending the workshop. Again, both WSU and CSULB obtained generally good feedbacks (means larger than 4). However, for the item "The workshop was applicable to my job.", both surveys showed lower scores compared with other items in this question. It suggested a potential improvement can be made in the future.

Table 5. The questions 5 to 7 and their sub-questions.

Question 5. Please indicate your ratings for the workshop content:	
5.1	The content was as described in publicity materials.
5.2	The content followed the learning objectives.
5.3	The talks were given in a way that helped me learn.
5.4	The talks were given at an acceptable pace.
5.5	The slides contained sufficient technical information.
Question 6. Please indicate your ratings for the speakers:	
6.1	The speakers are knowledgeable on the topics.
6.2	The speakers stated the learning objectives clearly.
6.3	The speakers presented in an organized manner.
6.4	The speakers encouraged interactions and questions.
Question 7. Please indicate your ratings for attending this workshop	
7.1	My expectations for attending the workshop were met.
7.2	The workshop was applicable to my job.
7.3	I would recommend this workshop to others.
7.4	I would be interested in attending a follow-up, more advanced workshop on this same subject.

Question 8 queried about the hardware and facilities of the workshops (visual, acoustic, in-person, and online), 1 to 5 scales for satisfactions levels (Table 6). The WSU results showed high means (larger than 4) for all the four factors but with also high standard deviations (three larger than 1). The in-person setup and acoustic effects of the CSULB workshop had lower means (below 4), which can be improved in the future for similar activities. All other comments were in Question 9. The means and standard deviations (SD) of the Question 5 to 8 responses are listed in Table 7 and graphically presented in Figure 2. The statistics analysis is based on the full sample spaces from both institutes, for the smaller participant numbers due to COVID-19 restrictions.

Table 2. Questions 8 and the sub-questions.

Question 8 - Please indicate your overall rating for the workshop:	
8.1	Visuals
8.2	Acoustics
8.3	Meeting venue (In-person attendance)
8.4	Webinar (Online attendance)

The Likert scale responses from WSU generally show higher means and lower SDs compared to those from CSULB for most questions, reflecting CSULB's larger participant pool and more diverse areas of specialization (from Question 2).

Table 7. The means and SDs of questions 5 to 8.

Questions	**WSU**		**CSULB**	
	Mean	**SD**	**Mean**	**SD**
5.1	4.39	0.68	3.86	1.16
5.2	4.47	0.70	4.08	0.95
5.3	4.39	0.89	4.14	0.98
5.4	4.59	0.77	4.25	0.83
5.5	4.50	0.83	4.22	0.95

6.1	4.67	0.94	4.71	0.81
6.2	4.39	1.01	4.26	0.87
6.3	4.56	0.96	4.31	0.85
6.4	4.61	0.95	4.09	1.16
7.1	4.17	1.07	4.23	0.99
7.2	4.11	0.94	4.17	1.03
7.3	4.44	1.01	3.80	1.09
7.4	4.33	1.11	4.06	1.04
8.1	4.39	1.01	4.29	0.78
8.2	4.28	1.04	3.80	0.98
8.3	4.44	1.07	3.32	1.54
8.4	4.53	0.72	4.33	0.80

Critical Reflection Discussion

A lower score in the CSULB survey for Question 5.1 suggests that managing participant expectations through clear communication could improve satisfaction. Future workshops could ensure consistency between advertised objectives and actual content to enhance perceived relevance.

Ratings for Question 7.1 were notably lower across both locations, indicating a gap between the content provided and the practical needs of attendees. This suggests an opportunity to incorporate more job-specific case studies or hands-on sessions tailored to specific industries, making the workshop content more directly relevant to participants' work.

Most participants felt the workshop length was appropriate, and the content was at an intermediate level (Questions 3 & 4). This balance suggests that the workshops successfully catered to a mid-level understanding of mechatronics topics. However, to meet the needs of those seeking either introductory or advanced content, future iterations could consider offering parallel sessions at varying complexity levels, providing a more customized learning experience for diverse participant needs.

Workshop Impacts

Network Building

Oregon State University, also an ECR program awardee in Mechatronics, was invited to share their experience in developing and deploying an online mechatronics certificate curriculum. Both WSU and CSULB established connections with community colleges, laying plans for future collaborations on workforce training and student transfer programs in mechatronics. Additionally, the Michigan Department of Labor and Economic Opportunity outlined state-supported educational and industry resources available for advancing mechatronics. Participants also had valuable opportunities to engage directly with industry representatives to discuss career paths and explore potential job opportunities in the field.

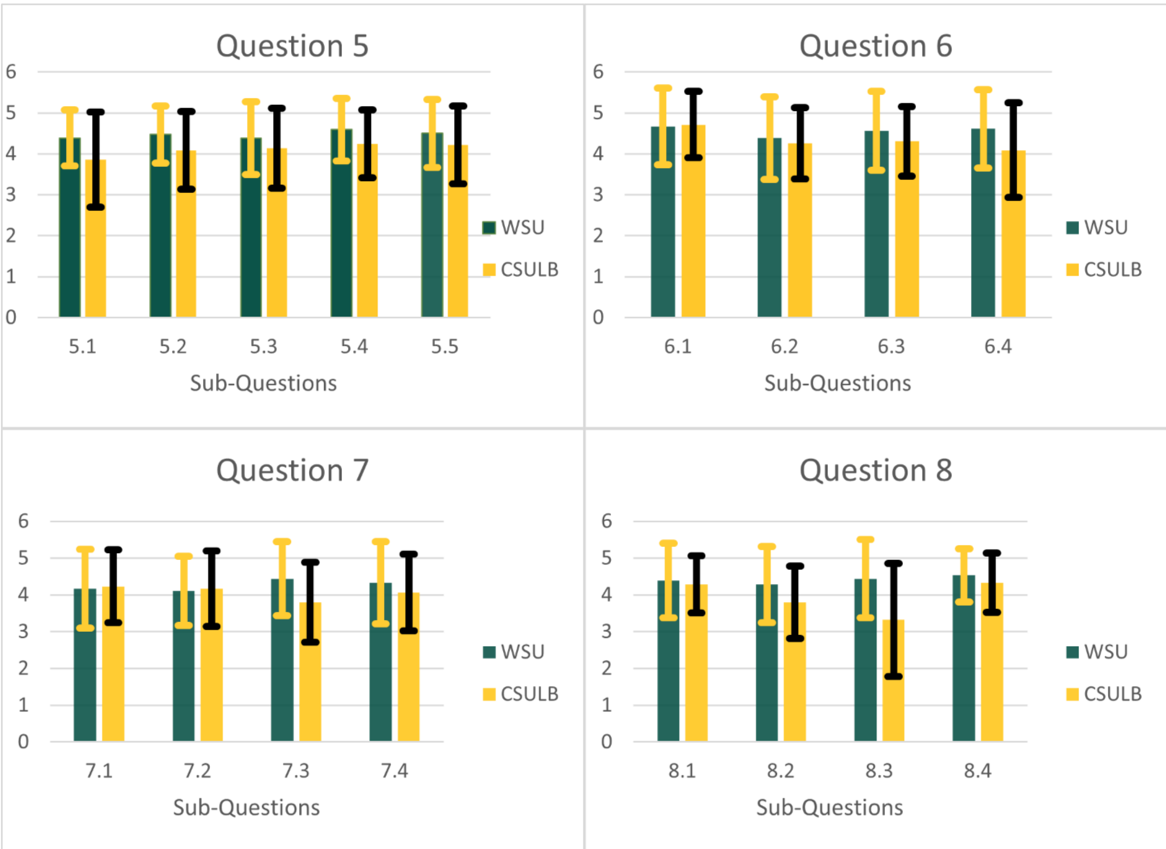

Figure 2. The means and standard deviations of the Question 5 to 8 responses.

Advanced Knowledge in Mechatronics

The industry leaders, including Siemens, Boeing, Northrop Grumman, and The Aerospace Corporation, presented the latest advancements in mechatronics technologies, offering participants valuable insights into current industry developments. Quanser also introduced their educational tools for mechatronics, which hold significant potential for use in mechatronics courses.

Mechatronics Course Development and Updates

The knowledge and materials presented during the workshops have informed and enhanced curriculum development at both institutions. For instance, new materials are incorporated into the course of ET 5100 Fundamentals of Mechatronics and Industrial Applications on sensors, controllers, and electric and automotive vehicle technologies at WSU, and MAE 476 Mechanical Control System I at CSULB. Additionally, some laboratory equipment was upgraded to align with the latest industry standards discussed during the workshops.

Conclusion

This project recognized an emerging and imminent need for workforce with skills in mechatronics technology for production engineering and manufacturing. High-quality workforces serving knowledge-intensive jobs provided by the innovative enterprises that lead to discovery and new technology are the assurance of the U.S. economy and American people's living standard. Mechatronics is one of the significant technologies that change and impact the future living style, community and society, and economics. The most current and popular applications of mechatronics include e-mobility, connected and autonomous vehicles (CAV), robotics, and unmanned aerial vehicle (UAV). The growing mechatronics industries demand high quality workforces with multidiscipline knowledge and training. Wayne State University (WSU) and California State University Long Beach (CSULB) were funded an ECR: PEER (EHR Core Research: Production Engineering Education and Research) project from NSF to organize two workshops to address this issue of workforce development in mechatronics.

We present in this paper our efforts and results of these two workshops. The workshops took two days, with professionals invited to address the current challenges of workforce development in mechatronics for production engineering. The topics include education opportunities and pathways, technical development of teaching methods and tools, as well as social impacts related to mechatronics technology. The workshop themes were partially different based on the expertise and locations of the two institutes. WSU focused on the mechatronics technologies in production engineering for ground mobility, and CSULB concentrated on production engineering in aerospace applications. A survey was designed and provided at the end of the workshops, while the statistics and results were analyzed to evaluate the effectiveness of the events and the overall results were positive. Although the NSF project was completed, the program is still active in both institutes to promote mechatronics and the corresponding workforce training. Certainly, the experiences and lessons we obtained from these workshops will be applied in the future events, to strengthen the program and encourage more students to pursue advanced studies and careers in the growing mechatronics applications in the industry.

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Conflict of Interest

The authors declare no conflict of interest.

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Development of an Arduino-Based Photometer for Reactive Red 120 Dye Detection COVID-19

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Abstract

During the COVID-19 pandemic, traditional laboratory access was limited, prompting innovative approaches to education and research. An undergraduate chemistry student undertook the development of an Arduino-based photometer as a remote learning final year project. This project aimed to measure RR-120 dye concentrations in water using affordable and accessible technology, providing practical experience in photometry, electronics, and programming despite the constraints of the pandemic. The removal of Reactive Red 120 from water bodies is a significant environmental concern. The photometer, constructed using an Arduino UNO microcontroller, a green LED (500-570 nm), resistors, a plastic cuvette, and a BH1750FVI digital light intensity sensor module, is designed to be a cost-effective and user-friendly device for classroom and laboratory use. The device's operation is controlled via Arduino IDE 1.8.19 software, providing hands-on experience with programming and electronics. Calibration with seven RR-120 solutions (0.2 to 1.4 mg/L) produced an R^2 value of 0.9823, with a detection limit of 0.47 mg/L. The photometer achieved 98.66% accuracy demonstrating its reliability. Performance comparison with a commercial benchtop UV-Visible spectrophotometer (R^2 = 0.9956) further demonstrates the photometer's reliability. This Arduino-based photometer not only offers a practical application for teaching principles of photometry and spectroscopy but also illustrates the integration of affordable technology in scientific education, enhancing student engagement and learning in STEM fields during challenging times. Most importantly, this device also provided hands-on experience in photometry, enhancing remote learning during restricted lab access. The device's scalability suggests potential applications in broader environmental monitoring and educational settings, beyond the initial scope of dye detection.

Keywords: Arduino, Photometer, COVID-19 remote learning, Home-built, Dye, Reactive Red 120

Introduction

Dyeing and finishing processes in textile production are estimated to contribute to approximately 20% of worldwide pollution of clean water resources as highlighted by Kant (2012). Synthetic dyes that exhibit resistance to light and biological degradation can pose a toxic and hazardous risk to the environment. This is attributed to the resonance of their aromatic structure, which enhances their persistence in water bodies presented in Ardila-Leal *et al.*, (2021). Since synthetic dyes are very soluble in water, effluents from the textile dyeing industries may easily transport and distribute them to rivers and lakes.

Dyes have been identified as causing toxic effects in their parent molecules or intermediate metabolites. Islam *et al.*, (2023) further emphasizes textile dyes, like numerous other industrial pollutants, are highly toxic and have the potential to be carcinogenic, resulting in significant environmental damage and posing various health issues for both animals and humans. The utilization of textile dyes in the textile industry has been associated with a range of health problems affecting humans, animals, and the environment. Azo dyes make up approximately 70% of the total industrial dye consumption, which amounts to 9.9 million tons annually. Gürses *et al.*, (2016) has highlighted the global market value of azo dyes is estimated at USD 30.42 billion. Balapure *et al.*, (2015) has reported reactive Red 120 (RR-120) is a commonly utilized azo dye in the textile industry due to its notable chemical, biological, and photocatalytic stability. As a diazo dye, RR-120 is known for its exceptional durability and resistance to degradation. However, this resistance to breakdown poses challenges in terms of environmental degradation over time, as exposure to sunlight, detergents, water, and microorganisms have limited effectiveness in breaking down RR-120 as discussed by Solís *et al.*, (2012). Hence, it is imperative that water bodies remain nearly free of substances that create visually displeasing colours for aesthetic reasons. Non-natural colours, including dyes, should be imperceptible to the human eye, as these colours are particularly unwanted to individuals who derive pleasure from observing water in its unaltered state. According to Department of Environmental Malaysia (2009), chemical analysis and additional treatment is usually conducted in the textile wastewater plant to remove the color before they are discharged into the water bodies. Moreover, understanding how to measure and analyse pollutants like RR-120 dye in water ties learning to real-world environmental issues, increasing student engagement and awareness of global challenges.

A benchtop analytical instrument known as an ultraviolet-visible (UV-Vis) spectrophotometer is usually utilized to assess the absorbance of light by the analyte at specific wavelengths. Different materials exhibit varied absorption at certain wavelengths, enabling the instrument to analyse and quantify their characteristics. It is applicable as most of the synthetic dyes are made up of organic compounds which have a strong chromophore to be detected in visible region, ranging from 400 nm – 700 nm. Benchtop spectrophotometry provide accurate results but are often expensive, require skilled operators, and demand sophisticated laboratory settings, making them impractical for on-site analysis. Carrying heavy and complex instruments for on-site investigations is also impractical. Alternatively, portable, and cost-effective solutions based on Arduino microcontroller are becoming popular to facilitate rapid monitoring and detection of dye concentrations in wastewater. Arduino, a popular open-source platform in building electronics projects consisted of a hardware part, a physical programmable circuit board, called microcontroller, and a software part, namely Integrated Development Environment (IDE), which are used to control the physical board by giving instructions. A Universal Serial Bus (USB) interface is a common connection between the hardware and software part of the Arduino.

The Arduino microcontroller, equipped with different sensors, can be used for different purposes and assessment. By integrating Arduino microcontrollers with optical sensing components, students can learn to develop and use practical tools for real-world applications. This hands-on approach not only reinforces theoretical knowledge but also enhances problem-solving and technical skills that are invaluable for educational settings. The Arduino-based photometer project offered an alternative that could be assembled and operated at home, providing a valuable educational experience. This practical experience helps students understand complex concepts in photometry, electronics, and programming through direct application. Furthermore, this project bridges multiple disciplines, including chemistry, physics, computer science, and environmental science, allowing students to see the interconnectedness of these fields and how they come together to solve real-world problems. By working with Arduino microcontrollers and sensors, student develop a range of skills from basic electronics and circuit design to programming and data analysis, all of which are highly valuable in many STEM (Science, Technology, Engineering, and Mathematics) careers.

Several successful studies have been conducted on the development of home-built photometers for various compounds. Wang *et al.*, (2016) demonstrated the ease of constructing a single-wavelength photometer using inexpensive light-emitting diodes (LEDs) and household items for acid-base analysis. Steinberg *et al.*, (2014) has developed a novel wireless photometer that was tested and measured the color intensity as a function of dye concentration. These collective studies demonstrate the possibility of building an Arduino-based photometer as a screening tool for dye detection. While these previous studies have demonstrated the practicality of Arduino-based systems for photometric analysis, there are still significant gaps in the literature. These studies primarily focused on simple chemical analyses and did not address the detection of more complex pollutants, such as azo dyes, nor did they explore the integration of these tools in remote learning environments during emergencies like the COVID-19 pandemic. With the onset of the COVID-19 pandemic, educational institutions worldwide faced unprecedented challenges in delivering hands-on laboratory experience to students. Remote learning became the primary mode of education, making it essential to provide students with practical, home-based alternatives to traditional lab equipment. To date, no studies have focused on using Arduino-based photometers as a remote learning tool for environmental and chemical analysis, particularly for complex pollutants. This gap is critical because it highlights the lack of resources available to students during periods of restricted laboratory access, as was the case during the pandemic.

Notably, Balapure *et al.*, (2015) has reported reactive Red 120 (RR-120), an azo dye commonly used in the textile industry poses significant environmental challenges due to its chemical stability and resistance to degradation. The need for affordable, accessible tools for detecting pollutants like RR-120 is especially pressing in regions with limited access to sophisticated laboratory equipment. The use of photometer enables the determination of RR-120 dye concentration in water, which is in rather low concentration and imperceptible to be observed by naked eyes.

In the development of an Arduino-based photometer, an Arduino microcontroller is used as the microprocessor in the system, while LED can be used as the light source. Arduino board is simply connected to a computer or laptop using a USB cable. The whole system is controlled by connected computer, using Arduino languages written in C or C++ language script. The primary aim of this work was to develop an Arduino-based photometer that could be used to determine RR-120 dye concentration in water, specifically for educational purposes during the COVID-19 pandemic, when access to traditional laboratories was restricted. This project not only served as a valuable tool for remote learning but also contributed to enhancing students' practical skills in photometry, electronics, and programming. The objectives were to develop an Arduino-based photometer complete with the programming script, determine the RR-120 dye concentration, and subsequently validate the findings with values obtained using a commercially available benchtop UV-visible spectrophotometer instrument. Traditionally, students rely on benchtop UV-Visible (UV-Vis) spectrophotometers to understand the principles of light absorption and photometry.

However, access to these expensive instruments is often limited, particularly in under-resourced institutions or during times of restricted access like the COVID-19 pandemic. The Arduino-based photometer developed in this study provides a cost-effective alternative, allowing students to build their own devices and gain practical experience with scientific instruments at home. Students learn about the principles of spectroscopy, including the interaction of light with matter, absorption spectra, and the Beer-Lambert law, which relates absorbance to concentration. By constructing and calibrating the photometer, students gain practical insights into these theoretical concepts. They learn how different wavelengths of light can be used to detect specific compounds, understanding the role of chromophores in dyes like RR-120, which absorb visible light and cause coloration. This hands-on approach to learning enhances their comprehension of key chemical principles and their applications in environmental monitoring. By leveraging the computational capabilities of Arduino and incorporating optical sensing techniques, an undergraduate student has successfully created an affordable, customizable, and user-friendly photometer. This device not only serves as a practical tool for environmental monitoring but also provides an engaging educational platform for the student to explore the intersection of technology and chemistry. Through this project, the student gains hands-on experience and develops a deeper understanding of both scientific principles and the impact of technology on environmental science. Additionally, the project fosters an independent learning experience, promoting self-reliance, critical thinking, and the ability to undertake complex scientific tasks individually.

Materials and Methods

This study was divided into two parts, where the Arduino-based photometer was developed at the first stage, and it was then used in the analysis of RR-120 dye at the second stage. The materials used in this project were chosen for their accessibility, affordability, and educational value, providing a rich learning experience for an undergraduate student. All the materials and components used for development of Arduino-based photometer were brought via Cytron (2022) Official Website and Shopee online platform.

The primary component was an Arduino UNO microcontroller, an open-source platform renowned for its simplicity and versatility, making it an ideal tool for educational purposes. The features of Arduino UNO were as follows: microprocessor controller Atmel Atmega328P; USB chip Atmel Mega16u2 (CP2012 driver); digital input/output from 0 to 13; analog input/output from 0 to 5; PWM pin of 3, 5, 6, 9, 10, 11; input voltage was using USB Cable / 7-12 V DC plug; output voltage was 5 V and 3.3 V DC. A green LED, with a wavelength range of 500 to 570 nm, served as the light source, allowing the student to gain hands-on understanding of the properties of light and its interactions with various materials. The LED had an intensity from 3000- 4000 millicandela (mcd). A digital ambient light sensor (BH1750FVI) with an unsoldered pin, acted as a luminance to digital converter was used in this study. I2C communication protocol was used by this sensor to make an easier to be controlled by a microcontroller. The photometric analysis was controlled by using a laptop through an USB interface. The software Arduino IDE 1.8.19 was used and the programmes was written in C++ programming language. The Arduino IDE 1.8.19 software provided a user-friendly interface for writing and uploading code to the Arduino board, thus fostering programming skills within a real-world context. The standard RR-120 dye calibration solutions were prepared in the concentration of 0.2 – 1.4 mg/L and analysed first by using the home-built Arduino-based photometer, followed by result validation using benchtop Shimadzu-1800 UV-Vis spectrophotometer.

In the analysis using home-built Arduino-based photometer, the incident light intensity, I0, was observed via scanning of blank, i.e., ultrapure water. Then, 2.5 mL of standard calibration solution was filled into the plastic cuvette and the data was recorded as transmitted light intensity, I. The plastic cuvette holds the dye solutions, which introduced the student to sample handling and preparation in chemical analysis. The absorbance, A was calculated using Equation (1). The R2 value obtained from the calibration curved plotted, whereas the limit of detection (LOD) was calculated using Equation (2) and (3). The results were compared with that of analysed using benchtop Shimadzu-1800 UV-Vis spectrophotometry.

$$A = \log_{10}\frac{I_o}{I} \quad (1)$$

$$\text{Intercept of SD} = \text{Intercept of SE} \times \sqrt{N} \quad (2)$$

$$\text{LOD} = 3.3 \times \frac{\text{Intercept of SD}}{\text{slope}} \quad (3)$$

Results and Discussion

The set-up of the home-built Arduino-based photometer

The successful setting up of the home-built Arduino-based photometer was a significant educational milestone for the undergraduate student, integrating theoretical knowledge with practical application. A photometer consists of four basic components, which are the light source, filter, detector, and a control system. The basic principle of this technology involves measurement of quantity of light absorbing analyte, either organic or inorganic, in a solution at a certain wavelength. The home-built Arduino-based photometer was set up as in Figure 1. It shows the arrangement of components and Arduino UNO board. The cuvette was placed in between the light source (green LED) and the sensor module to maximize the light intensity reached the sensor. The green LED was fixed on the breadboard while the sensor module was fixed on a vertical cardboard. There was a cardboard with a small hole in between the light source and the cuvette, acted as the entrance and exit slit to minimize the light dispersion and focus the light on the power diagnostic area of the sensor. This hands-on experience reinforced several key educational concepts. Firstly, the student applied principles of photometry, understanding how light absorption and transmission through a sample can be used to determine the concentration of a substance. The use of an LED as a light source and a digital sensor to measure light intensity provided practical insights into the interaction between light and matter, an essential concept in both chemistry and physics.

The Arduino board was firstly connected with the breadboard as in Figure 2a, using male to male jumper wires. The breadboard was used to connect LED and resistor in series with Arduino board without any soldering. These basic electronic components help the student learn the fundamentals of circuit design and assembly. The green LED was selected due to its wavelength in the range of 495 – 570 nm, which was suitable for the detection of RR-120 dye. It was connected to digital pin 9 with a 100 ohm (Ω) current limiting resistor in series. The behaviour of the green LED was controlled by connected computer through Arduino IDE 1.8.19, using Arduino languages written in C++. Programming the Arduino was the next crucial step. Using the Arduino IDE, the student wrote a program to control the LED and read data from the light intensity sensor. Figure 2b shows the coding script to light up the green LED using Arduino UNO microcontroller.

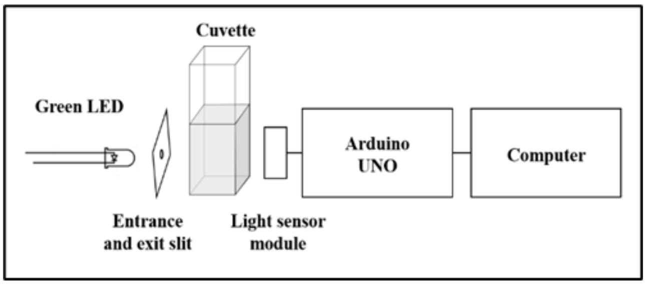

Figure 1. The diagram of the home-built Arduino based photometer showing the arrangement of components and Arduino UNO board.

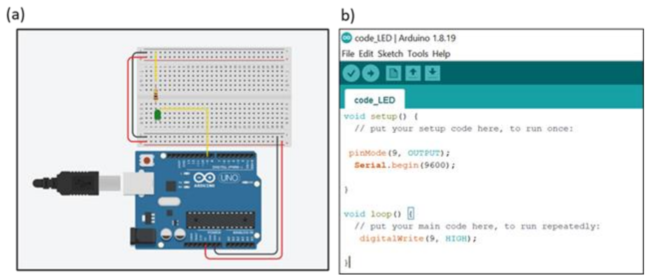

Figure 2. The a) schematic diagram of the connection between green LED and Arduino UNO board and b) the code to light up the green LED.

As for the connection of digital light sensor module with Arduino board, the library of the BH1750FVI digital light sensor module was first downloaded into the computer from the website GitHub (2022). (https://github.com/claws/BH1750), and the header pin for this sensor module was soldered properly and carefully before the connection started. Then, the sensor module was connected to the Arduino board, using male to female jumper wires as in the schematic diagram in Figure 3a. The behaviour of the sensor was controlled and monitored through Arduino IDE 1.8.19 on the computer, using Arduino languages written in C++. The necessity to debug and refine the code fostered problem-solving abilities and a deeper understanding of how software can be used to control hardware for specific scientific measurements. The code to control and monitor the sensor was shown in Figure 3b.

Both green LED and the sensor were connected simultaneously with the Arduino board as in schematic diagram in Figure 4a. The coding parts of green LED and BH1750 digital light intensity sensor were combined in an Arduino file as in Figure 4b. The photograph in Figure 4c showed the connection between (1) Arduino UNO board and (2) breadboard (3) green LED (4) light sensor module.

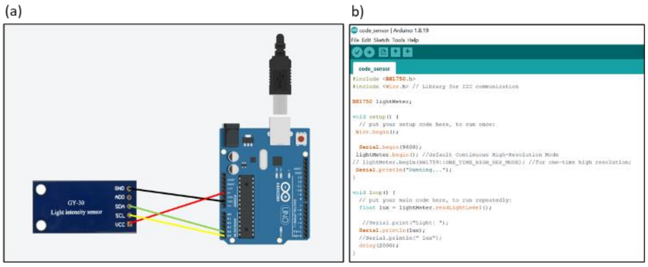

Figure 3. The a) schematic diagram of the connection between BH1750FVI digital light intensity sensor and Arduino UNO board and b) Schematic diagram of the connection between BH1750FVI digital light intensity sensor and Arduino UNO board.

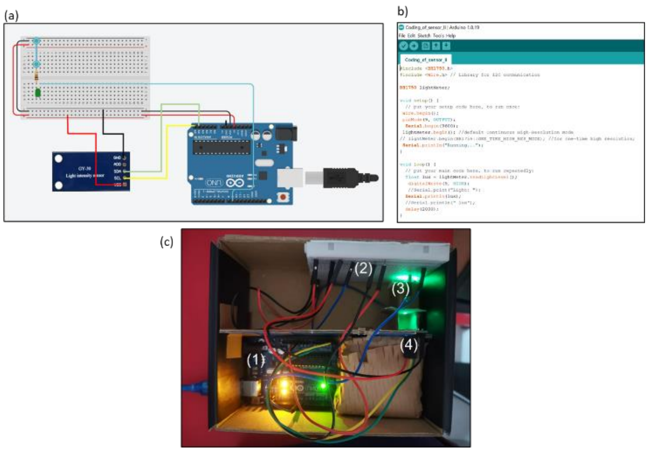

Figure 4. The a) schematic diagram of the connection between all components and Arduino UNO board, b) The code to control both green LED and BH1750FVI digital light intensity sensor simultaneously, and c) the photograph showing all the connection.

Analysis of RR-120 dye standard solutions using the home-built Arduino-based photometer

The functionality of the home-built Arduino-based photometer was tested to assess its reliability and accuracy in measuring light transmittance and absorbance. The data analysis phase of the project provided the student with practical experience in interpreting scientific data. Standard solutions with known concentrations of RR-120 dye were prepared and used to evaluate the photometer's performance. This step provided hands-on experience in solution preparation and dilution techniques, which are fundamental skills in any chemical analysis. The output signal from the sensor was measured as lux and then recorded as light transmittance. The absorbance was calculated using Equation 1.1. To establish the relationship between RR-120 dye and absorbance, a calibration curve was constructed as shown in Figure 5.

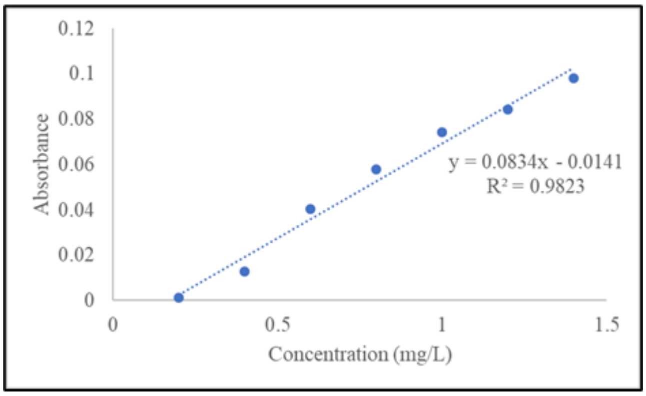

Figure 5. The calibration curve of RR-120 dye measured using home-built Arduino-based photometer device.

The acceptable R^2 value of 0.9823 showed quite a linear relationship between the RR-120 dye concentration and the absorbance measured using the developed device. The R^2 value indicates how well the calibration curve fits the data points, and a value close to 1 signifies a strong correlation. The intercept of standard error (SE) was calculated using the "Regression Statistic" in "Data Analysis" of Microsoft Excel, at 95% confident level. The data obtained was used in the calculation of the intercept of standard deviation (SD) using Equation (1), and LOD was then calculated using the Equation (1), where n is the number of RR-120 dye concentration, n=7. The LOD obtained from the analysis of RR-120 dye using home-built Arduino-based photometer was 0.4686 mg/L, which indicated the lowest concentration of RR-120 dye in the solution that can be consistently detected at 95% confidence level. The relatively low LOD indicates the photometer sensitivity and capability to detect trace amount of the dye in the tested solutions. These results were then compared with that of analyzed using a commercially available benchtop UV-Vis spectrophotometer. The commercially available benchtop Shimadzu-1800 UV-Vis spectrophotometer was used to verify the result obtained using the home-built Arduino-based photometer. The maximum absorption peak of RR-120 dye was observed at 514 nm in visible regions. Figure 6 illustrates the calibration curve for dye absorbance at 514 nm using the benchtop spectrophotometer, with R2 value of 0.9953. The calibration curve showed a strong linear relationship between dye concentration and absorbance value. The LOD obtained from the analysis of RR-120 dye using benchtop UV-Vis spectrophotometer was 0.2394 mg/L, which indicated the lowest concentration of RR-120 dye in the solution that could be consistently detected at 95% confidence level. The LOD value was close to the LOD that the home-built Arduino-based photometer measured. The difference in LOD and correlation values between the two instruments was marginal, highlighting the Arduino-based photometer's reliability as a cost-effective alternative for educational and field use. This exercise taught the student about the importance of calibration, validation, and the reliability of scientific instruments.

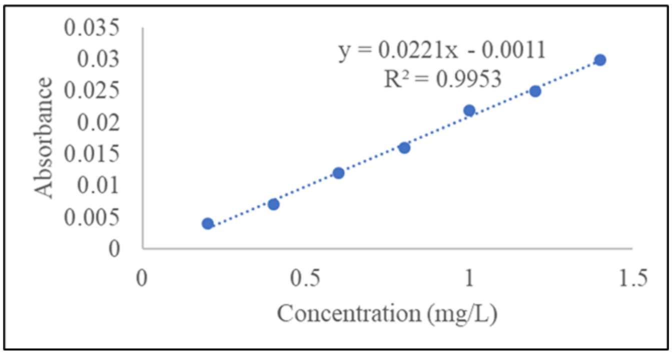

Figure 6. Calibration curve of RR-120 dye measured at 514 nm using benchtop UV-Vis spectrophotometer.

The error rate of the analysis of RR-120 dye using home-built Arduino-based photometer was calculated using Equation 4. The R^2 value obtained from analysis using benchtop UV-Vis spectrophotometer was used as the true value, while the R^2 value obtained from analysis using home-built Arduino-based photometer was used as the observed value. Then, the accuracy of RR-120 dye analysis using home-built photometer was calculated using Equation 5.

$$\text{Error rate} = \frac{|\text{True Value} - \text{Observed Value}|}{\text{True Value}} \times 100\% \quad (4)$$

$$\text{Accuracy} = 100\% - \text{Error rate} \quad (5)$$

The analysis of RR-120 dye using the home-built Arduino-based photometer has demonstrated its reliability and high accuracy, with an impressive precision of 98.66%. This level of accuracy indicates that the photometer could consistently and dependably measure RR-120 dye concentrations with a high degree of confidence. The strong linear relationship observed in the calibration curve (R^2 value of 0.9823) further supports the accuracy of the photometer's measurements. While the Arduino-based photometer demonstrated high accuracy and strong linearity, several potential sources of error and limitations should be noted. The open setup of the Arduino-based photometer makes it more susceptible to ambient light interference, which could affect the accuracy of the absorbance measurements. To mitigate this, measurements were conducted in a controlled environment, but in field applications, additional shielding around the setup would be necessary to prevent external light from affecting the results. The combination of the photometer's accuracy, cost-effectiveness, and portability makes it a valuable tool in environmental monitoring, water quality assessment, and various industrial applications. The photometer's ability to reliably measure dye concentrations above 0.4 mg/L ensures it could be employed in scenarios where higher dye levels are expected or need to be monitored. This realization underscored the educational value of the project, showing how innovative, cost-effective solutions can be developed using readily available technology.

Educational Impact and Curriculum Integration

In addition to the technical results, this project has significant educational implications. The Arduino-based photometer provides a practical, hands-on experience for students learning about photometry, spectroscopy, and environmental monitoring. By constructing and programming the device, students gain valuable skills in electronics, data analysis, and programming, all of which are crucial in STEM fields. Furthermore, the affordability and accessibility of the Arduino platform make it an ideal tool for educational institutions with limited resources. This project can be easily incorporated into undergraduate chemistry and environmental science curricula, providing a low-cost alternative to traditional spectrophotometry labs. Students can build the photometer themselves, learning not only the principles of photometry but also how to program and calibrate scientific instruments. This do-it-yourself (DIY) approach enhances problem-solving skills and fosters a deeper understanding of how scientific instruments work. Instructors could use this project to teach topics such as (a) the Beer-Lambert Law and its application in determining absorbance and concentration, (b) the role of light wavelengths in detecting specific compounds, (c) calibration and validation techniques using scientific instruments and (d) the environmental impact of textile dyes and methods of monitoring pollution. Given the increasing need for flexible and remote learning tools, especially during the COVID-19 pandemic, the Arduino-based photometer offers a way for students to conduct meaningful scientific experiments at home. It allows for the continuity of hands-on learning despite restricted access to laboratories, making it an invaluable educational tool during times of crisis. This project could also be adapted for fieldwork, where students can use the portable device to monitor environmental pollutants in real time.

Conclusion

The development of an Arduino-based photometer by an undergraduate chemistry student during the COVID-19 pandemic demonstrated both scientific innovation and educational resilience. Despite the challenges of remote learning and limited laboratory access, the student successfully constructed and validated a portable device for measuring Reactive Red 120 (RR-120) dye concentration in water. The photometer's performance, with high accuracy and reliability, underscored the potential of affordable technology in scientific research. The hands-on process of designing, assembling, and programming the photometer enhanced the student's skills in electronics and programming. The photometer's LOD of 0.47 mg/L indicates its sensitivity in reliably detecting low concentrations of RR-120 dye. Moreover, the accuracy of 98.66% comparable to the results obtained from a benchtop Shimadzu-1800 UV-Vis spectrophotometer demonstrates the photometer's reliability in quantifying dye concentrations. This project demonstrated that a cost-effective and portable photometer can be constructed using accessible components and open-source technology. Validated against a commercial UV-Vis spectrophotometer, the device showed high accuracy and reliability. This developed photometer could be used as a screening tool to identify the presence of RR-120 dye in a suspected dye-contaminated sample. Saying that, it is important to assess its suitability for specific industrial processes and environmental monitoring scenarios, which would be the future scope of this study. The interdisciplinary nature of the project highlighted the interconnectedness of STEM fields, providing a holistic educational experience that emphasizes the real-world applications of theoretical knowledge during challenging times. While the device has certain limitations, its high accuracy and reliability make it a valuable tool for teaching, research, and fieldwork. Future research could focus on improving the sensitivity of the light sensor, refining the design to reduce ambient light interference, and expanding the photometer's application to detect other pollutants or compounds. By incorporating this project into the STEM curriculum, educational institutions can provide students with hands-on experience that bridges theoretical knowledge and practical application, fostering a deeper understanding of both the science and technology behind environmental monitoring.

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Conflict of Interest

The authors declare no conflict of interest.

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Modeling Student Problem Solving for Improving Project-Based Learning

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Abstract
Project-Based Learning courses are widespread in engineering curriculums worldwide. As such, understanding how students problem-solve in these settings benefits curriculum designers, educators, and future learners. The objective of this research was to employ a human factors approach of modeling and error analysis to develop and apply a cognitive model to illustrate how students make decisions and problem-solve in a Project-Based Learning course. In addition, the Systematic Human Error Reduction and Prediction (SHERPA) was applied to identify errors in the process illustrated through the model. Data was collected from direct observations of 84 students in the classroom over two terms, along with qualitative reflection surveys and individual interviews to understand the project's impact on their problem-solving skills during their studies. The final model can be extended to other PBL courses to allow the targeted design of course materials to fit the student problem-solving processes, improve the project, and thereby improve learning outcomes. One main finding of this study was that students consistently failed to predict consequences, and predominately relied on each other as well as course PowerPoints to solve any problems that arose, illustrating the value in developing processes for improved materials.

Keywords: engineering education, Project-Based Learning, cognitive model, decision ladder, error analysis.

Introduction

Since Project-Based Learning (PBL) has been widely adopted in engineering education, it is imperative that instructors learn more about PBL to benefit learners in the classroom (Chen et al., 2021). PBL is a learning method where students are exposed to real-world projects in the classroom (Yusof et al., 2012). Students are given hands-on projects on day one, where they are given the ability to develop communication skills, critical thinking, and address complex questions (Yusof et al., 2012). PBL can be stressful for students as it requires skills such as proper communication, critical thinking, and problem-solving, which students may develop while actively working on their projects (Mohd-Yusof, 2014). Since every student learns at their own pace, PBL may not be the most appropriate learning technique because they may not have received the necessary support, background, or attention needed to thrive in PBL (Mohd-Yusof, 2014). However, PBL has also been shown to be more effective than traditional learning in the classroom (Luke et al., 2021; Hendry, 2016; Greiff, 2013). Traditional learning does not equip the student with the necessary skills to solve real-life problems; however, PBL does (Henriksen, 2009). Much research has been done not only on PBL but also on how to effectively implement PBL in an engineering classroom (Mills & Treagust, 2003; Gonczi & Maeng, 2020; Fink et al., 2002), as well as and shown success with PBL in classrooms in other disciplines (Clausen, H. B & Andersson, 2019; Ding et al., 2014; Jin & Bridges, 2014; Alrahlah, 2016).

Many engineering jobs require problem-solving skills. The primary purpose of the use-case project described here is to teach students skills they may use in their future engineering careers. The instructor hopes to cultivate communication skills, critical thinking, and problem-solving abilities in interdisciplinary teams, as is needed to excel in industry jobs (Nguyen, 1998). Although the plotter project is implemented in a mechanical engineering course, the project incorporates skills that may not be typically seen in a mechanical engineer's skill set. The plotter project provides engineering students with different skill sets, such as coding, manufacturing, and building that they can use in their future careers.

Even though much research has been done on PBL in engineering education, including social interactions with others in a PBL classroom (Sedaghat, 2018; Du & Kolmo, 2009), this study provides a novel approach using human factors tools and methods to improve design of course materials, through the development and application of a cognitive model to illustrate how students approach decision making in a PBL course. An error analysis, aligned with the model, was applied to identify common errors encountered in the process. Our approach considers both aspects to address the following research questions:

1. Do students follow a problem-solving model that could be useful for instructors in a Project-Based Learning course?
2. Does the quality of resources and social experience with fellow students influence how a student problem-solves in an engineering classroom?

Figure 1 illustrates the human factors approach taken that will be described in the following sections.

First, an introduction to the relevant background is provided, along with a description of the PBL course and project presented as a use case. The cognitive models developed are next described in detail, followed by the methodology of observations, interviews, and surveys to provide relevant data for revising the model, the SHERPA for error analysis, and finally, recommendations based on the findings from this work for improving PBL course projects.

Background

Problem-solving in the Classroom

The ability to effectively problem solve is a key skill that students must have to do well in the classroom and their future careers (Greiff, 2013). The project implemented in the class requires students to know how to solve problems effectively. However, some students tend to struggle with being able to solve problems in the classroom, predominantly because of difficulties working well with other students. Students may struggle to work with others because of social or cultural issues such as gender, previous experience, or previous friendships (Sedaghat, 2018).

Even though the project is an individual assignment, students are encouraged to work together on any problems that arise. Much research has been done on how to set students up for success when working in teams in an engineering classroom (Sedaghat, 2018; Rodríguez-Simmonds, 2018). Finelli et al. (2011) discusses the ample research that has been done that highlights the benefits to students of effective teamwork both during coursework and in a professional setting. Good teamwork plays a crucial role in effective problem-solving, which is highlighted in the proposed model.

Many studies have been done to show the benefits of problem-based learning in the classroom (Maker, 2020; Gonczi & Maeng, 2020; Luke et al., 2021; Hendry et al., 2016; Greiff et al., 2013). Some benefits are that students are given the opportunity to gain theory, content knowledge, and comprehension, as well as help students learn creative thinking, problem-solving, and communication skills (Awang & Ramly, 2008). Wegner et al., (2015) collected data to understand better how students worked together in a team for a design project. In the final assignment, students were asked to reflect on critical milestones in their personal development during their design projects. With these milestones identified, researchers could see common themes that impacted the students the most. The results of this study have been utilized to enhance how instructors teach engineering design to benefit the students most in their future professional careers.

Cognitive Models (Decision Making Model and PBL Model)

Modeling, a cornerstone of human factors research, involves creating representations of human-system interactions to predict performance and identify areas for improvement. In the context of engineering education, several types of models have shown promise, including, cognitive task analysis (CTA), information processing models and models from mental model elicitation. CTA models break down complex cognitive processes, such as those involved in learning engineering concepts, helping instructors identify potential areas of difficulty for students (Kirwan & Ainsworth, 1992). Information processing models are based on the flow of information as it is processed by the human brain (Wickens 2021). By mapping how students perceive, process, and retain information, these models can inform the design of

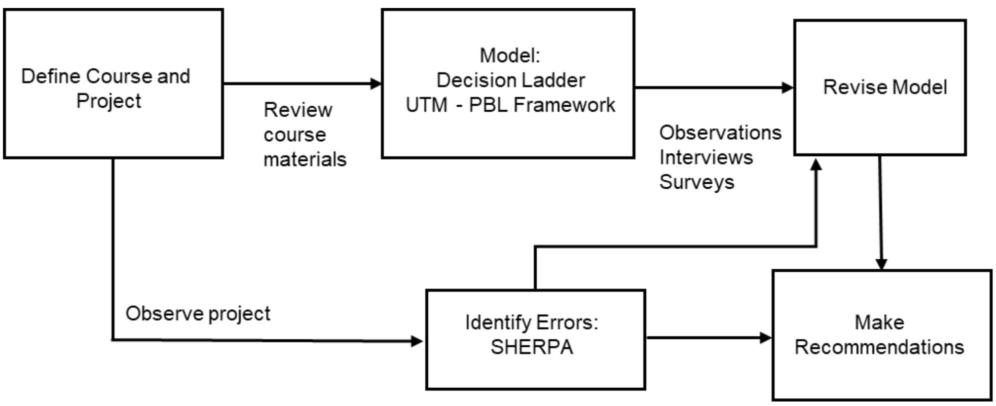

Figure 1. Research approach using human factors tools and methods of cognitive modeling and human error analysis.

lecture materials and learning activities (Johnson et al., 2023). Mental models can help instructors understand students' pre-existing conceptual frameworks, enabling more targeted and effective instruction (Vogel-Heuser *et al*., 2019). The decision ladder model incorporates several of these concepts by presenting the information processing steps and states of knowledge required by an operator to make decisions and ultimately achieve a stated goal (McNeese, *et al*. 1999; Jenkins *et al*., 2010). Any of these models can be constructed as normative or descriptive and both are important in understanding the student decision making processes. Normative models describe "norms" or "what people should do (in theory)". Descriptive models describe what people actually do or have done, and prescriptive models describe what people should and can do (Baron, 2004). A normative model (Figure 3) was initially created to better understand how students problem-solve and make decisions. Jaušovec (1994) showed that students who understand their thought processes when solving problems tend to solve problems better. Mental models also explain how students understand concepts differently (Ibrahim & Rebello, 2013). For this reason, a cognitive model is beneficial for instructors to understand how students problem-solve and design their project components accordingly. This model incorporates elements of the Decision Ladder model, (Jenkins et al., 2016) which supports activities like situation analysis, goal selection, as well as planning and execution (Naikar, 2010), and the Universiti Teknologi Malaysia (UTM) cooperative PBL framework (Yusof et al., 2012). We chose the Decision Ladder model since students were required to plan out the steps of completing the project as well as actually completing the project. Students were also required to diagnose and fix any issues that arose when completing the project. We chose the UTM cooperative PBL framework since the course is a PBL course. Both models were used to develop this cognitive model, since both problem-solving and decision-making are critical elements for the successful completion of the project.

Contributions of this Study

This study uses human factors tools and methods to extend the engineering education literature by providing researchers with a framework to understand student problem solving and recommendations to support the development of PBL activities for the engineering classroom. Using normative models to evaluate user behaviour and modifying the models based on actual user behaviour results in descriptive models to help instructors in PBL courses adapt their projects to suit the needs of learners. Instructors will also be able to better adapt the resources given to students in engineering classrooms to help students effectively solve problems. This model can be adapted and extended to represent PBL processes in classrooms around the world to suit educational and cultural differences.

Methods

This study was conducted through a series of observations, surveys, and interviews in a junior-level engineering class (Manufacturing Processes) at a university over two terms. The course materials were reviewed to develop the initial decision making model, while the observations, surveys and interviews were used to validate and revise the model. An error analysis was also conducted to understand the implications of the decisions over the sequence of steps of the project completion.

Participants

Manufacturing Processes is a required class for Mechanical and Industrial Engineering majors. However, other engineering majors may enroll in the course. There were 84 students (71 male, 12 female, 1 no response) who participated in this study over two terms. There were 44 students who participated in the Winter term and 40 students who participated in the Spring term.

Materials

This course was structured as a series of lectures, quizzes, and the PBL activity. The project, building a plotter, was completed over a period of eight weeks. Throughout the project, students followed PowerPoint instructions to complete the plotter. The project provides students with two opportunities to create a design solution throughout the project, allowing students the opportunity to explore a real-world problem creatively. The students are first asked to create a design from scratch for their pen holder. They are then required to determine what graphic to use and how to modify code for the plotter to draw the chosen graphic. Figure 2 illustrates an overview of the steps of building the plotter.

Procedure

Due to a delay in Institutional Review Board (IRB) approval, observational data was collected over a 4-week period in the first term. During the second to last week of the term, a survey was administered to the students (seen in Appendix A). Going into the Spring 2022 term; the survey was revised to elicit more quantitative results, with some questions being converted into Likert Scales. Observations were collected over 8 weeks in the second term. The revised survey can be seen in Appendix B. The error analysis, specifically the SHERPA, was conducted using course materials, and the results of the observations and was used as input to revising the final descriptive model of decision making.

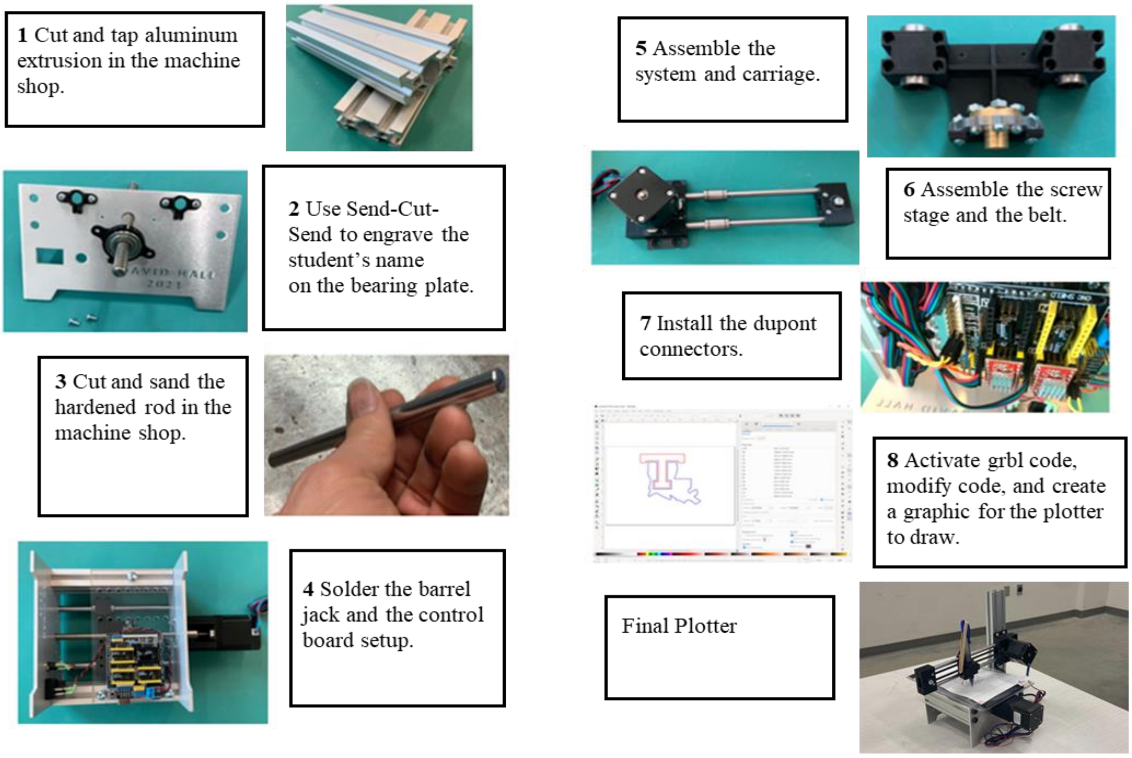

Figure 2. Overview of steps students follow to complete the plotter project

Surveys were given out in the second to last week of the quarter. By this point, most students were done with building their plotter. The only step any of the students had left to complete was to implement the code for their plotter to write/draw. The survey gathered demographic information in addition to questions regarding the project approach. Since the qualitative data is observation-based, the researchers of this study wanted to make sure to have responses from every student. This allowed the researchers to have more quantitative data to analyze to help validate the study's results. Likert scale questions were also given on the survey to have an overall mean of how confident students felt when problem solving.

Interviews were conducted with six students, in a subsequent term, who had previously taken the course, to gain insight into how they thought the project had impacted their engineering education so far. After the Winter term, an email was sent to the students who completed the class asking if they would be willing to be interviewed on their experiences in the class. Six students agreed to be interviewed. During the interview, the students were asked three Likert Scale questions and a series of open-ended questions that can be seen in Appendix C. Overall, the interview responses provided the researchers insight into how the use-case PBL project helped the students in future classes as well as if the PBL project provided them with more confidence in their problem-solving skills. Based on the student's responses, instructors of future course iterations will know how to tailor the project more to help their students develop more problem-solving skills.

Results

Data was aggregated from the observations, surveys, and interviews for the cognitive model, to answer the following research questions: 1) *Do students follow a problem-solving model that could be useful for instructors in a Project-Based Learning course? And 2) Does the quality of resources and social experience with fellow students influence how a student problem-solves in an engineering classroom?*

For the first research question, a cognitive model was created and evaluated to determine if students follow the problem-solving model in a PBL course. The resulting model was based on an aggregation of existing models in the literature (Jenkins et al., 2016 & Yusof et al., 2012). The model was validated through a combination of in-person observations and the survey and interview results. To answer second research question, the researcher directly observed the students, taking notes on how students interacted with the resources and fellow students in the classroom. To analyze the qualitative data, the method of thematic content analysis is used, where the researcher reviews the data, analyze the themes within the data, and then compiles the main themes into groups (Burnard et al., 2008). The data included the output of the SHERPA analysis.

This section describes the results of creating the initial model, the output of the SHERPA analysis, and quantitative analysis from the surveys to arrive at the final, validated model that can be used for designing PBL materials.

Normative Model

The resulting model describing how students should make decisions is shown in Figure 3. For the model, students first meet the problem of how to build and design the plotter. They then start to make decisions, by first determining the final goal of the project. After being alerted about needing to make a decision, students should begin to find the information needed to solve the problem and complete the task. Students will then determine if the system is working properly. Based on the system's state, the students should look at their available options. They may change the system state based on these options to accomplish the overall goal by predicting any potential consequences. They then test their system to evaluate its performance. Next, they plan and execute the remaining tasks to build their plotter. At the end of the project, students reflect on their work to gain closure on the project.

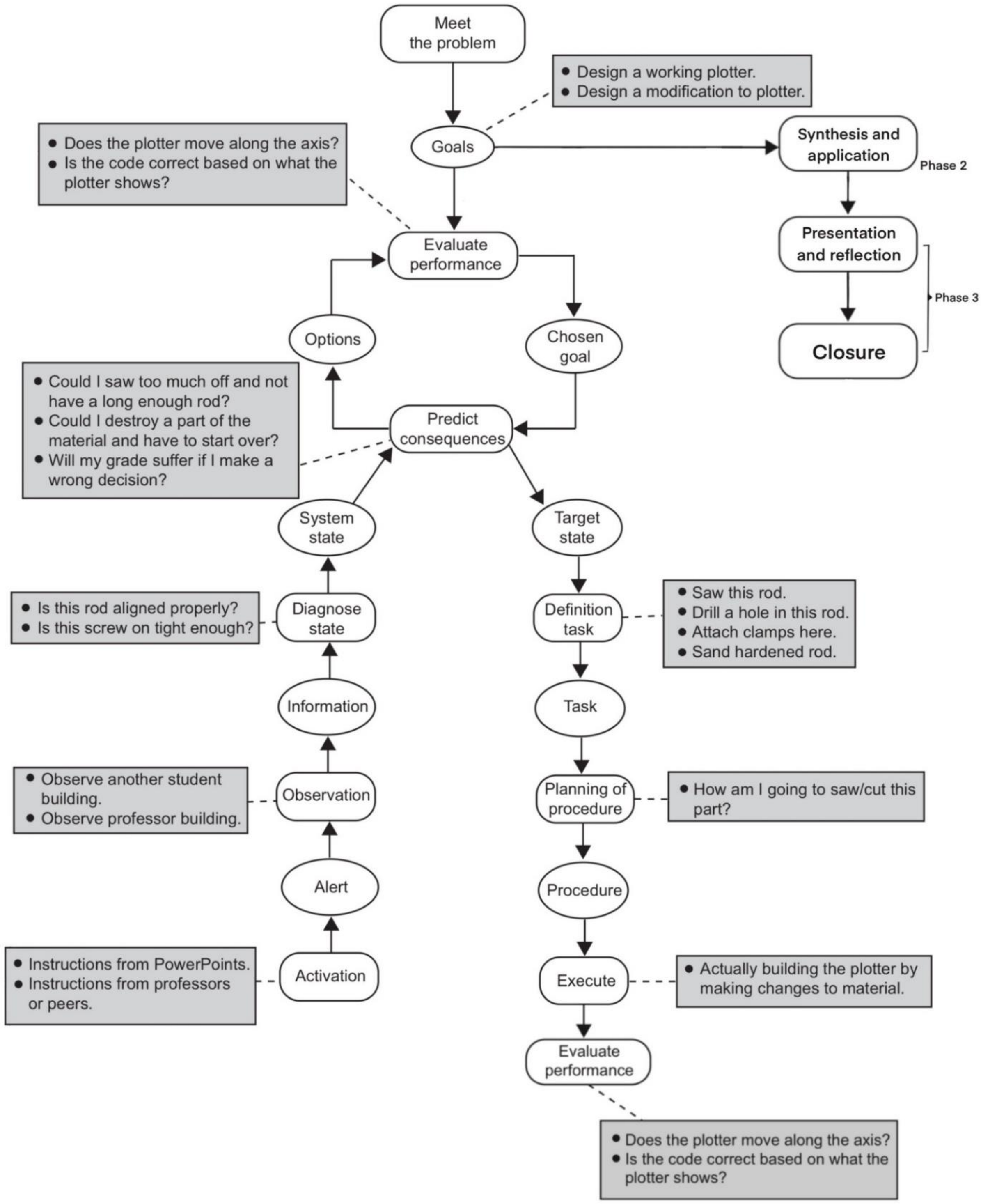

Figure 3. A decision ladder model incorporated into a problem-based learning framework

The ultimate purpose is to make recommendations on improving the instructional materials and process for this project based on how student learners' problem-solve and make decisions. Having a model that highlights decision points and problem-solving opportunities will improve the experience in PBL courses since instructors will know how to better design their PBL courses. For example, this model shows the order of steps that students partake in which will allow instructors to properly design their projects and course design to meet these steps. One of the main things seen is that students do not always predict consequences which is a crucial step as seen in the cognitive model. Knowing this, instructors can make sure to specify any potential consequences that could result when implementing a certain task of their project. Instructors may even add an extra slide at the end of each PowerPoint showing what could go wrong if the project step is not executed properly.

Throughout both terms, we observed that the students failed to predict consequences. For example, one student noticed he had a wobbly surface once he started to run the plotter. When questioned about the wobbly surface, the student admitted that he did not predict this could happen. He realized that he had not tightened one of the screws enough, which caused his board to wobble. Another student failed to predict his screws would roll off the table. However, after seeing this happen, the next class he decided to bring a paper plate to hold his screws since he noticed that everyone was losing screws since they would roll off the table.

Error Analysis

As students consistently failed to predict consequences, the researchers of this study applied the systematic human error reduction and prediction approach (SHERPA) analysis (Embrey, 1986). The SHERPA utilizes an error mode taxonomy to classify errors. Each error mode described in the SHERPA table has the same id as seen in a SHERPA table. For example, A9 corresponds to "Operation incomplete" (Embrey, 1986). The SHERPA table allows the instructor to see where and how errors are occurring, the consequence of these errors, the potential for recovery, the probability (P), and the criticality (C) of the error. The SHERPA table also provides remediation strategies for items that can be addressed in class to increase the potential for learning and project success. If students are given the proper instruction for the PBL activity, students will be able to learn more from the activity while experiencing less frustration.

Table 1. SHERPA (P and C columns refer to levels of low, medium, or high probability and criticality respectively) Each error mode has an assigned mode given by a letter and number, along with a mode description

Error Mode	Error Description	Consequence	Recovery	P	C	Remedial Strategy
A9-Operation incomplete	Failure to properly tap the holes	Screws will not tighten- will wobble	None	L	H	Provide training on how to tighten screws properly; demonstrate for the class what one should look for
A4-Operation too little/much	Cutting the black wire attached to barrel jack	Wires will not be long enough to reach power input on CNC shield	None	L	H	Instruct the students on the length required and make the students measure before cutting
A4- Operation too little/much	Failure to set correct temp for solder	Solder will not be hot enough to properly solder the wires	Immediate	M	L	Instruct the students on the correct temperature settings
A6- Right operation on wrong object	Wrong screw used	Part will not fit snugly together	Immediate	H	L	Provide clearer pictures/labels of the screws needed; Provide training on how to properly measure the size of the screws
A6- Right operation on wrong object	Wrong drill bit selected to size holes	Given screws will not fit	None	M	L	Provide clearer pictures/labels of the drill bit needed; demonstrate how to properly select the drill bit

A5- Misalign	Extrusion of aluminum not cut properly	Plotter will not sit flat- will wobble	Immediate	L	M	Provide training on how to properly cut the aluminum; demonstrate cutting steps
A1- Operation too long/short	Stripping screws	Will need to replace screws	Immediate	M	L	Provide training on how not to strip screws; demonstrate correct motions to the students
A9- Operation incomplete	Failure to properly code	Plotter pen will not move properly	Immediate	H	H	Provide training on how to code; provide trouble-shooting resources for students

Observations

Overall, through direct observations conducted by the main researcher of this study, the researchers found that the social experience with fellow students does influence how a student problem-solves in the classroom. Survey feedback indicated that students solved problems differently based on the resources they were given. The focus was to observe how students approached problem-solving and used available resources. Throughout the term, data was collected by observing the students building their plotters in the classroom. The researcher observed that most students would ask their peers questions when trying to solve problems that arose.

Some students worked by themselves and mostly utilized the PowerPoints provided. Other students asked the professor for help if they could not figure it out. Having fewer social interactions impacted how these certain students approached the project as they chose to rely on their own ideas instead of reaching out to other people in the class. In the Spring term, one student ended up super frustrated and angry when told by the professor that he put together a part of the plotter wrong and needed to work backward to fix the issue. This particular student was working at a table by himself, and one can say that part of his frustration was caused by not having anyone at the table to help him solve problems. Almost all students only asked the professor for help as a last resort. Overall, students tended to rely on the PowerPoints and each other to decide how to build their plotter and solve any problems that arose throughout the execution of the project.

Surveys

The results of the surveys showed that when solving problems, most students asked their classmates how to build certain parts of their plotter. Table 2 shows, from most commonly used to least, the approaches observed. These results aligned with the observations seen in the classroom. Seven students stated that they reached out to past students rather than ask the instructor. Since students tended to ask other classmates, students who did not have previous relationships with classmates would problem solve on their own versus asking for help from other students. The model *identifies* opportunities in the process where students need information to diagnose the system state and plan procedures to reach the target state.

Table 2. Preferred problem-solving approaches in PBL classroom (from student surveys)

Problem-Solving Approach	Number of Times Employed by Students
Ask Classmates	54
Online Search	19
Ask Instructors	11
Ask Previous Students	7
Course Material	3

Nineteen students stated that they tended to google solutions when problems arose, and only eleven students stated that they would ask their instructor first for help. Some students stated they would refer to the PowerPoints anytime they could not figure out how to do something in the building of the plotter. One particular student stated that he used a trial-and-error approach when solving problems. The student stated that he would try one solution and if the solution did not work, he would start over and try another solution until he eventually solved any problems that arose. Students also stated that they thought the GNC shield, and coding were the hardest part of the project, while the general assembly of the plotter was the easiest. Understanding student approaches and preferences allows instructors to provide better resources to help learners solve problems in a PBL course more effectively.

The survey was revised based on the students' responses during the Winter term by including three additional Likert scale questions (Table 3). Results indicate that all students felt at least moderately confident that they could solve problems as they arose. These results showed that students overall felt they could solve problems on their own which is a crucial skill that engineers must have, and should be supported by the PBL course resources.

Table 3. Student responses on a Likert scale of Not at all confident or clear to Extremely confident or clear

Questions	Mean	Standard Deviation
How confident were you that you could solve problems when they arise?	3.85	0.70
How confident did you feel working on this project on your own?	3.88	0.82
How clear were the instructions for you to be able to work on your own?	3.68	0.80

The next two questions asked students if they were confident in working on the project alone and if the instructions were clear enough for them to do so. The results show that the students were not completely confident about working on the project independently and felt that the instructions could be clearer. Updated PowerPoints with clearer instructions would allow future learners to work more independently on the project.

Interviews

Based on the responses of the students; we were provided with more evidence that the quality of resources and social experience with fellow students does influence how a student problem-solves in an engineering classroom. One of the students said: "This project would have been hard as a Freshman, but now, with experience, I could handle the project in a junior-level class. Made the class easier to be able to talk to other classmates since I knew people. Would have been hard to do the project if I did not know people. Connections are necessary."

Many students spoke about the quality of resources given affecting their ability to complete the project. One student stated "One thing would be to update the PowerPoints. More pictures and in-depth steps would be nice. Some assembly pictures were not clear." Another student stated "The instructions were not very clear in some parts. Would have changed it to make more straightforward instructions instead of having to assume stuff. Could tell that some stuff was not polished yet. Better raw materials, some of the stuff that we got, the lead screw bent which made it hard to have everything line up when you assembled everything. The surface wobbled because the lead screw was bent."

Another student spoke about the instructor not being able to help with the coding, which affected his ability to problem-solve during the project. This student stated "I was enjoying the project until I got stuck with the coding. The professor was not able to help with the coding. He spent a lot of time troubleshooting the code. Wish we could have sorted out the issue faster." Overall, based on the interview results, we can conclude that students' interactions with one another and the quality of the resources given to them affected how they were able to problem-solve.

Descriptive Model of Student Problem-solving

The initial normative model was revised using all of the data gathered, resulting in the descriptive model shown in Figure 4. For the most part, students tended to follow the path of the initial model. However, there were several key changes. The first change was to take out the *predicting consequences* block in the model.

The students would not consider any consequences due to building the plotter incorrectly, and frequently had to re-do parts of their plotter after being told by the professor that they did something wrong, to make the plotter function properly. For example, as previously mentioned, students did not predict that their plotter would wobble if parts were not installed correctly. Students also did not predict that the screws would roll off the table if they did not put them in a safe place on the table. To correct this, the PowerPoints should show any potential errors resulting from the students building a part of the plotter incorrectly. The PowerPoints' quality influences how students solve problems based on the results we saw. An additional change was moving the *evaluate performance* block to the end of the model. It was observed that was the last thing students would do when building their plotter. Instructors can use this revised model to emphasize to students the importance of constantly and iteratively evaluating their project throughout the process instead of waiting until the end of the building to evaluate. This way, students can predict consequences and make any necessary changes with less frustration and better use of resources during the process. Using this revised model, instructors in other PBL courses will know to emphasize that students should thoroughly think through the potential consequences at each stage (or system state). Instructors will also know to tell their students to constantly check that their project components are working properly throughout the building process as fixing an issue will be much harder at the end of the project versus fixing issues throughout the building of their project.

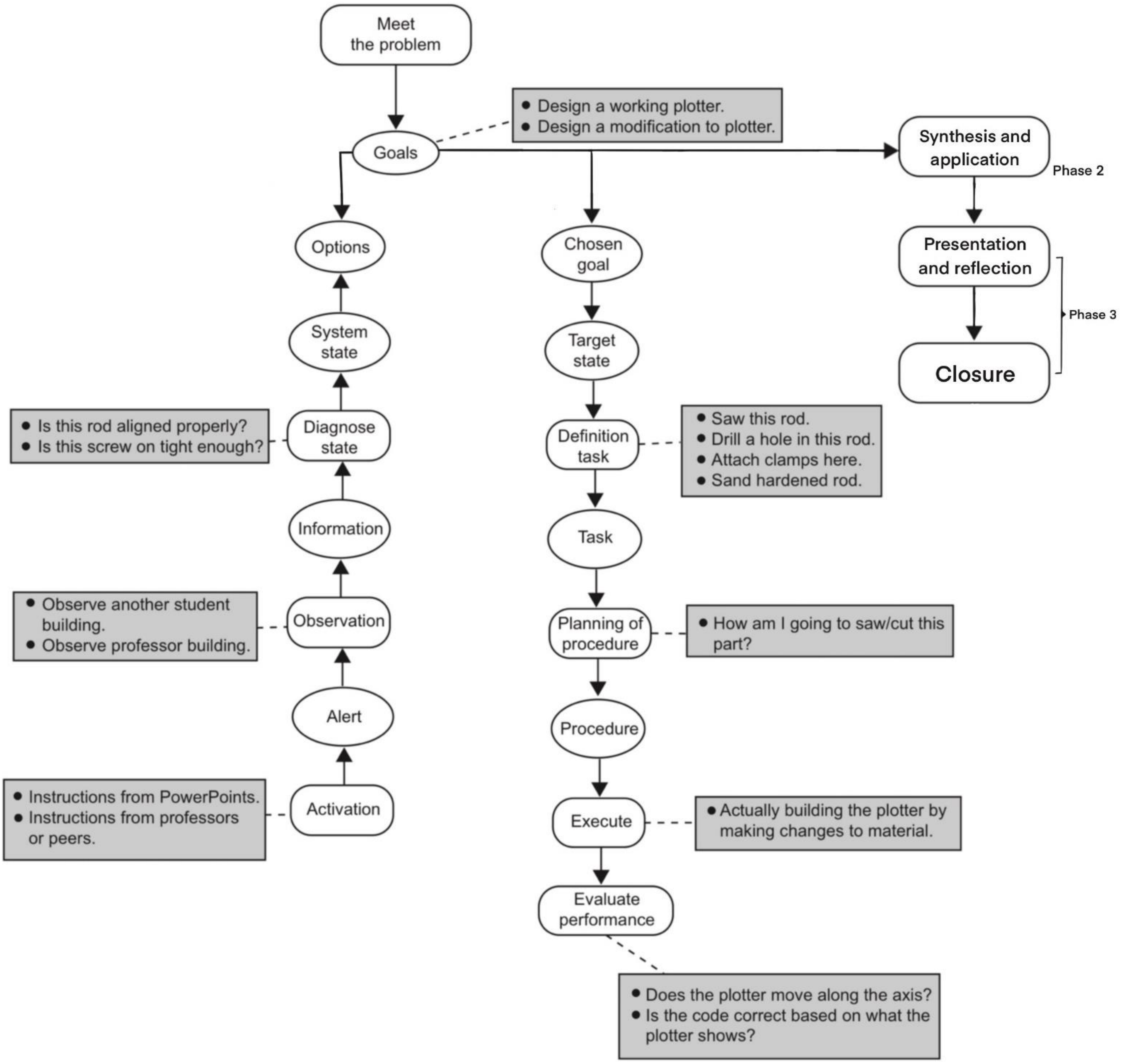

Figure 4. A revised decision ladder model incorporated into a problem-based learning framework based on results of the study. Shaded rectangles refer to specific examples related to the use case.

Discussion

This study employed a human factors approach to show how students make decisions and problem-solve during a PBL activity in an engineering classroom. As a result, instructors have a set of resources, a validated cognitive model, and SHERPA, that can be used when designing their project-based learning activities to benefit future learners. These resources are grounded on how engineering students approach problem-solving, as prior research has shown that PBL benefits learners in the classroom (Chen et al., 2021). The overall key findings of this research are that students failed to predict consequences throughout the project as well as waited until the end of the project to evaluate the performance of the plotter. Because of this, we recommend that future instructors in PBL courses emphasize to students to thoroughly check each component throughout the building of a project. We also recommend that instructors provide students with enough resources for them to accurately build their PBL projects. Generally, cognitive models are not widely seen in prior research studies in PBL studies. This research expands on these by integrating the UTM-PBL and decision ladder models to better illustrate how students actually problem solve during execution of these projects. The implications of this study will help both instructors and curriculum developers in PBL classrooms as they will know how students think and problem-solve. Application of the model and error analysis resulted in recommendations to aid curriculum developers and/or instructors in designing their PBL courses accordingly.

Using the output form the combination of observations, surveys and interviews, the following recommendations can be made. At the very least, it is recommended that the slides and other course materials be updated to visually depict what the students should be building and diagrams of the circuitry, etc., as we can see that the quality of resources influences how students solve problems. Providing these materials at the beginning of the project would provide an end goal of expected results. A physical, as well as a SolidWorks model of the completed plotter was also requested to help aid the students in the building of their plotter. Students also requested more resources for the coding aspect, as most people were unfamiliar with how to code their plotter. Even though this is specific to the use case, this holds true for many engineering projects that involve multiple skill sets. There is a need to provide supporting resources for secondary skills not necessarily taught in the course. These necessary skills have been shown in prior research to be critical for students to know how to apply (Nguyen, 1998). The last recommendation for the instructor is to have more precise due dates, or a timeline of expectations, on where the students should be in building their plotter so that they know if they are behind in the building process and can meet expectations (as seen in the cognitive model). Overall, if these recommendations are implemented, students should have a better learning experience when completing the project in the PBL course.

While this study has added to the literature on improving PBL in the engineering classroom, some limitations should be acknowledged. One such limitation, is that data was only collected in one PBL course, although it was collected over two different terms. Another limitation is that there was not a diverse group of students upon which to collect data, as most students in the course were mechanical engineering majors. Due to the majority of the data being qualitative, the researchers note that there may be some bias in the data observations and this should be noted. An addition limitation is that with a small research group, not all students could be observed during each class to have additional quantitative data, but this survey results for resource use aligned with what the researcher observed in the classroom, validating the responses.

Conclusions and Further Research

Since Project-Based Learning activities are more pervasive in the engineering classroom, providing instructors with a cognitive model of problem-solving and decision-making will allow the instructors to see how they should design their projects to fit the needs of the students. The model can be easily modified to fit many different types of engineering projects to support a broad spectrum of educational structures universally. Students can better grasp the course's concepts since the instructors have insight into how students problem-solve when completing a PBL activity. Additionally, instructors now have insight into useful aspects of their presentation material and resources for students to smoothly complete their project. Implementing the recommendations will provide students with clearer outcome expectations that can be visualized, support for secondary skills needed, and progress checkpoints to help improve learning outcomes.

For future work, recommendations will be given to the course's instructor to implement. Once these have been implemented, the study can be implemented again to determine if the students now have the appropriate resources to reduce frustration and improve resource use with the project. Applying the SHERPA output to other PBL activities, instructors can also design the project to help students predict consequences. By using the cognitive model, instructors in other PBL courses will be able to design their projects based on how engineering students problem-solve during a PBL activity.

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Conflict of Interest

The authors declare no conflict of interest.

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APPENDIX A

MEEN 321 Survey

1. What is your sex?
   a. Male b. Female c. Prefer not to respond

2. What is your race?
   a. White b. African American c. American Indian or Alaska Native d. Asian e. Native Hawaiian or Other Pacific Islander

3. What is your major?

4. When struggling with an aspect of the project, what did you tend to do?
   a. Reach out to professor b. Reach out to classmates c. Reach out to past students d. Google solutions e. Other
   If other is selected, please explain what you do.

5. In general, how do you tend to solve problems when they arise in class projects?

6. What aspect of the project was the most difficult? Why?

7. What aspect of the project was the easiest? Why?

8. How could the instructions for the project be clearer and easier to understand?

9. What resources do you wish you would have had when completing this project?

10. Would you do anything differently if allowed to start the project over? If so, what?

11. How confident did you feel working on this project on your own?
    Not confident at all 1 2 3 4 5 Highly confident

12. Were the instructions clear for you to work on the project on your own?
    Yes No

13. Do you have any suggestions for this class?

14. If you could talk to someone about your project experience before they start the project, what would you tell them?

APPENDIX B

MEEN 321 Survey

1. What is your sex?
   a. Male b. Female c. Prefer not to respond

2. What is your race?
   a. White b. African American c. American Indian or Alaska Native d. Asian e. Native Hawaiian or Other Pacific Islander

3. What is your major?

4. When struggling with an aspect of the project, what did you tend to do?
   Reach out to professor b. Reach out to classmates c. Reach out to past students d. Google solutions e. Other
   If other is selected, please explain what you do.

5. How confident were you that you could solve problems when they arise?
   Extremely Confident
   Very Confident
   Moderately Confident
   Slightly Confident
   Not at all Confident

6. What aspect of the project was the most difficult? Why?

7. What aspect of the project was the easiest? Why?

8. How could the instructions for the project be clearer and easier to understand?

9. What resources do you wish you would have had when completing this project?

10. Would you do anything differently if allowed to start the project over? If so, what?

11. How confident did you feel working on this project on your own?
    Extremely Confident
    Very Confident
    Moderately Confident
    Slightly Confident
    Not at all Confident

12. How clear were the instructions for you to be able to work on your own?
    Extremely Clear
    Very Clear
    Moderately Clear
    Slightly Clear
    Not at all Clear

13. Do you have any suggestions for this class?

14. If you could talk to someone about your project experience before they start the project, what would you tell them?

APPENDIX C

Interview Questions

1. What is your gender?

2. What is your race?

3. Looking back on the plotter project, have you used any of the skills you learned in other classes or life? If so, which skills?

4. Do you feel that you will use any of the skills you learned in a future job? If so, which skills?

5. How confident are you on using the skills you learned from the class?
   Extremely Confident
   Very Confident
   Moderately Confident
   Slightly Confident
   Not at all Confident

6. How would you change the project now to better suite the skills you need to do well in your engineering classes as well as your future career?

7. How confident are you that you will be able to do well in an engineering career now having taken the MEEN 321 course?
   Extremely Confident
   Very Confident
   Moderately Confident
   Slightly Confident
   Not at all Confident

8. How confident are you with your problem solving skills now having taken this course?
   Extremely Confident
   Very Confident
   Moderately Confident
   Slightly Confident
   Not at all Confident

9. Is there anything else you would like me to know to make the project better?

Book Review: Instructional Scaffolding in STEM Education – Strategies and Efficacy Evidence

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Abstract
Brian R. Belland's Instructional Scaffolding in STEM Education: Strategies and Efficacy Evidence provides an in-depth analysis of instructional scaffolding's role in enhancing student learning within STEM disciplines. The book focuses on the efficacy of computer-based scaffolding, exploring its potential to support students engaged in problem-centered instructional approaches such as project-based and inquiry-based learning. Belland meticulously reviews the theoretical foundations of scaffolding and presents findings from a meta-analysis of 144 studies, identifying scaffolding strategies that most effectively promote higher-order thinking, problem-solving, and deep content knowledge. The book also addresses the customization of scaffolding, stressing the importance of adapting support to meet individual learner needs. Key themes include the integration of conceptual, strategic, and motivational scaffolding, as well as their impact on cognitive outcomes. This review highlights the book's relevance to educators, researchers, and curriculum developers, offering practical insights for integrating scaffolding into STEM education to foster more engaged and capable learners.

Keywords: higher-order thinking, problem-centered learning, meta-analysis, cognitive outcomes, educational strategies.

Belland, B. R. (2017). *Instructional scaffolding in STEM education: Strategies and efficacy evidence.* Springer International Publishing. https://doi.org/10.1007/978-3-319-02565-0

Introduction

Brian R. Belland's Instructional Scaffolding in STEM Education: Strategies and Efficacy Evidence is an insightful and comprehensive examination of the role of scaffolding in supporting learning within STEM disciplines. This book delves deeply into the theory and application of instructional scaffolding, focusing specifically on computer-based scaffolding and its effectiveness in fostering cognitive outcomes in students engaged with problem-centred learning approaches. Through a synthesis of empirical research, Belland highlights the strategies that are most effective in helping students achieve higher-order thinking and deep content knowledge, addressing a significant gap in STEM education.

The author, Brian R. Belland, is a professor at Utah State University, specializing in instructional scaffolding. His expertise is evident as he articulates the conceptual evolution of scaffolding from its origins in one-on-one interactions to its current applications in computer-supported learning environments. The book is particularly valuable for researchers and educators looking to integrate scaffolding strategies into their curricula, as it combines theoretical underpinnings with practical recommendations based on rigorous meta-analyses.

Outline of the book

The book is structured systematically, beginning with Chapter 1: Introduction, which explores the rationale for writing about computer-based scaffolding in STEM education. It provides an overview of the book's focus, including problem-centered instructional approaches, the role of scaffolding, and its central premises. This chapter concludes with a description of the book's structure. Chapter 2: Instructional Scaffolding: Foundations and Evolving Definition delves into the historical and theoretical bases of scaffolding, including its elements, forms, and how the metaphor translates into computer tools. It also addresses theoretical models such as Activity Theory, ACT-R, and Knowledge Integration.

Chapter 3: Context of Use of Computer-Based Scaffolding examines its applications across grade levels, STEM disciplines, and student demographics, supported by meta-analysis results. Various instructional models, including problem-based, inquiry-based, and design-based learning, are discussed. Chapter 4: Intended Learning Outcomes and Assessment focuses on scaffolding's impact on higher-order thinking skills, deep content learning, and alignment with STEM education goals. Chapter 5:

Computer-Based Scaffolding Strategy presents scaffolding functions like conceptual, metacognitive, and motivational support, while addressing customization and context specificity, with meta-analysis results provided throughout. Finally, Chapter 6: Conclusion discusses overarching implications, responses to debates in scaffolding literature, and future research directions, synthesizing the insights gained from the preceding chapters.

Summary of key themes

Belland's book covers a wide range of topics related to scaffolding, beginning with its definition and historical roots in Chapter 2, where he traces the evolution of the concept from its origins in Vygotsky's zone of proximal development and its cultural-historical activity theory. One of the central premises of the book is that scaffolding—whether computer-based, peer, or one-to-one—extends learners' abilities to engage with authentic, ill-structured problems, a key feature of problem-centered instructional approaches (Jaipal-Jamani, 2023).

The author focuses heavily on computer-based scaffolding (CBS), which he presents as an essential tool for K-12 STEM education due to the high student-to-teacher ratios that often make one-on-one scaffolding impractical. CBS is presented as a solution to bridge gaps, offering dynamic, adaptable, and ongoing support to students as they engage with complex problems in real-world contexts (Kim et al., 2019).

Pedagogical approaches to scaffolding

Belland is particularly interested in the interplay between problem-centered instructional models such as project-based learning (PBL) and the support mechanisms that can enhance student learning. He notes that while problem-centered approaches are widely praised for their ability to foster deep content understanding and long-term retention of knowledge, their success hinges on effective scaffolding. Without appropriate guidance, students may struggle with the complex, ill-structured problems typical of these models. As a solution, Belland proposes scaffolding strategies that are customized to the learner's needs and evolve over time, such as through the fading or adding of support as learners gain competence.

The book also delves into different scaffolding strategies tailored to various stages of learning and problem-solving processes. For example, Chapter 5 discusses strategic, conceptual, and metacognitive scaffolding, emphasizing the need to address not only content knowledge but also the skills required for problem-solving and critical thinking. By offering such multi-faceted support, scaffolding can better prepare students to navigate the interdisciplinary challenges of STEM fields.

Theoretical foundations

One of the strengths of Belland's work is the integration of diverse theoretical perspectives. He draws on activity theory, ACT-R (Adaptive Character of Thought-Rational), and knowledge integration models to provide a robust conceptual foundation for scaffolding in STEM education. This multi-theoretical approach enables Belland to argue for the importance of scaffolding as a flexible tool, one that can adapt to different learning contexts and objectives (Korhonen et al., 2019).

For example, activity theory emphasizes the role of cultural and historical context in shaping learning, making it particularly relevant for scaffolding that is designed to support collaborative, socially situated learning experiences (Schmidt, 2022). In contrast, the ACT-R model focuses on cognitive processes and suggests that scaffolding can help learners develop automated problem-solving skills through repeated practice and feedback. By synthesizing these perspectives, Belland provides a nuanced understanding of how scaffolding can operate across different educational settings.

Assessment and learning outcomes

Chapter 4 of the book addresses the critical issue of assessing the effectiveness of scaffolding interventions. Belland notes that while scaffolding is often designed to enhance higher-order thinking and problem-solving skills, it is essential to have reliable assessment tools that can measure these outcomes. He argues for assessments that go beyond traditional content knowledge tests, instead focusing on students' ability to engage in ill-structured problem-solving and apply what they have learned to new, complex situations.

One interesting finding from the meta-analysis presented in the book is that scaffolding appears to be more effective in certain STEM disciplines than others. This variability highlights the need for context-specific scaffolding designs that take into account the unique challenges and learning objectives of each discipline. Furthermore, Belland advocates for continued research into how scaffolding can be optimized to support different types of learners, including those from underrepresented or marginalized backgrounds.

Implications for STEM Education

Belland's exploration of scaffolding has significant implications for STEM educators. He provides practical guidance on how to implement scaffolding in the classroom, suggesting that teachers use a combination of peer, teacher, and computer-based scaffolding to provide the most comprehensive support. He also emphasizes the importance of scaffolding that is responsive to the learner's evolving needs, with support gradually withdrawn as students become more proficient.

Moreover, Belland’s findings suggest that scaffolding is most effective when aligned with the goals of STEM education as outlined in standards like the Next Generation Science Standards (NGSS). These goals include not only content mastery but also the development of critical thinking, collaboration, and problem-solving skills, all of which can be enhanced through well-designed scaffolding.

Highlighted Chapter

Chapter 5 is captivating because it focuses on the diverse forms of scaffolding—strategic, conceptual, and metacognitive—and their distinct yet interconnected roles in helping students navigate complex STEM problems. This chapter is particularly interesting as it sheds light on how scaffolding can move beyond basic content support and delve into the processes that students use to approach and solve problems.

Strategic scaffolding refers to the guidance offered to help students plan and execute problem-solving strategies (Vo et al., 2022). For instance, in a STEM context, strategic scaffolding might involve breaking down a complex engineering problem into smaller, manageable steps and providing a roadmap for students to follow. What is intriguing is how Belland connects this to the development of independent problem-solving skills—by gradually removing strategic support, educators can help students build the confidence and competence to approach similar problems on their own.

Conceptual scaffolding, meanwhile, is aimed at helping students understand the fundamental principles or frameworks behind a problem. In STEM disciplines, this type of scaffolding is critical because students often struggle with applying theoretical concepts to real-world problems. By offering conceptual support, educators can help students make these connections, which ultimately leads to a deeper understanding of the material.

Metacognitive Scaffolding: A Highlight

What makes this chapter particularly compelling is its discussion of metacognitive scaffolding. This form of scaffolding encourages students to reflect on their own thinking processes, allowing them to become more self-aware learners. In the context of STEM education, where students often grapple with abstract concepts and complex problem-solving tasks, metacognitive scaffolding can be a game-changer. Belland argues that by fostering metacognitive awareness, educators can help students not only solve the problems at hand but also develop the ability to transfer these skills to new and unfamiliar situations.

This chapter aligns closely with recent research that underscores the importance of metacognition in learning. According to Santangelo et al. (2021), metacognitive skills—such as the ability to plan, monitor, and evaluate one's own learning—are essential for success in STEM fields. Belland’s exploration of how scaffolding can support these skills is particularly relevant for educators who are looking to prepare students for the increasingly interdisciplinary and problem-based nature of STEM careers.

What makes Chapter 5 resonate so deeply is its applicability to real-world teaching and learning scenarios. As a student or educator in STEM, it becomes evident that solving problems is not just about having the right answers—it's about developing the right thinking processes. The way Belland breaks down the scaffolding types makes this chapter not only informative but also practically useful for anyone involved in education. By emphasizing the importance of reflection and self-regulation in learning, this chapter brings to the fore the crucial role that metacognitive scaffolding plays in empowering students to become lifelong learners.

Conclusion

In Instructional Scaffolding in STEM Education, Brian R. Belland provides a critical framework for understanding scaffolding’s role in enhancing learning outcomes in problem-centered instructional environments. While the book effectively integrates theoretical perspectives and highlights the potential of computer-based scaffolding (CBS) as a scalable solution, it leaves some areas underexplored. For instance, although the discussion on metacognitive scaffolding is compelling, the book could provide more practical, real-world examples or case studies to bridge the gap between theory and application. Educators and curriculum developers might find it challenging to translate the insights into actionable strategies without these concrete examples.

Additionally, while the meta-analysis findings are informative, they lack a deeper comparative discussion across different grade levels, STEM disciplines, and student demographics, which would provide a more nuanced understanding of scaffolding’s impact in diverse contexts. Another limitation is the insufficient focus on emerging technologies like artificial intelligence, virtual reality, and gamification, which could significantly enhance scaffolding’s design and implementation. These omissions, though not diminishing the book’s overall value, suggest areas where future editions could improve to better address the evolving needs of STEM education. By including more practical applications, comparative analyses, and discussions on cutting-edge technologies, Belland’s work could achieve even greater relevance and impact.

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Conflict of Interest

The authors declare no conflict of interest.

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Reshaping Engineering Education: Addressing Complex Human Challenges: A Book Review

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Abstract

Reshaping Engineering Education: Addressing Complex Human Challenges, authored by Fawwaz Habbal, Anette Kolmos, Roger G. Hadgraft, Jette Egelund Holgaard, and Kamar Reda, addresses the urgent need for transformative changes in engineering education. The authors argue that the traditional curriculum, primarily focused on mathematical rigour and applied sciences, is insufficient to equip graduates for the complex, interdisciplinary challenges of the modern world. These challenges, such as global sustainability, climate change, and the digital revolution, require holistic, systems-thinking approaches. The book is structured into four main sections. Part I highlights the importance of systems thinking and design methodologies in engineering education, positioning engineers as problem-solvers in complex real-world systems. Part II explores pedagogical changes, advocating for problem-based and project-based learning as key methods to foster critical thinking and creativity. Part III presents case studies from Harvard University, Aalborg University, and the University of Technology Sydney, demonstrating successful applications of these educational reforms. Part IV concludes with actionable recommendations for institutions to integrate interdisciplinary and design-focused curricula. Through its examination of innovative teaching strategies and case studies, the book emphasizes the need for collaboration, adaptability, and interdisciplinary learning in modern engineering education. It offers a comprehensive framework for reshaping engineering programs and preparing future engineers with the skills necessary to tackle complex human challenges.

Keywords: Systems thinking, interdisciplinary learning, problem-based learning, project-based learning, curriculum transformation.

Habbal, F., Kolmos, A., Hadgraft, R. G., Holgaard, J. E., & Reda, K. (2024). *Reshaping engineering education: Addressing complex human challenges*. Springer. https://doi.org/10.1007/978-981-99-5873-3

Introduction

In a world where engineering challenges are becoming increasingly complex, interdisciplinary, and global in scope, *Reshaping Engineering Education: Addressing Complex Human Challenges* offers a transformative vision for the future of engineering education. Authored by a distinguished group of academics—Fawwaz Habbal, Anette Kolmos, Roger G. Hadgraft, Jette Egelund Holgaard, and Kamar Reda—the book emphasises the need to shift from traditional technical education to one that promotes systems thinking, interdisciplinary collaboration, and innovative problem-solving.

The authors bring a wealth of experience and achievements to this work, making it an authoritative guide on educational reform. Fawwaz Habbal, a senior lecturer at Harvard University's School of Engineering and Applied Sciences, has successfully implemented innovative pedagogical strategies like studio-based learning. His involvement in founding the Harvard Learning Incubator and co-directing the Master in Design Engineering (MDE) program highlights his commitment to integrating design thinking into engineering education.

Anette Kolmos, a professor at Aalborg University and a leading figure in engineering education research, has extensively studied Problem-Based Learning (PBL) and Project-Based Learning (PjBL). Her role as the Founding Director of the UNESCO Centre for Problem-Based Learning in Engineering Science and Sustainability underscores her influence on global educational practices.

Roger G. Hadgraft, a civil engineer with over 30 years of experience, is known for reforming engineering curricula to integrate project-based learning. His leadership in introducing interdisciplinary programs at institutions such as Monash University and the University of Technology Sydney reflects his innovative approach to engineering education.

Jette Egelund Holgaard, also from Aalborg University, has contributed significantly to research on sustainability and interdisciplinary education in engineering, while Kamar Reda's work in bioengineering at Harvard focuses on systems thinking and its application in solving complex human challenges.

Together, these authors argue that the traditional, mathematically focused engineering curriculum is insufficient for addressing today's multifaceted global challenges, such as climate change, digitalization, and sustainability. The book also highlights the role of policymakers—those who shape educational policies and curricula at national and institutional levels—in driving this transformation. Relevant policymakers include educational ministries, such as the U.S. Department of Education or the European Commission's Directorate-General for Education, Youth, Sport and Culture, as well as accreditation bodies like ABET, which set standards for engineering programs. Governmental agencies responsible for workforce development, such as the National Science Foundation (NSF) or similar bodies globally, are also key stakeholders who can benefit from the insights offered in this book. This makes the book an essential resource not only for educators and researchers but also for policymakers seeking to align engineering education with the needs of a rapidly evolving, interdisciplinary world.

Summary and opinions

Summary of Key Themes

The authors structure the book into four parts: *Systems Thinking and Design, Learning Processes for Students and Academics, Case Studies from International Universities,* and *Recommendations for Implementing Change*. In Part I, the authors emphasize the growing complexity of human challenges and the critical role systems thinking plays in addressing these issues. Systems thinking encourages engineers to view problems as interconnected, involving technical, social, and environmental elements, which must be addressed collectively rather than in isolation. The authors argue that this approach is vital for developing solutions that are sustainable and scalable.

Part II delves into the learning processes needed to cultivate systems thinkers. It emphasizes that both students and academics must adopt new pedagogies that prioritize problem-based learning (PBL) and project-based learning (PjBL). These methods encourage active learning, critical thinking, and real-world problem-solving, all of which are crucial in today's engineering landscape. By transforming how engineering students learn and engage with complex challenges, institutions can better prepare graduates for the interdisciplinary demands of modern engineering. However, implementing PBL and PjBL methodologies is not without challenges. For instance, scaling these pedagogies across diverse educational contexts can be hindered by varying institutional support, faculty readiness, and student engagement levels (Hmelo-Silver, 2004). While this book highlights the transformative potential of PBL and PjBL, the implementation of these methodologies faces significant barriers. Faculty often require substantial retraining to transition from traditional lecture-based teaching to interactive learning methods. Moreover, students may resist active learning due to unfamiliarity, preferring the structure of conventional instruction.

To address these challenges, adaptable frameworks tailored to institutional contexts are needed. For example, modular PBL structures can be integrated into existing curricula with minimal disruption. Additionally, faculty development programs, such as peer-mentoring initiatives and workshops focusing on active learning strategies, can bridge gaps in readiness. Studies like those by Peña & de les Valls (2023) underscore the effectiveness of such tailored professional development programs in improving educational outcomes.

Part III presents a series of case studies from universities in the United States, Denmark, and Australia, illustrating how different institutions have adopted these pedagogies. For example, Harvard University's engineering program focuses on design thinking and interdisciplinary collaboration, while Aalborg University in Denmark implements a problem-based approach that emphasizes teamwork and societal impact. These case studies serve as valuable examples of how diverse institutional contexts can adopt similar approaches to achieve successful educational outcomes.

Finally, Part IV offers ten key recommendations for institutions looking to reshape their engineering curricula. These include adopting design-oriented and interdisciplinary approaches, focusing on societal needs, and fostering environments that promote active, hands-on learning. The recommendations provide practical steps for universities to begin transforming their programs, making this section an actionable guide for future reforms.

Detailed Discussion on Part II: Learning processes for both students and academics

Although all sections offer valuable insights, Part II emerges as particularly critical for advancing research in engineering education. This part not only explores the pedagogical shift required to cultivate systems thinking and interdisciplinary collaboration but also highlights the importance of changing both student and academic mindsets to foster creativity, adaptability, and problem-solving skills.

One of the key takeaways from this section is the potential of PBL and PjBL to create more engaging and effective educational environments. These pedagogies place students at the centre of their learning, encouraging them to tackle real-world problems in collaborative settings. By working on authentic, complex challenges, students develop the critical thinking and teamwork skills that are essential for modern engineers. Moreover, these methods allow for the integration of multiple disciplines, reflecting the interconnected nature of today's engineering problems.

In our opinion, PBL and PjBL are crucial to making engineering education more dynamic and relevant in today's world. These methods align well with the increasing complexity of global challenges, which require engineers to possess not only technical expertise but also the ability to work effectively in teams and across disciplines. For example, Guerra et al. (2023) conducted a qualitative study examining the impact of PBL on critical thinking, collaboration, and real-world problem-solving skills among engineering students. By focusing on interdisciplinary team projects, their research demonstrated how PBL fosters adaptability and creativity—skills that are often underdeveloped in traditional engineering curricula. This evidence reinforces the argument that PBL is a crucial pedagogical approach for modern engineering education.

For future research, there is a need to explore how these active learning environments can be further optimized to support diverse learning styles and needs. Studies by Hmelo-Silver (2004) and Chen et al. (2023) emphasize the importance of adapting PBL to different contexts and student demographics, but more work is required to understand the long-term impacts of these pedagogies, particularly in terms of employability, innovation, and leadership in interdisciplinary teams. Additionally, the role of technology in enhancing these learning processes—such as using artificial intelligence (AI), big data, and digital simulations—offers fertile ground for future studies. As the book suggests, integrating advanced technologies into engineering curricula can provide students with the tools they need to address complex systems more effectively (Du et al., 2022). Emerging technologies, such as artificial intelligence (AI) and digital simulations, offer significant potential to address the complexities of modern engineering education. AI-powered adaptive learning platforms, as discussed by Chen et al. (2023), can personalize content to help students learn at their own pace while addressing individual gaps. Similarly, AI tools for teamwork, like natural language processing (NLP) applications, enhance collaboration by summarizing technical documents, managing timelines, and improving communication.

Digital simulations further enrich the learning experience by immersing students in realistic, risk-free environments. For instance, civil engineering simulations allow students to design and test infrastructure projects using real-time data, fostering critical thinking and problem-solving skills (Hmelo-Silver, 2004). Future research should focus on the long-term impacts of these tools on skill development, employability, and innovation capacity.Another critical area for future research is the impact of these pedagogies on diversity in engineering education. As engineering programs around the world continue to struggle with gender and racial disparities, understanding how PBL and PjBL can create more inclusive learning environments is of utmost importance. Research should focus on how these methodologies affect underrepresented groups in STEM and whether they can help close the gap in participation and success for women and minorities in engineering fields. Felder & Brent (2007) argue that cooperative learning environments like PBL can help reduce the sense of isolation often felt by underrepresented students, fostering a more inclusive atmosphere.

Finally, the role of educators in this transformation cannot be overlooked. Part II emphasizes that faculty must also adapt to new teaching methods and mindsets. Future research should examine the most effective ways to train and support educators as they implement these pedagogies. This could include exploring professional development programs, peer mentoring, and other support systems that enable educators to successfully shift from traditional lecture-based teaching to more interactive, student-centred approaches. According to Peña & de les Valls (2023), professional development in PBL and PjBL has proven effective in improving teaching practices and aligning them with contemporary educational goals.

Conclusion

In conclusion, the book *Reshaping Engineering Education: Addressing Complex Human Challenges* compellingly advocates for a reimagined approach to educating future engineers. The systems-based approach and emphasis on interdisciplinary learning outlined in the book provide a comprehensive framework for educational reform. Part II, in particular, offers valuable insights into the pedagogical shifts needed to prepare students for the challenges of the 21st century, making it a prime area for future research. By continuing to explore how PBL, PjBL, and digital technologies can enhance learning and promote diversity, researchers and educators can contribute to creating more effective and equitable engineering education systems. This book serves as an essential guide for anyone involved in engineering education reform and provides a solid foundation for future studies. This book serves as an indispensable resource for educators, policymakers, and curriculum designers. For educators, it offers actionable insights on adopting and scaling PBL and PjBL methodologies to enhance student engagement and learning outcomes. Policymakers, in turn, can utilize the book's recommendations to better align engineering curricula with global workforce demands, fostering interdisciplinary competencies that address societal challenges.

Curriculum designers, particularly those in accreditation agencies like ABET, can leverage its frameworks to develop standards emphasizing hands-on, systems-thinking approaches. Collectively, these stakeholders can drive the systemic changes necessary to reshape engineering education and prepare future engineers for the demands of the 21st century.

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The authors declare no conflict of interest.

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UMS-ALIEN: UMS Active Learning in Engineering Education

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Abstract
The Universiti Malaysia Sabah Active Learning in Engineering Education (UMS-ALIEN) initiative, part of the UMS Future Ready Engineering Educators (UMS-Future) framework, introduces a structured, hierarchical approach to engineering education. The framework consists of ten progressive competency levels, starting with foundational active learning techniques and advancing to blended cooperative problem-solving methodologies. UMS-ALIEN integrates strategies such as cooperative learning, problem-based learning, and blended learning, supported by tools like Learning Management Systems (e.g., Moodle) and discipline-specific simulators (e.g., Aspen HYSYS). The initiative transitions educators from traditional roles to facilitators, fostering participatory learning environments that prepare students for real-world challenges. Implemented across multiple engineering courses, UMS-ALIEN demonstrates improvements in student performance and skill acquisition, earning international recognition for its innovative contributions to active and blended learning in engineering education.

Keywords: Active Learning; Blended Learning; Engineering Education; Cooperative Learning.

Introduction

The Universiti Malaysia Sabah (UMS) Active Learning in Engineering Education (UMS-ALIEN) initiative, refer to Figure 1, part of the UMS Future Ready Engineering Educators (UMS-Future) framework (see Figure 2), addresses the urgent need for innovation in engineering education. Traditional lecture-based approaches, while effective for content delivery, often fail to actively engage students, foster critical thinking, or bridge the gap between theoretical knowledge and practical applications. In response, UMS-ALIEN adopts a structured, hierarchical framework designed to transform engineering education through active and blended learning methodologies.

UMS-ALIEN features ten progressive competency levels, beginning with foundational active learning techniques and advancing to collaborative and cooperative problem-solving approaches. Each level represents an evolution in teaching strategies, enabling educators to transition from traditional roles to facilitators of student-centered learning. This progression emphasizes the cultivation of critical skills, including collaboration, problem-solving, and adaptability, which are essential for preparing industry-ready graduates (Felder, & Brent, 2007).

The framework is adaptable across various engineering disciplines, integrating both general and discipline-specific tools tailored to course objectives. For instance, Moodle serves as a versatile Learning Management System (LMS), while tools like Aspen HYSYS for chemical engineering, CAD software for mechanical engineering, and Python or MATLAB for computational tasks enhance discipline-specific learning. These tools enable the framework to support diverse instructional needs while maintaining a unified focus on active learning.

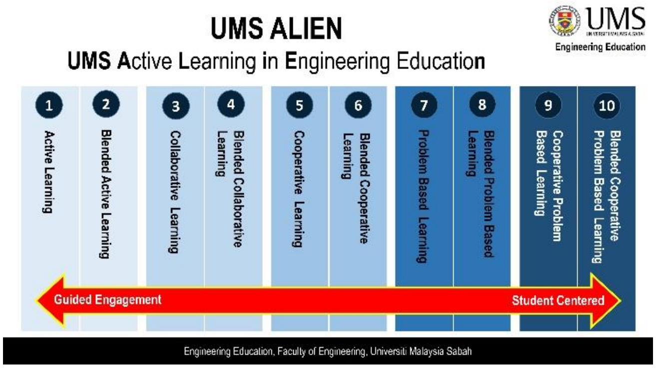

Figure 1. UMS Active Learning in Engineering Education (UMS-ALIEN)

Since its implementation, UMS-ALIEN has been successfully adopted in multiple engineering courses, showcasing significant improvements in student engagement, critical thinking, and learning outcomes. These outcomes are bolstered by the initiative's ability to blend digital tools with participatory teaching methodologies, creating dynamic learning environments. The hierarchical structure of UMS-ALIEN ensures educators are equipped to implement increasingly complex and impactful pedagogies, transforming the teaching and learning experience in engineering education (Prince, 2004).

Furthermore, UMS-ALIEN has gained international recognition for its innovative approach, particularly in areas such as micro-credentialing and blended learning. These achievements underscore the framework's potential as a model for modern engineering education, demonstrating its capacity to prepare students for real-world challenges in a rapidly evolving global landscape.

Figure 2. UMS Future Ready Engineering Educators (UMS-Future)

Conceptual Framework of UMS-ALIEN

The UMS-ALIEN framework presents a structured, hierarchical approach designed to enhance teaching and learning in engineering education. This framework comprises ten progressive competency levels, each building upon the previous to systematically transition educators from traditional teaching roles to facilitators of student-centered, active learning. The framework emphasizes the integration of active, blended, collaborative, and cooperative learning strategies, supported by both in-person and digital tools tailored to various engineering disciplines (Graham, 2013).

Hierarchical Learning Levels and Differentiated Approaches

The UMS-ALIEN framework organizes its learning levels to foster comprehensive skill development among educators and students. Initial levels introduce foundational active learning techniques, such as discussions and hands-on tasks, while maintaining educator guidance to ensure structured engagement. As competency levels increase, students are exposed to blended and collaborative learning methods that encourage teamwork, accountability, and communication.

Higher levels emphasize cooperative learning and problem-based learning (PBL), culminating in blended cooperative problem-solving, where students address complex, real-world engineering challenges (Freeman et al., 2014). This progression aligns with the demands of modern engineering education, preparing students to think critically and collaborate effectively in diverse, industry-relevant scenarios (Strobel, & van Barneveld, 2009).

Integration of Digital Tools Across Disciplines

A key strength of UMS-ALIEN is its adaptability across engineering disciplines, supported by the integration of digital tools. For example, LMS such as Moodle provide a platform for managing course content, facilitating discussions, and tracking progress. Discipline-Specific Tools such as Aspen HYSYS (chemical engineering), CAD software (mechanical engineering), MATLAB or Python (computational tasks), and Proteus (electrical engineering) ensure relevance to industry practices. These tools enable educators to tailor their teaching strategies to align with course objectives while providing students with hands-on experience in tools commonly used in their respective fields. This multidisciplinary adaptability ensures that UMS-ALIEN remains relevant and inclusive, catering to the diverse needs of engineering education while maintaining a unified, systematic approach (Johnson, et al., 2015).

Transition from Instructor to Facilitator

One of the most transformative aspects of the UMS-ALIEN framework is the transition it facilitates for educators, guiding them from traditional teaching roles to facilitators of active learning. As educators progress through the framework, their role evolves to empower students in self-directed learning, fostering independence and collaborative skills essential for lifelong learning. This shift aligns with the demands of the engineering industry, where graduates are expected to navigate complex challenges autonomously and collaboratively (Weimer, 2013).

Impact and Flexibility of UMS-ALIEN

UMS-ALIEN has been successfully implemented across multiple engineering courses, resulting in significant improvements in student engagement, problem-solving skills, and collaborative abilities. Its hierarchical structure provides a flexible model that can be adapted to different engineering disciplines and course requirements. Additionally, the framework's integration of active and blended learning methodologies ensures that it remains at the forefront of innovative teaching practices.

By bridging the gap between theoretical knowledge and practical application, UMS-ALIEN equips students with the skills needed to excel in the engineering industry. This systematic approach not only enhances teaching effectiveness but also prepares students for real-world challenges, illustrating the transformative potential of active and blended learning in engineering education.

Goals and Anticipated Outcomes

The UMS-ALIEN framework ultimately aims to prepare educators and students alike to embrace active and blended learning models. By systematically advancing through the competency levels, UMS-ALIEN fosters an engaging, participatory learning culture that enhances students' critical thinking, technical skills, and adaptability to real-world engineering challenges (Spady, 1994). This structured approach not only transforms the teaching and learning experience but also establishes UMS-ALIEN as a model for innovative engineering education that prepares future-ready graduates for a dynamic world.

Levels of Learning in the UMS-ALIEN Framework

The Levels of Learning in the UMS-ALIEN framework offer a sequential, structured pathway to progressively enhance both teaching effectiveness and student learning outcomes. This hierarchical design begins with foundational skills and advances to complex, collaborative methodologies, ultimately preparing students for real-world engineering challenges and enabling educators to facilitate deeper, student-centered learning.

1. Active Learning

At the foundational level, active learning engages students directly in the learning process through discussions, problem-solving activities, and hands-on tasks. Here, students begin developing basic analytical and application skills in a supportive, structured environment. Educators play an active role, guiding students and ensuring a robust understanding of key concepts.

2. Blended Active Learning

Building on active learning, blended active learning introduces a combination of face-to-face and online interactions to reinforce the material. This approach enables students to engage with learning materials at their own pace outside of the classroom, enhancing retention and encouraging independent study.

3. Collaborative Learning

In this level, students engage in group-based activities that promote teamwork and communication. Collaborative learning is designed to foster interdependence, as students work together to achieve common goals. Educators begin to take on a more supportive, facilitative role, encouraging students to take ownership of the learning process while still providing necessary guidance.

4. Blended Collaborative Learning

Blended collaborative learning incorporates digital tools and resources to support group-based activities in and out of the classroom. Students work together on shared projects or discussions via online platforms, which fosters continuous interaction and enables flexibility in collaborative engagement. This level builds communication skills and accountability among team members.

5. Cooperative Learning

Cooperative learning introduces structured team-based tasks, where each member is responsible for a specific role or task within the project. This approach not only emphasizes individual accountability but also enhances teamwork, as success depends on each member's contribution. Educators further transition into a facilitative role, supporting team dynamics and encouraging problem-solving within groups.

6. Blended Cooperative Learning

Here, cooperative learning is integrated with online components, allowing students to coordinate tasks and responsibilities digitally. Platforms like Moodle enable team members to communicate and track each other's progress, supporting an environment where teamwork and accountability are reinforced in both physical and virtual spaces.

7. Problem-Based Learning

Problem-based learning (PBL) challenges students with open-ended, real-world problems that require critical thinking, analysis, and solution-oriented approaches. In PBL, students actively engage with complex scenarios, applying theoretical knowledge to develop viable solutions. Educators guide this process by acting as facilitators, providing support without directly intervening in problem-solving.

8. Blended Problem-Based Learning

At this level, problem-based learning incorporates online tools to enhance flexibility and depth in addressing complex problems. Digital resources and simulations allow students to explore different problem-solving approaches and test solutions. This blended approach enables students to access resources, collaborate remotely, and delve deeper into analytical tasks.

9. Cooperative Problem-Based Learning

Combining elements of cooperative and problem-based learning, this level requires students to work in structured teams to tackle challenging, real-world engineering problems. Each team member takes on specific roles within the problem-solving process, promoting interdependence and critical thinking within the group. Educators function as mentors, encouraging independent inquiry and peer learning.

10. Blended Cooperative Problem-Based Learning

At the most advanced level, blended cooperative problem-based learning fully integrates online resources and digital platforms to support comprehensive, team-based problem-solving. Students work collaboratively on real-world engineering challenges, leveraging both in-person and virtual interactions to coordinate roles, discuss solutions, and apply technical skills in an immersive setting. This level cultivates high-level competencies in teamwork, critical thinking, and practical problem-solving.

Educator's Role and Student Autonomy

A core principle of the UMS-ALIEN framework is its emphasis on transforming the educator's role from a traditional instructor to a facilitator of active learning. This transformation aligns with the framework's hierarchical progression, guiding educators to adopt teaching practices that empower students to take ownership of their learning journey. As educators advance through the competency levels, their role evolves to support and nurture student autonomy, fostering an environment that encourages active participation, critical thinking, and collaboration.

Transitioning from Instructors to Facilitators

At the foundational levels, educators play a more directive role, introducing students to active learning techniques such as structured discussions, guided problem-solving, and hands-on tasks. These activities, while student-centered, are initiated and closely monitored by the educator to ensure proper engagement and understanding. As the levels progress, educators begin to adopt a facilitative approach, gradually transferring responsibility to students.

In the intermediate levels, the educator's role shifts to designing collaborative and cooperative learning activities, where students work in teams to tackle structured tasks. At this stage, educators serve as mentors, providing guidance and support while encouraging students to manage their team dynamics, contribute equitably, and make collective decisions.

At the advanced levels, particularly in problem-based and blended cooperative problem-solving contexts, educators fully transition into facilitators. Here, they provide minimal direct instruction, instead fostering a learning environment where students independently analyze complex problems, explore solutions, and apply technical skills collaboratively. This approach mirrors real-world engineering scenarios, preparing students for industry challenges by encouraging self-reliance and adaptability.

Promoting Student Autonomy

The UMS-ALIEN framework is designed to cultivate student autonomy by progressively reducing reliance on educator-led instruction. Through active and blended learning strategies, students are encouraged to take initiative in their education by engaging in self-directed learning activities, collaborating effectively with peers to solve open-ended problems and reflecting on their learning processes to identify strengths and areas for improvement.

This autonomy is further reinforced through the use of digital tools, such as Learning Management Systems and discipline-specific simulators, which enable students to access resources, revisit concepts, and practice skills independently.

UMS-ALIEN Implementation in Chemical Engineering Courses

The UMS-ALIEN framework has been effectively implemented across several chemical engineering courses at UMS, including Process Simulation, Programming, and Process Design. These courses, each with distinct learning objectives and challenges, were chosen for their relevance to UMS-ALIEN's active and blended learning methodologies, which help bridge the gap between theoretical concepts and practical applications in engineering education. The structured, progressive approach of UMS-ALIEN supports students in mastering essential engineering skills through real-world challenges and industry-aligned projects.

It should be noted that the UMS-ALIEN framework is designed around the individual engineering educator's competencies in implementing the ten hierarchical levels of the framework. The examples provided in this manuscript, which apply the blended-cooperative learning method, reflect the specific competency and expertise of the author in this approach. However, it is important to note that there are several ongoing implementations of UMS-ALIEN across different competency levels, representing diverse strategies and methodologies. These implementations, which further showcase the flexibility and adaptability of the framework, are not included in this manuscript but remain areas of active development and exploration.

1. Chemical Engineering Process Simulation

In Process Simulation, UMS-ALIEN incorporates a blended-cooperative learning framework designed to help students apply theoretical knowledge through simulation tools. Leveraging the TPACK (Technological, Pedagogical, and Content Knowledge) framework (Koehler et al., 2013), this course integrates UMS ITEL (Moodle), a self-paced process simulation MOOC, and the Aspen HYSYS Process Simulator (refer Figure 3). UMS ITEL is an e-learning platform based on Moodle version 4. These resources provide students with practical experience in simulating complex chemical processes, aligning with industry standards. The blended approach combines online modules with in-person support, allowing students to develop their skills in an interactive, self-directed environment that mirrors real-world engineering scenarios.

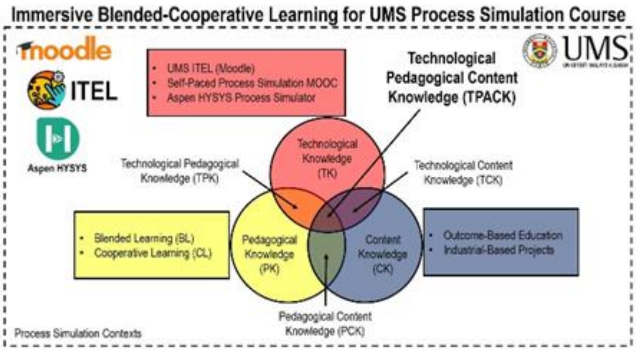

Figure 3. Immersive Blended-Cooperative Learning for UMS Process Simulation Course

2. Chemical Engineering Programming

For Programming, UMS-ALIEN utilizes a blended-cooperative learning model to build foundational technical skills and foster collaboration. The TPACK framework is applied here through UMS SmartV3 e-Learning (Moodle), MathWorks Online, and MATLAB Programming, as shown in Figure 4, which support both individual and team-based learning. UMS SmartV3 is an e-learning platform based on Moodle version 3. This setup enables students to gain proficiency in MATLAB while developing problem-solving skills critical for programming applications in engineering. The course's outcome-based design focuses on achieving measurable competencies in coding, troubleshooting, and team collaboration, which are reinforced through practical projects that reflect industry needs.

It should be noted that the pedagogical knowledge applied in the TPACK framework varies based on the delivery context of each course. For the Engineering Programming course, offered during the COVID-19 pandemic, the pedagogical approach emphasized online learning, leveraging fully virtual platforms to support remote instruction. In contrast, the Process Simulation course, conducted post-pandemic when students returned to campus, adopted a blended learning approach. This method combines face-to-face instruction with digital tools, providing a hybrid learning experience that integrates the flexibility of online resources with the benefits of in-person interactions.

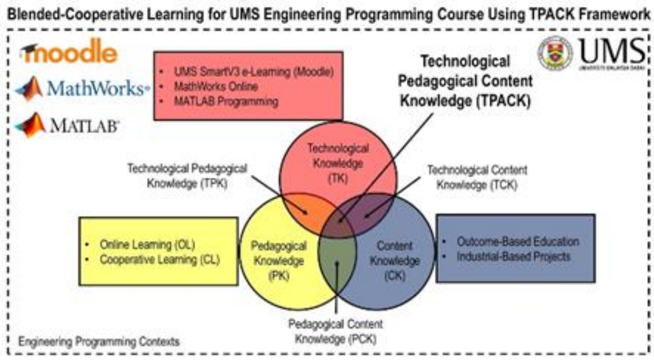

Figure 4. Blended-Cooperative Learning for UMS Engineering Programming Course

3. Chemical Engineering Process Design

The Process Design course integrates the blended-cooperative learning framework, using UMS ITEL (Moodle), UMS MOOC, and Aspen HYSYS Process Simulator (refer to Figure 5). This combination of digital and in-person resources enables students to work through complex design projects in teams, aligning closely with engineering design processes used in industry. Through outcome-based education (OBE) and industry-based projects, the course encourages students to tackle real-world challenges, from initial problem analysis to solution development. This hands-on approach enhances their technical expertise in process design and prepares them for engineering roles that require collaborative and innovative thinking.

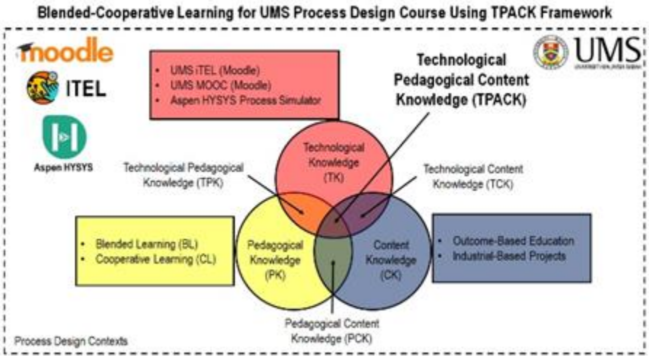

Figure 5. Blended-Cooperative Learning for UMS Process Design Course

Role of Digital Tools and TPACK Framework

The UMS-ALIEN framework integrates the TPACK framework to effectively combine digital tools with active and blended learning methodologies. This integration supports the hierarchical progression of teaching and learning levels by aligning technological resources with course objectives, pedagogical strategies, and discipline-specific content knowledge. By leveraging appropriate digital tools, UMS-ALIEN facilitates a flexible and inclusive approach to engineering education, accommodating diverse instructional needs and enhancing both teaching effectiveness and student engagement.

Strategic Integration of Digital Tools

Digital tools play a pivotal role in UMS-ALIEN, enabling educators to create dynamic learning environments that bridge theoretical concepts and practical applications. The framework incorporates tools tailored to specific engineering disciplines, ensuring relevance and effectiveness in achieving learning outcomes. Examples include:

- **Learning Management Systems (e.g., Moodle)**: Used as a platform for content delivery, assignment submission, and collaborative discussions across disciplines.
- **Discipline-Specific Tools**:
  - *Aspen HYSYS*: Supports process simulation in chemical engineering.
  - *MATLAB and Python*: Facilitate computational tasks and programming across multiple fields.
  - *CAD Software*: Enhances mechanical engineering design projects.
  - *Proteus*: Assists in circuit design for electrical engineering.

These tools not only provide practical, hands-on experience but also promote independent and collaborative learning by allowing students to engage with complex simulations, designs, and computations at their own pace.

Application of the TPACK Framework

The TPACK framework ensures a cohesive integration of technology, pedagogy, and content to optimize teaching and learning in UMS-ALIEN. For instance:

- **Technological Knowledge**: Digital tools like Aspen HYSYS and MATLAB are selected based on their alignment with course content and their ability to simulate real-world scenarios.
- **Pedagogical Knowledge**: Active, collaborative, and problem-based learning strategies are applied to create engaging and participatory learning experiences.
- **Content Knowledge**: Each tool is used to deepen students' understanding of engineering concepts, aligning with specific course objectives and industry requirements.

This alignment enables educators to tailor their teaching strategies to the unique needs of their courses while maintaining a consistent focus on student-centered learning.

Outcome-Based Education and Industry Alignment

A key component of UMS-ALIEN's implementation is its alignment with outcome-based education and industry standards. Each course incorporates industry-based projects, which provide students with realistic challenges that mirror professional engineering practices. Through these projects, students develop essential skills such as teamwork, technical proficiency, and adherence to industry standards. This alignment ensures that students are not only meeting academic goals but also acquiring competencies highly valued in the engineering field.

Student Benefits and Measurable Outcomes

The implementation of UMS-ALIEN in these courses has demonstrated positive outcomes, including increased student engagement, improved teamwork, and enhanced technical skills. Feedback from students has highlighted the value of interactive simulations and group projects in solidifying their understanding of complex engineering concepts. Additionally, UMS-ALIEN's success has been recognized through awards, further validating its impact on student learning and engagement in engineering education.

Future Applications and Scalability

Given the success of UMS-ALIEN in these courses, its methodology presents opportunities for expansion into other engineering disciplines at UMS. The framework's adaptability to different course structures and objectives positions it as a scalable model for engineering education, capable of preparing future-ready graduates across multiple fields (Halverson, & Graham, 2019).

UMS-ALIEN Impact Towards Teaching and Learning

The UMS-ALIEN framework has significantly advanced teaching and learning in engineering education at UMS. Its impact is reflected not only in international recognitions but also in tangible improvements in student engagement, knowledge retention, and critical thinking skills. By transforming educators into facilitators and employing innovative active and blended learning methods, UMS-ALIEN cultivates an interactive, skills-oriented learning environment that aligns with modern industry expectations.

Recognition of Micro-Credentialing Innovation

UMS-ALIEN's commitment to modular, flexible learning pathways has been widely recognized, especially for its pioneering use of micro-credentials. These focused learning units allow students to gain verified skills in specialized areas, adding value to their educational experience and enhancing their readiness for specific industry roles (Oliver, 2019). Key accolades include:

- **The Best Micro-Credential in e-CONDEV 2022**: This award highlights UMS-ALIEN's innovative approach to micro-credentialing, underscoring its role in promoting specialized, adaptable learning opportunities within engineering education.
- **Gold Medal in the MOOC Competition at e-CONDEV 2023**: This award for UMS-ALIEN's Massive Open Online Course (MOOC) demonstrates the framework's commitment to creating accessible, high-quality educational content, further extending UMS-ALIEN's reach and influence.

Achievements in Creative and Blended Learning Integration

UMS-ALIEN's excellence in integrating e-learning and active learning strategies has garnered significant recognition, emphasizing its creative and effective approach to modern education:

- **Gold Medal at i-PICTL 2022**: This award, received at the International Putra InnoCreative in Teaching and Learning, recognizes UMS-ALIEN's unique ability to engage students through active and immersive learning techniques. The accolade highlights the framework's creative contributions to enhancing the learning experience.
- **Gold Medal at IUCEL 2022**: Presented at the International University Carnival on E-Learning, this award underscores UMS-ALIEN's success in blending technology with pedagogy, making learning more interactive and accessible. It reflects the framework's versatility in adapting to diverse learning styles and environments.
- **Gold Medal at i-PICTL 2023**: Awarded again at the International Putra InnoCreative Expo, this recognition reaffirms UMS-ALIEN's impact on student engagement and cooperative learning in engineering education.

Direct Impact on Teaching and Learning Outcomes

The impact of UMS-ALIEN is also evident in measurable improvements in student learning outcomes and teaching effectiveness. By focusing on real-world applications and collaborative learning, the framework has increased student engagement, fostered higher-order thinking, and strengthened essential skills like teamwork and problem-solving.

Figure 6 presents the results of a thematic analysis of students' learning reflection journals from the KC32603 Process Simulation & Integration course. The analysis identifies the top 10 skills that students developed through their participation in the course, with the skills ranked according to their normalized scores.

Analysis of the Top Four Skills from Thematic Analysis:

1. **Teamworking (Highest Score):** Teamworking being the highest-scoring skill indicates that the KC32603 Process Simulation & Integration course strongly promotes collaboration among students. This is crucial in engineering, where projects often require multidisciplinary teamwork to solve complex problems. The high score suggests that students are not only engaging in teamwork but also mastering the ability to work effectively in teams, sharing responsibilities, and learning from each other.

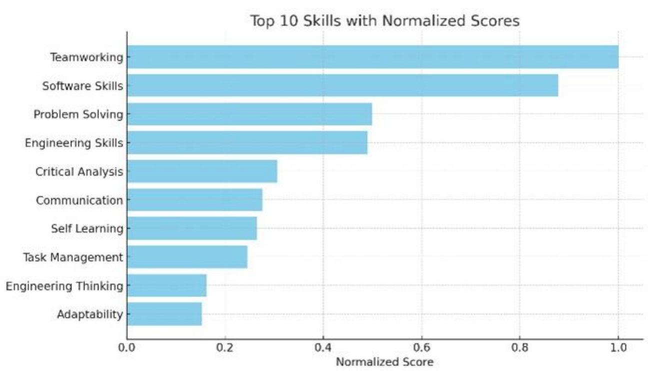

Figure 3: Top 10 Skills Developed by Students under IBCL Implementation

2. **Software Skills:** The significant emphasis on software skills highlights the course's focus on ensuring students are proficient with the technical tools required in the engineering industry. This likely includes simulation software such as Aspen HYSYS, which is central to process engineering. The high score in software skills indicates that students are gaining practical,

hands-on experience with these tools, which is essential for their future roles in the industry where digital competency is increasingly important.

3. **Problem Solving:** Problem-solving is a critical skill in engineering, and its high ranking reflects the course's success in developing students' abilities to approach and resolve complex challenges. The course likely uses PBL techniques to engage students in real-world scenarios, requiring them to apply their knowledge and critical thinking skills to find effective solutions. This skill is particularly vital in process simulation, where students must navigate and resolve intricate system behaviors and design issues.
4. **Engineering Skills:** The high score in engineering skills underscores the course's effectiveness in teaching core engineering principles and practices. Students are likely engaging in activities that require the application of theoretical concepts to practical situations, bridging the gap between classroom learning and real-world engineering. This suggests that the course successfully equips students with the fundamental engineering skills needed for their professional careers, ensuring they can translate academic knowledge into practical applications.

Feedback and Future Influence

Feedback from students and educators highlights the value of UMS-ALIEN's practical and interactive learning approach. Students appreciate the hands-on projects and simulations that enhance their understanding of complex engineering concepts, while educators find the framework beneficial for fostering an active learning culture. The continuous recognition and success of UMS-ALIEN emphasize its potential to influence engineering education broadly, offering a scalable model adaptable across various disciplines and institutions.

Conclusion

The UMS-ALIEN framework has proven to be a transformative approach in engineering education, significantly advancing teaching practices and student learning outcomes at UMS. By integrating active and blended learning models with digital tools, UMS-ALIEN equips students with essential skills, such as critical thinking, collaboration, and problem-solving, that are crucial for thriving in today's complex, fast-paced engineering environments. Through its structured, progressive learning levels, the framework not only engages students but also enables educators to transition from traditional instructional roles to facilitators of interactive, student-centered learning.

UMS-ALIEN's success is evidenced by measurable improvements in student engagement, higher-order thinking, and teamwork across multiple courses. For instance, the implementation of cooperative problem-based learning, supported by digital tools like Aspen HYSYS, has allowed students to work collaboratively on realistic engineering challenges, resulting in improved technical competencies and industry-aligned skills. Furthermore, the international recognition of UMS-ALIEN's innovative approach, including awards such as the Best Micro-Credential in e-CONDEV 2022, highlights its impact on e-learning and micro-credentialing, underscoring the framework's role as a benchmark in modern engineering education.

Looking ahead, UMS-ALIEN offers substantial potential for scalability, presenting a versatile model adaptable across other engineering disciplines and institutions. By expanding its application, UMS-ALIEN could serve as a foundational approach to education reform, promoting active and blended learning in diverse academic contexts. As the framework continues to evolve, it can inspire educational institutions worldwide to adopt modular, adaptable learning pathways that prepare students for real-world challenges.

In summary, UMS-ALIEN has established itself as a pioneering framework that aligns with industry expectations and prepares future-ready graduates. Its achievements serve as a call to action for educators and institutions to explore similar innovative pedagogies, positioning UMS-ALIEN as a model for driving impactful, student-centered learning in engineering education and beyond.

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Conflict of Interest

The author declares no conflict of interest.

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Competency-Based Learning for Improved Teaching and Learning the Thermodynamics Course for Chemical Engineering Students

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Abstract
A proper design of the Competency-Based Learning (CBL) teaching and learning (T&L) environment is crucial for attaining the desired learning outcomes (DLOs), by chemical engineering students. This paper aims to analyze the successful practices of implementing common CBL elements into the existing OBE, ABET-accredited, chemical engineering curriculum, without disturbing the logistics of the current engineering programs. The paper describes and analyzes the implementation of a CBL environment in teaching thermodynamics, as an example of typical chemical engineering courses, at Higher Colleges of Technology (HCT), United Arab Emirates (UAE). The analysis considered teaching thermodynamics after and before CBL implementation, during the 2023-24 and 2022-23 academic years, respectively. The process included scaffolding steps necessary for engineering students to attain DLOs. In addition, the process may serve as a metric for educators in CBL implementation across other engineering courses.

Keywords: Competency-Based Learning (CBL), Chemical Engineering Courses, Thermodynamics.

Introduction

Globally engineering education programs strive to graduate quality engineers, equipped with discipline-related knowledge and the necessary set of skills, to face the current and future challenges of the job market (Rugarcia et al., 2000). Moreover, many researchers in the area of engineering education have been emphasizing that the implementation of advanced T&L philosophies is one of the key factors in meeting the increasing industrial demand for quality engineers (Felder and Brent, 2017; Felder, 2006; Felder et al., 2000; Boyer, 1990). Competency-based learning (CBL) represents one of these advanced student-centered learning methods. CBL is a very intriguing framework, and it has been gaining popularity in higher education, including engineering education, as well as in workplace training (Sistermans, 2020; Torres et al. 2015)

Higher Colleges of Technology (HCT) is the largest academic institution in the United Arab Emirates (UAE). Established in 1988, HCT has extended into 16 campuses distributed throughout the UAE. Currently, HCT accommodates more than 23 thousand students; they enrolled in 70 programs in Applied Media, Business, Computer Information Science, Engineering Technology & Science, Education, and Health Sciences. Female students make up more than 68% (or 14,669 students) of the total enrolled students, while the remaining 32% (or 6,903 students) are male students. Engineering Technology & Science (ETS) students make up almost one-fourth of the total (or 5,194 students), and there is a reasonable gender balance among them: 46% are female and the remaining 54% are male engineering students. Engineering students enrolled in 12 programs: Aeronautical, Aviation, Chemical, Civil, Electrical, Industrial, Logistics, Mechanical, Mechatronics, Marine, Marine Transport, and Maritime Engineering Technology (HCT website).

HCT offers a bachelor in chemical engineering technology program upon completion of 120 credit hours, distributed over 4 academic years. This workload covers four categories of courses: Engineering Core, Math & Natural Sciences, Electives, and General Studies. Like all other engineering programs, Chemical engineering is an ABET-accredited program, and it has been structured based on outcome-based education (OBE). Table 1 shows the Course Learning Outcomes (CLOs) (HCT- Chemical Technology). The first five POs are based on ABET Student Outcomes, which are related to the knowledge, skills, and behaviors that students gain through the study program, and describe what students are expected to know and do after graduation (ABET, 2019)]. The sixth PO reflects one of the HCT strategic undertakings.

HCT continuously seeks to improve its engineering programs, to graduate employable engineers with proper knowledge and the right skills. Continuous improvement has a double role: one is to meet ABET's requirement of continuous improvement, and the other is to observe one of HCT 4.0 strategic undertakings.

Table 1. Chemical engineering course learning outcomes (HCT- Chemical Technology)

Program Outcomes (POs)
1. An ability to apply knowledge, techniques, skills, and modern tools of mathematics, science, engineering, and technology to solve broadly defined engineering problems appropriate to the Chemical Engineering Technology.
2. An ability to design systems, components, or processes meeting specified needs for broadly defined engineering problems appropriate to the Chemical Engineering Technology.
3. An ability to apply written, oral, and graphical communication in broadly defined technical and non-technical environments; and the ability to identify and use appropriate technical literature.
4. An ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes.
5. An ability to function effectively as a member as well as a leader on technical teams.
6. An ability to develop and evaluate a business plan to transform an engineering design (systems, products, services, and solutions) into a business opportunity utilizing entrepreneurial skills and knowledge.

Thermodynamics

The year 1824 is considered the birthdate of thermodynamics, and scientists consider Sadi Carnot (1796-1832) as its founder; he published, 'Reflections on the Motive Power of Fire (1824)', a discourse on heat, power, energy, and engine efficiency. The book illustrates the basic relations between the Carnot engine, Carnot's cycle, and motive power. It marked the start of thermodynamics as a modern science (Perrot, 1998).

Thermodynamics is a branch of science that deals with the study of various forms of energy: heat, work, potential energy, kinetic energy, and internal energy. It is considered one of the core engineering courses; It applies to a variety of science and engineering topics such as chemical, physical, and mechanical engineering. For example, chemical thermodynamics is extremely useful in understanding and predicting the behavior of chemical reactions (e. g. digestion, and combustion). Chemical reactions involve changes in energy, enthalpy, and entropy, which are governed by thermodynamic principles. Table 2 shows the thermodynamics learning outcomes at HCT.

Thermodynamics can be incredibly challenging because it requires knowledge of complex mathematical equations and physics principles; it involves aligning theoretical and abstract concepts to a wide range of real-life applications.

Table 2. Chemical thermodynamics learning outcomes at HCT (HCT- Chemical Technology)

Course Learning Outcome (CLO)
1. Analyze the principles of thermodynamics and the properties associated with it.
2. Distinguish the different energy transfer mechanisms during chemical processes.
3. Examine the First law of thermodynamics and the relationships between the various forms of energy in closed and open systems.
4. Examine the entropy concept of the Second Law of thermodynamics in heat engines, heat pumps, and the spontaneity of Chemical reactions.
5. Analyze the ideal vapor compression refrigeration cycle.

Thermodynamics is perceived by many as an exceedingly difficult subject to study. There is a quote on learning thermodynamics, by Arnold Sommerfeld, "Thermodynamics is a funny subject. The first time you go through it, you do not understand it at all. The second time you go through it, you think you understand it, except for one or two small points. The third time you go through it, you know you do not understand it, but by the time you are so used to it, it does not bother you anymore" (Cited in Mulop et. al., 2012).

Its difficulty arises from confusing and complex concepts such as work, heat, temperature, specific heat capacity, internal energy, pressure, enthalpy, and bond energy, which are not easy to understand. On top of that, students' misconceptions about the difference, for instance, between heat and temperature, adiabatic and isothermal processes, types of systems and their relation to surroundings, etc. (Yang et. al., 2020)

For decades, many researchers have considered issues related to learning thermodynamics, and how to resolve them.

- Zabihian (2020) introduced 'Service Learning' as a pedagogical tool through which engineering students demonstrate their thermodynamics knowledge to public audiences. It is also known as an experiential learning approach, which could be integrated into education for a deep understanding of the subject matter rather than memorizing simple facts.
- Yang and colleagues (2020) presented two studies that used schema training to help students understand challenging engineering concepts, including thermodynamics concepts: One study used Chi's schema training framework to repair engineering students' misconceptions, which was developed by Chi and colleagues (2013).
- Mulop et. al. (2012) reviewed and analyzed approaches to enhancing the learning of

thermodynamics; between 2003 and 2009, they listed the efforts of 15 researchers on the matter: Computer Simulation of Experts (Lewis et al, 1993), Interactive Thermodynamic Cycles (Weston, 1998), Virtual Lab-Cyclepad (Baher et al, 1999), TESTTM Software (Kumpathy, 2002), A Virtual Power Plant Website (Kelly, 2002), Computer-based Active Learning Materials (Anderson et al, 2002), An online Thermodynamic Courseware (Ngo & Lai, 2003), Teaching with Physlets (Cox et al, 2003), Multimedia Engineering Thermodynamics (Huang & Gramoll, 2004), Experimental Apparatus (Abu-Mulaweh, 2004), Active Learning Environment (Hassan & Mat, 2005), Simulation Programs to Perform Virtual Experiments (Junglas, 2006), Virtual assembly- a web-based student learning tool related to multi-staging in compressors and turbines (Chaturvedi et al, 2007), A blended learning approach (Bullen & Russell, 2007), and Instructional courseware in thermodynamics education (Liu,2009), (Cited in Mulop et. al., 2012). In their analysis, Mulop and colleagues concluded that most of these methods have achieved a positive impact on T&L thermodynamics, although none of them is based on learning theories (Mulop et. al., 2012).

Methodology

Research Purpose

This paper aims to describe and analyze CBL implementation to improve the teaching and learning environment of a typical chemical engineering course. The paper used a Case Study in Thermodynamics.

Scope

The scope of the study is limited to analysis of the T&L environment of chemical thermodynamics, as an example, during the Fall and Spring semesters of the 2023-24 academic year; however, the analysis could be extended to other chemical engineering subjects.

Method

This paper uses mixed qualitative and quantitative methods to collect and analyze secondary data (Creswell, 2009). A documentary analysis of the subject of thermodynamics, before and after the implementation of the common CBL elements into the existing curriculum, was conducted. Documents were obtained from the HCT website. They include HCT's CBL guide, thermodynamics syllabus (CHE 3313), course assessment plan (CAP), assessment specification documents (ASD), HCT course assessment reports, and students' and teachers' evaluations of the overall subject. These documents were originally produced using various methods and intended for different purposes.

However, to develop realistic meanings of the gathered data, the analysis step was split into: First, this paper divided obtained documents, according to the purpose of analysis, into three parts, namely CBL implementation, assessment process, and students' performance (see Table 3). Second, the paper analyzed both obvious and deep written content, also called manifest and latent analysis, respectively (Bengtsson, 2016).

The pedagogical analysis of chemical thermodynamics was conducted, including students' performance, after CBL implementation, during the Fall and Spring semesters of the 2023-24 academic year (three courses). Their performance was tracked using both formative and summative assessments. The result compared with the students' performance, before CBL implementation over the 2022-23 academic year, also three courses.

Table 3. Purposes of Data Collection & Related Documents (HCT website)

Purpose of Analysis	Related Documents
CBL Implementation	• HCT's CBL guide (CBL principles, purposes, and practices) • Students' and teachers' evaluations
Assessment Process	• Syllabus of the course (CHE3313) • Course assessment plan (CAP) • Assessment specification documents (ASD)
Students Performance	• HCT course assessment reports • Instructors' feedback (formative assessment) • Instructors' feedback (achieved competencies)

Literature Review

Competency-based learning (CBL)

CBL has been around for more than a century ago; however, it has gained popularity, for a brief period, during the seventies of the 20th century (Gallagher, 2014). More recently, interest in CBL has increased significantly worldwide.

CBL is based on Ralph Tyler's (1949) curriculum and Spady's (1994) OBE. It is not easy to define the CBL term, and no single agreed-upon definition appears to exist (Torres et al., 2015). The lack of coherent definition of the CBL arises from the fact that researchers tend to use this term loosely and interchangeably with a wide range of other terms, known as competence-based synonyms: Criterion-Referenced (Glaser, 1963), Mastery-Based (Bloom 1968), Instructional Objectives (Major, 1970), Instructional Design (Gagne, 1974), Outcome-Based

(Spady, 1994), Performance-Based (Harden et al., 1999), Proficiency-Based, Standards-Based education, among others. Nevertheless, a reasonable CBL definition is stated by the glossary of education reform, "Competency-based learning refers to systems of instruction, assessment, grading, and academic reporting that are based on students demonstrating that they have learned the knowledge and skills they are expected to learn as they progress through their education" (Glossary of Education Reform- website). CBL is a teaching and learning framework that develops competencies based on an aligned curriculum, instruction, and assessment (Torres et. al., 2015). It is completely different from the traditional T&L methods regarding culture, pedagogy, and structure (Torres et. al., 2015; Sturgis et. all., 2018).

Unlike the traditional system, which focuses on time-based credit hours and academic grading for graduating its students, CBL is based on mastery-based grading where each student must demonstrate knowledge and skill to transfer acquired knowledge into an advanced context (Sturgis et. al., 2018). Takamine (2019) stated, "Competency-based education is an approach that evaluates the mastery of learning from a performance basis, rather than a seat-time basis".

The labor market underscores the importance of the 4-year degree program; however, the degree alone is insufficient for employment readiness (Clawson and Girardi, 2021). The degree needs to be associated with industry-relevant skills. DeMark and Kozyrev (2021) state that industry-related skills must be integrated into the learning process to support the upskilling and reskilling needs of the job market. Sturgis et. al. (2018 p11) state, "Competency-based structures place an equal emphasis upon academic knowledge, the skills to transfer and apply that knowledge (higher order skills), and a set of lifelong learning skills that enable students to be independent learners. Lifelong learning skills that empower students include growth mindset, metacognition, self-regulation, and other social and emotional skills, advocacy, and the habits of success" (Sturgis et. al., 2018 p11).

CBL has three basic components: the experiential learning approach, the competency-oriented courses and interventions, and the competency assessment process (Torres et. al., 2015; Gervais, 2016). Also, the CBL framework contains many distinguishable elements; However, this paper considers the four common elements of CBL, as defined by Torres et. al. (2015), "1) Students must demonstrate mastery of all required competencies to earn credit or graduate. 2) Students advance once they have demonstrated mastery, and students have more time to demonstrate mastery if needed. 3) Students are assessed using multiple measures to determine competency. 4) Students earn credit toward graduation in ways other than seat time and course taking."

Theoretical Perspectives

The CBL environment is underpinned by two principles: Constructive Alignment (CA), and How People Learn (HPL) framework.

(i) Constructive Alignment

Biggs has developed the CA framework based on Ralph Tyler's (1949) model. Biggs (1996) claims that CA is a system that integrates all aspects of teaching and assessment to achieve high-level learning. In other words, the constructivism framework should guide all instructional design stages: from deriving curriculum objectives and deciding teaching/learning activities to assessing students' performance. According to Biggs (1996), CA has two elements: First, the 'Constructive' element, which refers to students 'constructing meaning' by using relevant learning activities, while teachers function as learning facilitators. The second is the 'Alignment' element, which refers to the teacher's role, as a course designer, in developing learning environments suitable for achieving intended learning outcomes. CA aligns desired learning outcomes (DLOs) with teaching and learning activities (TLA) and assessment tasks (AT), in the following order: i. Defining the desired learning outcomes (DLOs); ii. choosing teaching/learning activities likely to lead to DLOs; iii. assessing students' actual learning outcomes to see how well they match what was intended; and iv. arriving at the final grade (Biggs, 2014; Biggs and Tang, 2011). It is worth noting that the CA model and CBL environments complement each other.

(ii) How People Learn (HPL) Framework

The HPL framework is utilized to analyze and design T&L environments through four interrelated perspectives: Learner-centered, knowledge-centered, assessment-centered, and community-centered (Bransford et al., 2000).

Learner-Centered: this term refers to T&L environments that pay careful attention to the knowledge, skills, attitudes, and beliefs that learners bring to the educational setting (Bransford et al., 2000). In other words, educators need to understand and work with the prior knowledge, skills, attitudes, and beliefs of the learners that they bring to their formal educational setting. Also, teachers should acknowledge the effect of culture and language barriers on students' performance and be ready to address any negative effects. In learner-centered environments, teachers are required to monitor learner progress, maintain their engagement, and challenge them by providing manageable tasks (NRC-HPL, 2000). Moreover, educators should understand the misconceptions of novice learners, due to their prior knowledge and learning style, and how to overcome these misconceptions. Theories of conceptual change (CC) assume that a learner's conceptual understanding may dictate his or her learning. Yang et al. (2014) stated, "… what an individual learns is at least partially controlled by what he already knows".

Knowledge-Centered Environments: Knowledge-centered focuses on in-depth coverage of subject matter and not only factual memorizing, and how the acquired knowledge is used or transferred into a new context. HPL discussed the difference between experts and novices as well as knowledge transfer to new contexts. Following the HPL framework, successful implementation of CBL principles should result in the transfer of learning from students' previous academic experiences so that students become adaptive experts in their areas of study (NRC- HPL, 2000).

Assessment-Centered Environments: Assessment must emphasize understanding and not just memorizing facts and/or procedures, despite their importance (NRC- HPL, 2000). There are two types of assessment: First, summative assessments measure the students' outcome at the end of specific learning activities using, for instance, mid-terms and finals given during or at the end of a semester or academic year, respectively. The other type is formative assessments such as students' self-assessments, peers' assessments, and teacher's comments on the student's progress during learning activities, including classwork, tutorials, etc. Formative assessments are given to help both teachers and students monitor students' progress toward their learning objectives (NRC- HPL, 2000). Bransford et al. (2000) state, "Formative assessments—ongoing assessments designed to make students' thinking visible to both teachers and students—are essential. They permit the teacher to grasp the students' preconceptions, understand where the students are in the 'developmental corridor' from informal to formal thinking, and design instruction accordingly". Other formative assessment features are that they must be frequent, learner-friendly, promote deep understanding, and support active learning (NRC- HPL, 2000).

Community-Centered: HPL considers two levels of communities. One level of classrooms and schools where students, teachers, and administration interact among themselves; and the other level of community is between classrooms/school and the broader community, including homes, community centers, after-school programs, and businesses (NRC- HPL, 2000). The different social norms imposed by different schools may greatly affect learning. Learning tends to improve when classrooms and schools encourage students' participation, and freedom to make mistakes and ask questions while learning (Brown & Campione, 1998; Cobb et. al., 1992). Opposite norms, discouraging asking questions to understand the materials or making mistakes, while exploring new concepts, negatively impact learning (Holt, 1964).

The next section illustrates how the CBL implementation follows the constructive alignment principles and the four perspectives of the HPL framework.

Implementation of CBL Elements into Current Curriculum

As shown in Figure 1, HCT has developed a CBL framework consisting of three building blocks: Principle, Purpose, and Practice.

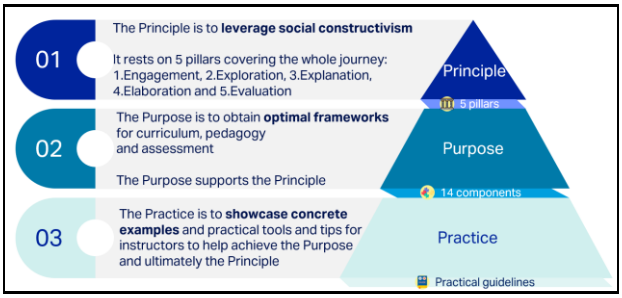

Figure 1. HCT's CBL framework (HCT's CBL Guide)

Principle

The core Principle in leveraging the CBL is social constructivism, based on Vygotsky's social learning theory of 1962. This theory emphasizes the collaborative nature of learning, which means that in addition to their cognitive stage, learners develop knowledge from people's interactions, among themselves, their culture, and society (Community-Centered). Social constructivism is a student-centered learning philosophy, where the learner actively constructs and stores models, based on the learner's prior knowledge, and the educator acts as a facilitator who encourages students to actively achieve in-depth knowledge (deep understanding).

HCT established a practical CBL educational model by pairing principles of constructivism and the 5E Instructional Model (Bybee, 2006): Engagement, Exploration, Explanation, Elaboration, and Evaluation. Noting that 5E plays a crucial role in curriculum development.

Purpose

The Purpose of the CBL, at HCT, is to guide instructors to apply the 5E to the three instructional elements: Curriculum development, pedagogy approach, and assessment strategy.

(i) Curriculum Development

In developing the curriculum, the CBL model at HCT focuses on matching competencies to the skills demanded by the labor market. A CBL curriculum is outcome-based and includes competencies required by the job market. At HCT the OBE curriculum tends to teach thermodynamic properties of pure substances, properties and the equations-of-state of ideal and real gases, the laws of thermodynamics and chemical thermodynamic principles, typical thermodynamic cycles including representation on a T-S diagram, and the performance of a steam power plant. Class activities consist of theory, demonstration, problem-solving, and laboratory work to reinforce theoretical concepts. Student learning is supported through a range of T&L methodologies including textbooks, physical labs, projects, tutorials, and assignments (CHE 3313 Syllabus).

The main objective of the thermodynamics course is to understand the behavior of systems at the macroscopic level. It gives the foundation for heat engines, heat pumps, refrigerators, power plants, chemical reactions, and many other important concepts. Its applications in chemical engineering include, but are not limited to, predicting the behavior of chemical reactions, process design, process control, and plant operation. Nevertheless, incorporating CBL features (HCT's CBL Guide) helped to identify and align competencies with industry-related skills.

(ii) Pedagogical approach

The pedagogical or instructional approach focuses on delivering practical CBL curriculum content. The pedagogical approach combines the Social Constructivism theory and the 5E Instructional Model to achieve the proper delivery of the CBL curriculum, including knowledge, skills, and attitude, and impart a mastery of knowledge through activities such as work-like simulations and industry exposure. At HCT, the pedagogical approach aims to prepare students for their after-school lives by blending theoretical knowledge with practical learning. This included real-life individual and group projects, industry-prescribed competencies, field visits, and internships.

(iii) Assessment Process

The assessment of teaching has two objectives: One is evaluation of teaching effectiveness (summative assessment), and the other is improvement of teaching (formative assessment). Pellegrino et al. (2014) identify three assessment purposes, "i) assessment to assist learning (formative assessment), ii) assessment of individual achievement (summative assessment), and iii) assessment to evaluate programs (administrators and policymakers' assessment)". These three types of assessment are also known as assessment for learning (AfL), assessment of learning (AoL), and assessment as learning (AaL), respectively (Rugarcia and Felder, 2000). Therefore, assessment tools, formal and/or informal, are developed aiming at the specific purpose of the assessment. For instance, the purpose of the traditional testing is to meet accreditation requirements: Formative assessment, including mid-terms and in-/out- of class assignments is required to enhance students' performance in the final summative assessment (Lord & Chen, 2014).

Huang et. al., (2022) identified a competency-based assessment strategy to determine developed competencies in three domains, namely knowledge, skills, and attitude. These three domains represent the components of engineering education. Rugarcia et. al. (2000) wrote, "Knowledge is the database of a professional engineer; skills are the tools used to manipulate the knowledge in order to meet a goal dictated or strongly influenced by the attitudes".

CBL formative assessment, an assessment for learning, is designed to help each student, individually, to master learning objectives, including his/her ability to transfer knowledge into a new context, the higher order skills of analysis, synthesis, and evaluation (Huang et. al., 2022). Therefore, to capture students' developed competencies, HCT's current assessment strategy includes the above-mentioned three types of assessment, as shown in Table 4, which is different from the previous assessment scheme. The previous traditional, timely-based, assessment scheme was based on the summative assessment that emphasized the lower portion of Bloom's taxonomy: memorization, comprehension, and application. The previous summative assessment scheme included the following assessment items: Quizzes (15%), midterm (20%), lab work (20%), projects (15%), practical final (10%), and theoretical final assessment (20%).

Table 4. Current assessment process of thermodynamics subject

<table>
<tr><td>Assessment Item</td><td>Weight</td><td>Assessee</td><td>Assessor</td><td>Assessment Type</td></tr>
<tr><td>Class Work, Presentation</td><td>--</td><td></td><td>Teacher & Peer</td><td rowspan="3">Formative Assessment</td></tr>
<tr><td>Lab Work</td><td>--</td><td></td><td>Lab Instructor</td></tr>
<tr><td>Assignment, Service Learning</td><td>--</td><td></td><td>Teacher</td></tr>
<tr><td rowspan="2">Lab Reports</td><td>15%</td><td>Team</td><td>Lab Instructor</td><td rowspan="4">Summative Assessment Toward (Final Grade)</td></tr>
<tr><td>10%</td><td>Individual</td><td>Lab Instructor</td></tr>
<tr><td>Midterm</td><td>35%</td><td>Individual</td><td>Teacher</td></tr>
<tr><td>Final</td><td>40%</td><td>Individual</td><td>Teacher</td></tr>
</table>

Practice

By utilizing the HCT's CBL framework, instructors can strengthen their CBL practices in terms of delivery, assessment, and promotion of education. Effective CBL implementation promotes a student-centered approach to learning outcomes and prepares graduates for their after-school lives. Table 5 shows the distribution of 14 Purpose components throughout the 5E pillars. Effective implementation of each component ensures that students acquire the practical skills (competencies) necessary for the job market.

Table 5. CBL principles (5E), purposes, and required competencies (HCT's CBL Guide)

5Es (i to v) & Purposes (1 to 14)	Competency
i. Engagement: 1) Institution & industry teaching 2) opportunity for collective learning, 3) application of real-world contexts. ii. Exploration: 4) Potential for empirical skill development, 5) readiness for contextual use of technology, 6) engagement of diverse stakeholders. iii. Explanation: 7) Potential for students to participate. iv. Elaboration: 8) Improve by building on the existing components, 9) opportunity for students to grow, 10) degree of personalization,11)Communication professionalism. v. Evaluation: 12) Degree of adoption formative assessments, 13) self-assessments & peer assessments, and 14) faculty and industry stakeholders' assessment.	Critical thinking Research Innovation Teamwork Leadership Problem-solving Communication Knowledge sharing Organizational skills Self-awareness

Effectiveness of CBL Implementation

Developed Skills

HCT has formed an Industry Advisory Committee (IAC) that is in charge of collaboration between HCT and industry in various areas such as internships, applied research opportunities, senior capstone real-life projects, industry requirements, etc. The CBL implementation helped students to develop the required competencies for the job market, as summarized in Table 5 above while improving their thermodynamics learning. These industry-relevant competencies have been identified through IAC biannual meetings.

Students' Performance

This section compares and discusses students' performance during the 2023-24 and 2022-23 academic years, before and after introducing the CBL elements into the thermodynamics curriculum. Incorporating the CBL elements in teaching and learning thermodynamics has enhanced students' performance. Table 6 illustrates the grade achieved by students over two academic years 2023-24 and 2022-23, respectively. After CBL implementation, during the Fall and Spring of 2023-24, the success rate was 97% or 28 out of the total 29 students have passed the thermodynamics course (CHE 3313), with an accumulative GPA of 2.64/4.0. The percentage of students who obtained grades 'A' was more than 28%; while those who obtained grades 'B' and 'C' were 34% and 31%, respectively. This performance has significantly exceeded students' performance during the previous 2022-23 academic year, before CBL implementation. Back then, only 5% achieved an 'A' grade, 34% achieved a 'B' grade, 36% achieved a 'C' grade, and 16% achieved a 'D' grade. Noting that the total success rate during the 2022-23 academic year was about 95%, with an accumulative GPA of 2.24/4.0.

Table 6. Students' performance during 2023-24 & 2022-23 (HCT course assessment report)

Grade	Academic Year 2023-24 (3 courses after CBL)	Academic Year 2023-24 (3 courses before CBL)
cGPA	(2.64/4.0)	(2.24/4.0)
A & A-	8 (28%)	2 (5%)
B+, B, B-	10 (34%)	15 (35.5%)
C+, C, C-	9 (31%)	16 (38%)
D	1 (3%)	7 (16.5%)
F	0	0
Withdraw	1 (3%)	0
Total	29 (100%)	42 (100%)

Students' Course Evaluation

Students gave their feedback on applying CBL as a tool for enhancing students' learning of thermodynamics. They answered 11 out of 13 question items, as shown in Table 7. These questions are related to course learning outcomes and how they are covered, assessment strategy, level of academic challenge, educational resources, T&L methodologies, lab sessions and the practical space, and the safety of the laboratory. Students gave no feedback on how much the course learning outcomes were covered and the overall course experience. Students' ratings favored most of the questions (above 80% rating), except for the level of academic challenge (only 62.5% rating) and appropriateness of the T&L methodologies (about 68.7% rating).

Overall, students were remarkably positive about the CBL enhancing the learning of thermodynamics. Their positive remarks were evident during formative assessment items, and by assessor evaluation of skills developed by students.

Challenges and Limitations of the Study

One of the main challenges during the CBL implementation was the faculty's role. To ensure faculties' positive impact, HCT has provided necessary professional development to help them recognize the CBL benefits and overcome any resistance to change.

Moreover, CBL implementation has occurred gradually.

The study also concluded that CBL implementation has improved student thermodynamics learning outcomes, in terms of knowledge and competencies. This conclusion was drawn from limited data, only three classes before and three after the CBL implementation, over two academic years. Nevertheless, this limitation did not adversely affect the conclusion, because the paper has collected and analyzed many related documents, see Table 3, and all of them led to the same conclusion that CBL implementation improved student thermodynamics outcomes. Yet, the analysis of the CBL implementation could be expanded to a wider range of engineering courses to generalize it as a model for similar situations.

Table 7. Students' course evaluation (adopted_HCT course assessment report)

Question Item	Satisfaction
1. Alignment of assessments to the course learning outcomes	81.25%
2. Availability of additional educational resources	81.25%
3. Level of academic challenge	62.50%
4. The course textbook/ eBooks	81.25%
5. The facilities provided for this course	75%
6. Appropriateness of the teaching and learning methodologies	68.75%
7. The extent to which the course learning outcomes were covered	--
8. Appropriateness of lab/practical sessions to enhance learning	87.50%
9. Functionality of equipment/ resources in the lab/practical space	81.25%
10. Adequateness of lab equipment/ software resources/practical space	91.67%
11. Level of lab/ instructor support to deliver the lab/practical sessions	81.25%
12. Safety of the lab/practical space	93.75%
13. Overall course experience	--

Conclusion

Difficulties in learning basic concepts of thermodynamics have been investigated by many researchers who have made vast efforts to enhance students' learning of thermodynamics. This article is about implementing CBL elements that helped students improve their performance in learning thermodynamics. The improvement has been evident in the student's performance and positive remarks.

Acknowledgement

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Conflict of Interest

The author declares no conflict of interest.

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Empowering Educators Through Technology-Enhanced Cooperative Problem-based Learning (TE-CPBL)

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Abstract
In today's fast-changing educational landscape, there is a need for teaching approaches that combine technology with active, student-centered learning. This study examines how Technology-Enhanced Cooperative Problem-Based Learning (TE-CPBL) workshops can transform educators' teaching practices. Based on constructivist learning theory, the research explores how TE-CPBL training impacts teaching strategies. Using qualitative methods, data were collected through reflective journals and post-workshop surveys from educators who attended the workshops. The findings highlight significant improvements in teaching approaches, including increased confidence in using tools like Canva and ChatGPT, better integration of technology into pedagogy, and a stronger focus on student-centered learning. While participants faced challenges such as time constraints and limited institutional support, they reported greater teaching effectiveness and motivation to apply TE-CPBL strategies. This study emphasizes the importance of constructivist-based professional development in helping educators adopt innovative practices to meet modern educational needs.

Keywords: cooperative problem-based learning (CPBL); Canva; ChatGPT; teaching effectiveness; technology enhanced pedagogy.

Introduction

In the rapidly evolving landscape of education, there is an increasing demand for teaching methodologies that not only deliver content but also foster critical thinking and problem-solving skills among students. Traditional teaching and learning (T&L) strategies, often characterized by passive learning and teacher-centred approaches, have been criticized for failing to equip students with these essential competencies. Despite the recognized need for pedagogical transformation, many educators remain resistant to changing their T&L strategies due to a lack of incentives, perceived increases in workload, and insufficient training in innovative educational methods (Bronkhorst et al., 2014 & Bear, 2013)

The integration of technology in education offers a promising avenue for addressing these challenges and enhancing teaching effectiveness. Digital tools like ChatGPT and Canva can streamline the preparation process, facilitate engaging and interactive learning experiences, and support the implementation of more student-centred approaches. However, simply introducing these technologies is not enough; educators must be adequately trained to utilize them effectively within pedagogical frameworks that promote active learning (Ertmer & Ottenbreit-Leftwich, 2010)

Cooperative Problem-Based Learning (CPBL) represents one such pedagogical approach that aligns with the principles of constructivist learning, emphasizing collaboration, real-world problem-solving, and the active construction of knowledge (Yusof et al., 2012). However, the successful integration of CPBL strategies and technological tools requires targeted professional development opportunities for educators. Workshops that focus on Technology-Enhanced Cooperative Problem-Based Learning can provide educators with the necessary skills and knowledge to transform their teaching practices and foster learner-centred environments. For example, a TE-CPBL workshop for STEM educators introduced a scenario requiring participants to simulate disaster relief planning. Using ChatGPT for brainstorming logistics and Canva for creating visual communication materials, educators practiced facilitating these tools in a student-centered activity. This hands-on experience equipped them with

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practical methods for encouraging collaboration and critical thinking in their own classrooms.

This study aims to investigate the role of Technology-Enhanced CPBL workshops in facilitating this pedagogical shift among educators by gathering the qualitative responses from these educators and identifying necessary supports and scaffolding to ensure this approach can be realised.

Literature Review

Cooperative Problem-Based Learning (CPBL) is grounded in constructivist learning theory, which posits that learners construct their own understanding and knowledge of the world through experiencing things and reflecting on those experiences (Mohd-Yusof et al., 2011). CPBL emphasizes collaboration among students, the application of knowledge to real-world problems, and the role of the educator as a facilitator rather than a direct source of information. Research has documented the positive impacts of CPBL in enhancing student engagement, critical thinking, and problem-solving skills across various educational settings, underscoring its effectiveness in fostering deeper learning.

The CPBL process begins with the formation of diverse learning groups. These groups are typically organized to ensure a mix of abilities, backgrounds, and perspectives. This diversity is critical to the cooperative aspect, as it encourages students to value different viewpoints and learn from each other's strengths and weaknesses. It was suggested that heterogeneous grouping can lead to improved problem-solving skills and greater empathy among group members (Johnson & Johnson, 2009; Hmelo-Silver, 2004).

Then, a well-designed, real-world problem is introduced to the students. This problem should be complex, engaging, and relevant to the learners' lives or future professional practices. It serves as the focal point for learning and discussion, engaging students' curiosity and motivating them to seek solutions. Research emphasizes the importance of the problem's relevance and authenticity, as these factors significantly influence students' engagement and learning outcomes (Barrows, 2002; Savery, 2006).

Once the problem is introduced, students explore it from different angles, discussing initial thoughts and possible solutions. This phase is crucial for identifying learning gaps and formulating learning objectives. According to literature, guiding students to identify their own learning needs can enhance self-directed learning skills and deepen their understanding of the subject matter (Dolmans et al., 2005).

Learners then engage in individual and collective research to address the identified learning needs. This stage is marked by the gathering of information, analysis of data, and synthesis of knowledge. Cooperative learning strategies, such as jigsaw or think-pair-share, can be effectively employed here to facilitate information sharing and collaborative learning (Aronson & Patnoe, 1997).

In the next step, groups develop solutions to the problem based on their research and analysis. This step allows students to apply their new knowledge and skills in a practical context, fostering deeper learning and innovation. Solutions are then presented to the class, providing an opportunity for feedback and further discussion. The literature highlights the role of this stage in developing students' communication skills and enhancing their ability to work effectively in teams (Fink, 2003).

The final stage involves reflection on the learning process and assessment of the solutions. Students reflect on what they have learned, how they have learned, and the effectiveness of their problem-solving strategies. This phase is critical for consolidating learning and fostering metacognitive skills. In addition, peer and self-assessment can be integrated to promote accountability and self-regulation (Boud & Falchikov, 2006).

Constructivist Learning Theory emphasizes that learners construct knowledge through active engagement with tasks, social interactions, and real-world contexts" (Mohd-Yusof et al., 2011). In the workshops, these principles were operationalized by structuring activities into scaffolded stages, such as initial readings to build foundational knowledge, collaborative problem-solving sessions using ChatGPT for idea generation, and Canva for creating visual prototypes. These tools served as cognitive scaffolds, enabling participants to actively construct and apply knowledge in authentic teaching scenarios (Farrelly & Baker, 2023).

Comparative studies between problem-based learning (PBL) and traditional learning methods have shown varied outcomes across different fields of study. In nursing and dental education, PBL has been found to be more effective in developing students' problem-solving skills, critical thinking, and internal locus of control, leading to a preference for PBL over traditional methods. Specifically, PBL improved nursing students' locus of control and problem-solving skills and was found to be an engaging, realistic, and beneficial approach for students in terms of promoting active participation and deeper understanding of the material.

However, in areas such as the obstetrics and gynecology clerkship, no significant differences in student performance were observed between the two learning approaches. These findings suggest that while PBL can enhance certain educational outcomes and is favored by students in certain contexts, its effectiveness can vary based on the subject matter and specific educational settings (Günüşen, Serçekuş, & Durmaz Edeer, 2014; Cooke & Moyle, 2002; Distlehorst & Robbs, 1998; Oderinu et. al., 2020; and Phelan, Jackson, & Berner, 1993).

Nonetheless, unlike traditional, lecture-based methods that often emphasize rote memorization, CPBL fosters critical thinking and problem-solving by engaging learners in authentic, contextualized challenges. For example, while traditional methods may involve passive note-taking during a lecture, CPBL activities require active participation, such as brainstorming solutions to real-world classroom management issues using ChatGPT. Comparative studies have shown that such active learning strategies lead to higher levels of engagement and retention (Barrows, 1996; Dolmans et al., 2005; Greenhow & Lewin, 2016).

Despite the benefits of active, student-centered learning strategies like CPBL, many educators face challenges in adopting these methods due to constraints like time, resources, and lack of institutional support. Teachers often remain within the confines of traditional practices due to ingrained habits and uncertainty towards new approaches. The transition towards more innovative teaching, such as Problem-Based Learning (PBL), shows promise in shifting teaching practices towards more student-centered approaches, although educators' beliefs about technology use may remain static (Park & Ertmer, 2007).

The integration of technology in education, through tools like ChatGPT and Canva, provides significant opportunities to enhance engagement, accessibility, and collaboration in teaching and learning. The use of digital technologies supports the CPBL framework effectively, facilitating research, idea generation, and solution presentation, while also demanding the development of digital literacy among educators and students to ensure effective pedagogical alignment (Nawi et al., 2019).

Canva has notably impacted educational environments by enabling the creation of visually engaging content, thus promoting a more interactive learning space. The recent survey by Canva underscores the growing interest among teachers in integrating AI into their classrooms to enhance lesson productivity, student creativity, and reduce administrative tasks. However, a significant gap in how to effectively utilize these tools indicates the necessity for greater support and training in these technologies (Canva, 2023).

Furthermore, the introduction of Canva's suite of educational tools and features, including customizable classroom resources and AI-powered tools, marks a considerable advancement in educational technology. This expansion is geared towards making digital and design literacy more accessible, addressing teacher uncertainties around AI integration, and ensuring a safer, more inclusive learning environment (Small Business Trends, 2023).

The introduction of Generative AI technologies like ChatGPT in the educational sector offer opportunities to revolutionize instructional methods and personalize learning experiences. However, their integration into the educational sector requires careful consideration of ethical implications such as data privacy, bias, and the impact on educators. These concerns must be navigated to ensure responsible and equitable use of AI in education contexts (Hill & Narine, 2023).

Nevertheless, Artificial Intelligence (AI) tools, such as ChatGPT, align seamlessly with constructivist principles by offering personalized and dynamic learning experiences. These tools facilitate active learning derived from personal experiences and prior knowledge, thereby enhancing student engagement and metacognitive skills (Grubaugh, Levitt & Deever, 2023).

From a constructivist perspective, these tools function as scaffolding mechanisms. ChatGPT, for instance, facilitates brainstorming and the synthesis of ideas, allowing participants to bridge knowledge gaps and generate innovative solutions. Canva, on the other hand, enables visual representation and iterative design processes, aligning with Vygotsky's Zone of Proximal Development by supporting learners as they progress from conceptual understanding to practical application (Nawi et al., 2019 & Isik, 2018).

In educational environments, fostering a culture of responsible AI use is crucial. This involves critically evaluating AI tools, aligning them with educational objectives, and addressing transparency, oversight, fairness, and privacy. Building social generative AI for education requires understanding its social implications and ensuring systems respect human teachers and learners (Sharples, 2023).

Despite challenges, generative AI can positively impact education by streamlining tasks and providing support beyond traditional settings. Clear guidelines and best practices are essential to navigate ethical and practical challenges, ensuring students produce original content and educators integrate AI tools ethically (Farrelly & Baker, 2023).

Therefore, the future of AI in education will depend on how well these ethical, privacy, and equity challenges are addressed. Ensuring that educators can incorporate AI tools effectively while maintaining academic integrity and ethical standards is crucial for leveraging AI's potential in enhancing learning experiences (Zohny, McMillan & King, 2023).

A study by Lin, Y. and Wang, W (2024) investigates the role of completeness and understandability in enhancing the effectiveness of collaborative problem-based learning (PBL) through wiki technologies. Drawing on social capital and social identity theories, the research examines how these factors influence trust, social identity, and perceived PBL performance among learners. A sample of 240 undergraduate students participated in PBL activities, leveraging wikis for coauthoring, corevising, and collaborative problem-solving. The findings reveal that completeness and understandability significantly enhance trust and social identity, which in turn improve perceived PBL performance. The study highlights the critical role of relational capital, emphasizing the importance of fostering trust and shared identity in online collaborative learning environments. Practical implications suggest that educators incorporate well-designed wiki platforms to support interaction, critical thinking, and deeper engagement in PBL tasks. provides empirical evidence supporting the role of digital platforms like wikis in fostering collaboration, trust, and social identity—elements aligned with constructivist learning principles. Specifically, it complements discussions on using tools like Canva and ChatGPT by illustrating how digital platforms enable effective collaborative learning and critical thinking.

Professional development programs for the educators are crucial in aiding educators to blend CPBL and technological advancements such as Canva and Generative AI into their teaching strategies effectively. Such programs, through experiential learning opportunities like professional development workshops, can lead to substantial pedagogical shifts, fostering environments that prioritize learner-centered approaches. The successful adoption of such instructional materials and methods underscores the transformative impact on teaching practices and educator mindsets (Czajka & McConnell, 2019).

Application Method

This study employed a qualitative research design to explore the impact of Technology-Enhanced Cooperative Problem-Based Learning (CPBL) workshops on educators' teaching strategies and their adoption of technology-enhanced learning environments. The workshops implemented these principles by structuring activities to mirror real-world problem-solving scenarios. For example:

1. **Scaffolding and Zone of Proximal Development (ZPD)**: Participants began with foundational reading materials (e.g., Constructive Alignment and Vygotsky's ZPD) to ground their understanding. Facilitators provided guidance as participants progressed from simpler tasks (individual exploration) to more complex group activities (solution synthesis), ensuring a gradual transfer of responsibility for learning.
2. **Collaborative Knowledge Construction**: The integration of peer activities, such as creating team mind maps using Canva, enabled participants to exchange diverse perspectives. This approach reflects the social constructivist belief that collaboration enhances cognitive development by exposing learners to varied viewpoints (Johnson & Johnson, 2009).
3. **Authentic Problem-Solving**: The workshop's design challenged educators to address real-life classroom scenarios, such as designing STEM-based lessons that integrate ChatGPT for brainstorming and Canva for creating visual presentations. These tasks align with Barrows' (2002) emphasis on problem relevance and application in constructivist learning environments.

Digital tools like Canva and ChatGPT play a pivotal role in enhancing CPBL by fostering creativity, interactivity, and collaboration. As Hannafin and Land (1997) argue, technology can serve as a scaffold that enables learners to engage more deeply with the learning process. For instance:

- **Canva** facilitated the creation of visual artifacts, such as project mind maps and team presentations, allowing participants to actively engage with the material.
- **ChatGPT** supported brainstorming and iterative solution development, promoting analytical thinking and collaborative ideation.

These tools operationalize constructivist principles by enabling learners to actively engage with content, co-construct knowledge, and reflect on their learning.

These professional development workshops' structure aligns with theoretical models like Savery's (2006) problem-based learning process and Vygotsky's ZPD. The deliberate use of scaffolding techniques, such as breaking down tasks into manageable stages (e.g., problem identification, solution synthesis), ensured participants could navigate complex problems while progressively building confidence. Additionally, reflective activities anchored learning by encouraging participants to consolidate insights and evaluate their application in real-world teaching contexts.

In order to analyse the effectiveness of these workshops, qualitative approach was chosen to gain in-depth insights into participants' experiences, perceptions, and reflections on the workshops. The research was guided by two main frameworks: the Constructivist Learning Theory, which underpins CPBL, and Kirkpatrick's Model, which was used to evaluate the outcomes of the professional development workshops.

This study involved eight educators selected through purposive sampling to ensure diversity across teaching backgrounds, disciplines, and levels of experience with technology-enhanced learning. Participants included schoolteachers, college instructors, and university lecturers from STEM and non-STEM disciplines, with teaching experience ranging from 1 to 20 years. This sampling approach aimed to capture a wide range of perspectives on the integration of CPBL and technology in diverse educational contexts. Prior to the study, all participants provided informed consent, and measures were taken to ensure their anonymity and confidentiality throughout the research process.

Data were collected using two primary methods: reflective journals using Gibbs Reflective Cycle and delayed post-workshop qualitative surveys. Participants were asked to maintain reflective journals throughout the duration of the workshops, documenting their thoughts, experiences, and perceived challenges and benefits of implementing CPBL strategies and technology tools in their teaching. Following the completion of the workshops, participants completed a qualitative survey designed to elicit detailed reflections on their learning outcomes, changes in teaching practices, and the integration of technology into their pedagogical approaches. The qualitative survey questions were aligned with the objectives of the Constructivist Learning Framework and Kirkpatrick's Model to ensure comprehensive coverage of the study's research questions.

The qualitative data from reflective journals and post-workshop surveys were analyzed using thematic analysis, guided by Gibbs' Reflective Cycle and Kirkpatrick's Model. Gibbs' Reflective Cycle provided a framework to explore participants' thoughts, challenges, and learning outcomes at each stage of the CPBL workshop. For example, reflections were coded for insights into emotional responses (initial confusion vs. clarity) and practical takeaways (strategies for implementing CPBL). Kirkpatrick's Model was used to evaluate learning outcomes at Level 2 (Learning) and Level 3 (Behavior), assessing shifts in pedagogical practices and technology integration post-workshop.

ChatGPTPlus was utilized to support data coding and interpretation by identifying patterns and recurring phrases in participant reflections. For instance, phrases like 'aha moments' were flagged as indicators of conceptual breakthroughs, while terms such as 'team collaboration' and 'student engagement' informed themes related to pedagogical strategies. The use of ChatGPTPlus expedited the thematic analysis process while ensuring consistency in coding.

The study was conducted in accordance with ethical standards for educational research. Participants were informed of the study's purpose, their rights as participants, and the confidentiality of their responses.

Findings and Discussions

This section presents the findings from the study, which include initial reflections from participants following the Cooperative Problem-Based Learning (CPBL) workshops and results from the post-delayed survey. The analysis is grounded in constructivist learning theory and Kirkpatrick's model, allowing for an in-depth understanding of the educators' experiences and the effectiveness of the workshops.

Table 1 depicts the findings made from the initial reflection from the Gibbs Reflective Cycle analysis of the selected participants after they went through the 3-Days CPBL workshop designed for them. Several themes were identified inductively from their reflections which are as follows:

1. Initial Confusion and Clarity Progression
2. Understanding and Implementation of PBL
3. Sharing and Collaboration
4. Role of Technology (ChatGPT and Canva)
5. Facilitator's Role and Scaffolding Techniques
6. Planning and Structuring Learning Activities
7. Student Engagement and Management
8. Personal Growth and Educator Strategies

Table 1. Initial Reflections Thematic Analysis

Themes	Summary	Verbatim Responses
Initial Confusion and Clarity Progression	Participants initially confused but gained clarity later.	*"Perasaan masa mula-mula...hari kedua dah ada jawapan kepada persoalan sebelumnya."*
Understanding and Implementation of PBL	Gained insights into practical PBL implementation.	*"Sepanjang 3 hari saya telah dapat memahami bagaimana untuk melaksanakan Problem Based Learning..."*
Sharing and Collaboration	Plan to share knowledge and collaborate.	*"Rancangan saya, mungkin berkongsi dengan kawan2..."*
Role of Technology	Utilized technology for effective learning.	*"Dapat mengetahui kelebihan chat gpt...dapat mengetahui apps yg terkini..."*
Facilitator's Role and Scaffolding Techniques	Recognized importance of facilitation and scaffolding.	*"...dapat mempelajari bagaimana untuk menjadi seorang fasilitator yang tenang dan mampu menyelesaikan konflik pelajar."*
Planning and Structuring Learning Activities	Improved planning and structuring of activities.	*"Mula merancang dengan lebih baik tugasan yang hendak diberikan kepada para pelajar dengan menggunakan ChatGPT."*
Student Engagement and Management	Learned to engage and manage students effectively.	*"...bagaimana mengawal karenah pelajar, menghargai kreativiti pelajar, celebrate success student..."*
Personal Growth and Educator Strategies	Reflected on personal growth and new	*"Sepanjang 3 hari berkursus, saya dapat melihat kekurangan*

	teaching strategies.	*dalam diri ketika mengendalikan kelas..."*

After 3 to 4 months, a follow up survey was made with several questions pre-designed earlier and the output is shared as in Table 2. The followings are the key themes identified after the educators had gone through CPBL workshop after few months.

Table 2. Thematic Analysis from Post-Delayed Survey

Themes	Summary	Verbatim Responses
Overall Experience	Participants found the CPBL workshop effective, emphasizing immersive, hands-on learning experiences.	*"It was an eye-opening experience. I never thought that there are valuable stages in assisting my students in working on their project."*
Key Learnings	Educators learned practical strategies enhanced by technological tools.	*"I learned the steps to solve a complex real-world problem. PBL mengubah cara saya mengajar secara total."*
Application Plans	Plans include continuous project-based learning and integrating real-life applications.	*"Sesi pembelajaran untuk memahami kaedah PBL sangat efektif. I plan to use PBL to strengthen my students' ability to think and work constructively."*
Impact Anticipation	Educators anticipate improved student engagement and enhanced critical thinking.	*"Students will be more resilient and have a growth mindset to strive through hardship. Impak positif dari segi pemahaman dan penggunaan ilmu di dunia sebenar."*
Technology Integration	Increased confidence in using technology like Canva and ChatGPT for teaching and student collaboration.	*"Students use Canva and ChatGPT many times already in my project-based learning. Pembelajaran mengenalpasti dan analisa produk dan juga bahan di dalam pembungkusan."*
Pedagogical Insights	A deeper understanding of the integration between teaching content, pedagogical approaches, and technological tools.	*"This workshop makes problem-based learning more accessible/doable as it immersed me through clear steps."*
Aha Moments	Moments of clarity on the practical application of CPBL strategies and technology in education.	*"When ChatGPT gives me the right output after try and error for a few times. Disebabkan saya mengajar teknikal iaitu packaging design."*
Learning Environment Plans	Strategies such as fostering collaborative settings and encouraging self-guided learning.	*"Do project-based learning continuously. Saya akan meneruskan pbl semampu saya sehingga mereka boleh berfikir secara kritis."*

The thematic analysis identified key themes, including 'Aha Moments,' 'Role of Technology,' and 'Student Engagement,' which reflect significant shifts in participants' teaching practices and perceptions of CPBL. For example:

- **Aha Moments**: Participants frequently described breakthroughs in understanding how CPBL strategies could be adapted to their contexts. One educator noted, 'When ChatGPT provided structured guidance, I realized its potential for scaffolding student brainstorming activities.'
- **Role of Technology**: The integration of Canva and ChatGPT emerged as a transformative aspect, enabling participants to design engaging, interactive learning activities. An educator reported, 'Students used Canva to create realistic prototypes, bridging creativity with real-world problem-solving.'
- **Student Engagement**: Educators observed increased student motivation and collaboration when using CPBL strategies. One reflection highlighted, 'My students actively debated solutions during the group task, something I rarely saw in traditional lectures.'

To enhance comprehension, Figure 1 presents a thematic map summarizing the relationships among the identified themes.

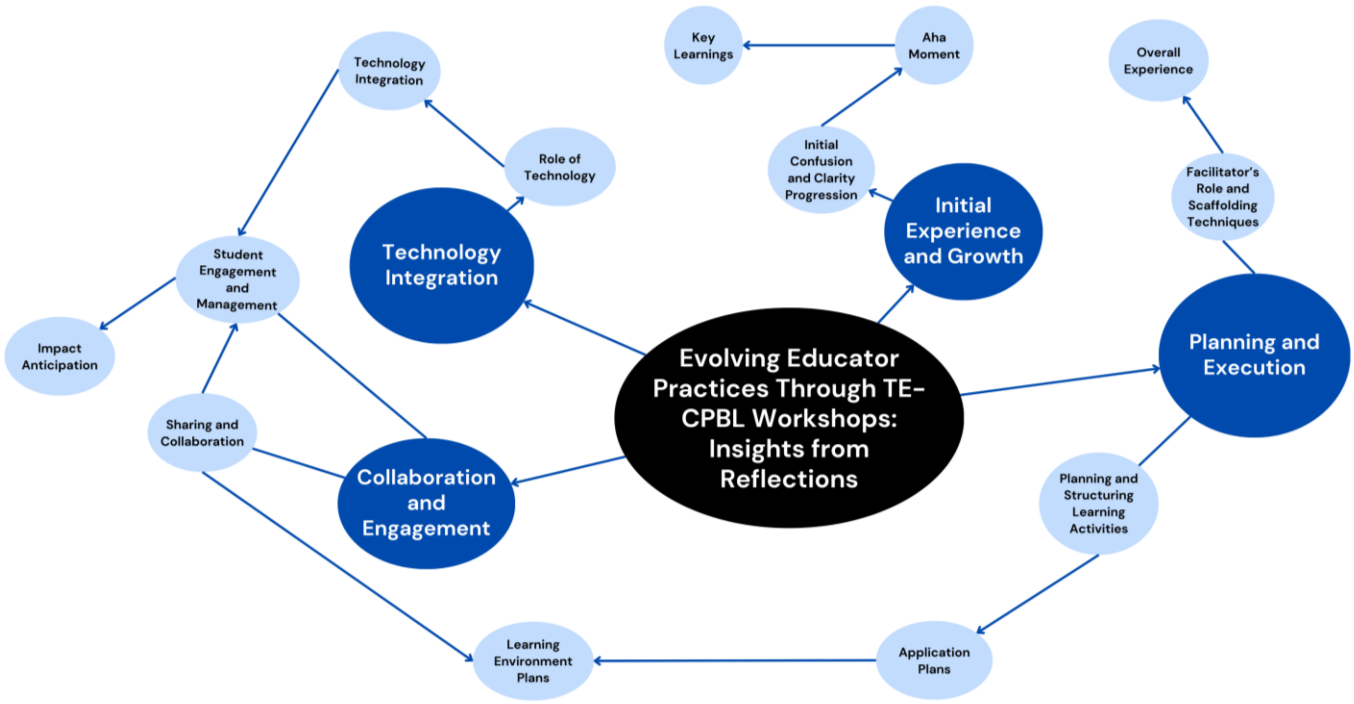

Figure 1. Thematic Map from the Findings

This thematic map illustrates the comprehensive findings derived from reflections on the TE-CPBL workshops, encapsulated within the central theme: "Evolving Educator Practices Through TE-CPBL Workshops: Insights from Reflections." The map is structured around four primary branches—Initial Experience and Growth, Planning and Execution, Technology Integration, and Collaboration and Engagement—each representing distinct but interconnected dimensions of participants' learning journeys. The Initial Experience and Growth branch captures the developmental trajectory from initial confusion, progressing through clarity and breakthroughs (Aha Moments), ultimately culminating in actionable insights (Key Learnings). This progression emphasizes the transformative impact of scaffolded learning, which builds on the constructivist principles of active engagement and reflective practice.

The other branches reinforce these findings by detailing how specific aspects interrelate. Planning and Execution highlights the evolution from structured planning of CPBL activities to application plans and enhanced learning environment strategies, guided by facilitators' scaffolding techniques. The Technology Integration branch underscores the pivotal role of tools like Canva and ChatGPT in fostering creativity and problem-solving, linking their effective use to improved student engagement and management under Collaboration and Engagement. This latter branch emphasizes the reciprocal relationship between collaboration (among educators and students), enhanced engagement, and anticipated educational impacts, such as critical thinking and resilience. The interconnected arrows indicate dynamic relationships between these themes, portraying a holistic and iterative development process that aligns with the principles of CPBL and modern educational practices.

The thematic analysis of data collected through reflective journals and delayed post-workshop surveys revealed significant insights into the educators' experiences and perceptions following their participation in the Technology-Enhanced Cooperative Problem-Based Learning (CPBL) workshops. The following depicts the verbatim responses obtained from the respondents and how each is being mapped to the respective theme.

1. Enhanced Understanding of CPBL

Participants unanimously reported an enhanced understanding of CPBL principles. They reflected on the immersive experience provided by the workshops, which allowed them to engage directly with real-world problems, mirroring the experiences their students would face. This hands-on approach facilitated a deeper appreciation of the constructivist underpinnings of CPBL, aligning with Savery's (2006) assertion of the importance of active engagement in learning.

2. Integration of Technology

Participants noted a significant increase in confidence when incorporating tools like Canva and ChatGPT into their pedagogy. For instance, one educator redesigned a lesson on sustainable development by assigning students a task to develop innovative product packaging. Students used Canva to create realistic mockups and ChatGPT to gather data on sustainability practices, effectively bridging creativity with research-driven solutions. This hands-on integration resulted in students demonstrating higher levels of critical analysis and engagement compared to their usual project-based assignments. Specifically, the use of Canva was highlighted for its effectiveness in creating engaging visual content, while ChatGPT was praised for its role in facilitating research and generating ideas. This finding corroborates Greenhow and Lewin's (2016) discussion on the potential of digital tools to enhance student engagement and learning.

3. Shifts in Teaching Paradigms

The workshops acted as a catalyst for educators to reassess their traditional teaching approaches. For instance, educators implemented real-world problem scenarios in their lessons, such as analyzing real business case studies using Canva and ChatGPT. These activities encouraged students to collaborate, research, and present innovative solutions, demonstrating a significant departure from traditional lecture-based methods. Educators observed that such activities not only increased student engagement but also fostered a deeper understanding of subject matter through applied learning, echoing the constructivist approach where students' active participation in constructing their own understanding is emphasized (Hmelo-Silver, 2004).

4. Challenges and Barriers

Despite the generally positive experiences, educators faced several challenges in implementing CPBL and technology-enhanced learning. Time constraints emerged as a critical barrier, as participants struggled to balance their existing workload with the additional time required for planning and executing CPBL activities. Additionally, the lack of institutional support, such as limited access to technology or professional development opportunities, inhibited the widespread adoption of these methods. Resistance to change among peers and administrative hurdles also surfaced as significant challenges, consistent with Ertmer and Ottenbreit-Leftwich's (2010) findings.

5. Professional Development and Support

The critical role of continuous professional development and peer support in adopting new teaching strategies was a recurring theme. Participants expressed a need for ongoing training and collaboration to effectively integrate CPBL and technology into their pedagogical practices.

6. Observable Changes in Teaching and Learning

The educators reported noticeable improvements in student engagement and motivation, as well as enhanced critical thinking and problem-solving skills, particularly when CPBL strategies supported by technology were employed. For example, a participant teaching technical design shared how integrating Canva to create visual prototypes and ChatGPT for brainstorming ideas during a CPBL session transformed their classroom dynamics. Students actively engaged in peer reviews and refined their designs collaboratively, showcasing improved critical thinking and teamwork. This contrasted sharply with the traditional approach of completing individual assignments, where engagement was minimal. This aligns with the literature suggesting that CPBL can lead to higher levels of student involvement and cognitive development (Kim, Belland, & Lefler, 2020).

Discussions

The findings from this study reinforce the principles of constructivist learning, demonstrating the efficacy of Challenge-Based Problem Learning (CPBL) in fostering environments where students actively engage in problem-solving and knowledge construction. The educators' shift towards student-centered approaches and the observed improvement in students' critical thinking skills are in line with constructivist theory, which posits learning as an active, constructive process (Scott, 2011 & Yuen & Hau, 2006).

The challenges identified by participants, particularly those related to time constraints and institutional support, mirror the broader issues faced by educators attempting to innovate their teaching practices. These barriers must be addressed by educational leaders and policymakers to create an ecosystem that supports and rewards pedagogical innovation. This reflects broader educational trends and challenges (Hendry, Frommer, & Walker, 1999).

The emphasis on professional development and peer support found in this study underscores the necessity for educational institutions to provide educators with the resources and community necessary to transition to CPBL and technology-enhanced methodologies. This aligns with findings on the effectiveness of experiential, collaborative professional development in fostering pedagogical change, although specific comparable studies were not directly identified, the concept is supported by the constructivist educational framework.

The positive outcomes reported by educators in this study suggest that CPBL workshops can significantly impact teaching practices and student learning. However, to facilitate wider adoption, there is a need for comprehensive support systems, including professional development, peer networks, and institutional backing. Future research should explore longitudinal impacts of such workshops, quantitative strategies to benefit larger and wider audiences, and investigate strategies to overcome the barriers to implementation of CPBL and technology integration in diverse educational settings.

While this study provides significant insights into the role of technology-enhanced CPBL in educator development, it is important to acknowledge its limitations. First, the small sample size of eight educators limits the generalizability of the findings, as the experiences captured may not fully represent the diversity of perspectives in broader populations. Second, the short-term evaluation of outcomes, based primarily on reflections and surveys conducted shortly after the workshops, does not provide insights into the long-term sustainability of the observed changes in teaching practices. Future research should incorporate follow-up assessments conducted six months to a year post-intervention to evaluate enduring impacts.

Additionally, the reliance on self-reported data, such as reflective journals and surveys, may introduce bias or overstate positive outcomes. Incorporating direct classroom observations or student feedback would enhance the robustness of future evaluations. Furthermore, the study's emphasis on specific technologies—Canva and ChatGPT—limits its ability to generalize findings to other platforms or tools. Future studies could address this by exploring a wider array of technologies to evaluate their relative effectiveness. Finally, the study's focus on TVET educators within a specific cultural and institutional context may restrict its applicability to other educational systems. Adapting the CPBL framework to different cultural and institutional settings would provide a more comprehensive understanding of its global potential.

Conclusion

This study explored the impact of Technology-Enhanced Cooperative Problem-Based Learning (CPBL) workshops on educators' approaches to teaching and learning. Through qualitative analysis of reflective journals and delayed post-workshop surveys, several key themes emerged, providing valuable insights into the transformative potential of integrating CPBL strategies and digital tools like Canva and ChatGPT in educational settings.

The findings demonstrate that TE-CPBL workshops significantly enhanced participants' understanding of CPBL and its constructivist underpinnings through practical, real-world applications. For instance, educators who participated in the workshops shared specific success stories, such as using Canva to design student-driven marketing campaigns or leveraging ChatGPT for collaborative brainstorming sessions in engineering problem-solving activities. These examples highlighted a clear shift from traditional, lecture-based methods to student-centered, interactive approaches. This paradigm shift not only aligns with contemporary educational theories but also reflects the transformative potential of integrating technology with collaborative pedagogy to address real-world challenges in the classroom.

Technology integration emerged as a central theme, with participants expressing increased confidence in incorporating tools such as Canva and ChatGPT into their pedagogy. These digital resources were recognized for their ability to facilitate creative expression, enhance student engagement, and support the collaborative nature of CPBL. The study underscores the importance of equipping educators with the skills and knowledge to effectively leverage technology in fostering dynamic and interactive learning environments.

However, the research also highlighted several challenges, including time constraints, lack of institutional support, and resistance to change, which can impede the adoption of innovative teaching strategies. Addressing these barriers is essential to enabling widespread implementation of CPBL and technology-enhanced learning approaches. To address these challenges, several strategies can be implemented:

1. **Time Management and Planning Support:** Provide structured templates and pre-designed activity modules for CPBL sessions. For example, educators can utilize pre-built lesson plans incorporating Canva and ChatGPT, reducing preparation time and ensuring pedagogical alignment.
2. **Peer Collaboration and Communities of Practice:** Establish peer support groups where educators can share resources, experiences, and solutions. This approach fosters a collaborative culture and mitigates resistance to new methodologies by building collective confidence and shared expertise (Johnson & Johnson, 2009).
3. **Institutional Incentives and Support:** Encourage institutions to offer incentives such as reduced teaching loads, recognition programs, or access to additional funding for innovative projects. Providing technology access and training, including workshops on tools like Canva and ChatGPT, can also ease the transition.
4. **Professional Development Programs:** Offer ongoing professional development opportunities that emphasize experiential learning. For instance, conducting follow-up workshops to address specific challenges faced by educators can provide targeted support and sustain momentum.
5. **Administrative Advocacy:** Engage administrators in the pedagogical change process by demonstrating the benefits of CPBL through pilot programs and presenting evidence of improved student outcomes. This can help secure institutional backing and reduce bureaucratic resistance.

Professional development, as demonstrated by the CPBL workshops, plays a crucial role in supporting educators through this transition. Continuous learning opportunities, peer support, and practical experiences are vital in helping teachers navigate the complexities of modern educational paradigms and integrate new tools and methodologies into their practice.

This study offers valuable insights into the potential of technology-enhanced CPBL workshops for educator development. However, future research could extend these findings by exploring the long-term impacts of CPBL on both educators and students. For instance, longitudinal studies could examine how sustained CPBL implementation influences students' critical thinking, collaboration, and problem-solving skills over multiple academic terms. Additionally, investigating the scalability of CPBL in institutions with varying resource levels—particularly those with limited access to digital tools—would provide a broader understanding of its applicability in diverse educational settings.

Comparative research between CPBL and other active learning strategies, such as flipped classrooms or inquiry-based learning, would also offer valuable insights into the relative effectiveness of these approaches in fostering educator development. Furthermore, future studies could explore alternative generative AI tools and platforms beyond Canva and ChatGPT, assessing their potential to complement or enhance CPBL methodologies. These directions for future research would build on the current study's findings while addressing its limitations and extending its contributions to the field.

In conclusion, the study reaffirms the value of CPBL and technology integration in promoting student-centered learning. By fostering environments that encourage collaboration, critical thinking, and problem-solving, educators can better prepare students to navigate the challenges of the 21st century. Future research should continue to explore effective strategies for overcoming barriers to pedagogical innovation and further investigate the long-term impacts of CPBL and technology-enhanced learning on student outcomes.

As educational landscapes continue to evolve, the insights gained from this study contribute to the growing body of knowledge on best practices in teaching and learning. By embracing the principles of CPBL and harnessing the power of technology, educators can create more engaging, effective, and meaningful learning experiences for their students.

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Conflict of Interest

The authors declare no conflict of interest.

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Assessing the Usability and Effectiveness of Chemical Engineering Capstone Design Project Teaching and Learning Model

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Abstract
In recent years, industry leaders, academicians, and ABET standards have expressed renewed interest in teaching engineers to solve real-world and open-ended problems. In chemical engineering program, a capstone design project is a course that allows students to deal with these problems whilst using the knowledge they have acquired from previous courses offered in the curriculum. The course represents all the Accreditation Board for Engineering Education (ABET) program outcomes required for accreditation. To enhance students' learning and meet the program outcomes requirements, we present this work focusing on the evaluation phase of an effective teaching and learning model. This model is specifically designed for chemical engineering capstone projects and aligns with the intended program outcomes. Additionally, it allows us to assess the model's effectiveness and its impact on student learning. This study aims to assess the usability and effectiveness of the designed survey questionnaires in investigating the suitability of conducting a capstone design project via this approach method. The research methodology centered on creating and validating a survey questionnaire to evaluate the suitability of the capstone design project approach. The population of this study was final-year students of the chemical engineering degree program, Faculty of Chemical Engineering & Technology, Universiti Malaysia Perlis (UniMAP), Malaysia, enrolment 2020/2021. To ensure the reliability and validity of the survey instrument, a pilot test was conducted with a minimum of thirty respondents, employing Cronbach Alpha (CA) and Principal Component Analysis (PCA). The analysis results indicate the survey questionnaires are reliable and valid, with a CA value of 0.891 and Kaiser-Meyer-Olkin (KMO) index of 0.690. The evaluation results show improved students' understanding of program outcomes and also their perceptions that the capstone design course helped their professional growth. Also, the detailed assessment and feedback given to students via this teaching and learning model made the course more valuable for preparing them for industry careers. This work resulted in better ways to teach, manage, and assess the technical and non-technical course outcomes. Indirectly, it can improve the current practices used by instructors.

Keywords: capstone design project, chemical engineering design, capstone design teaching and learning model, survey questionnaire assessment.

Introduction

The development of a capstone design course is an effort to bring the practical side of engineering back to the engineering curriculum (Scholes, 2021). Additionally, it has been influenced by many sources including the ABET, engineering educators, and numerous industrial companies. In the chemical engineering curriculum, the capstone design project is a key component of undergraduate engineering education that reflects the knowledge gained in the preparatory years, in which students apply and integrate all their knowledge from years one through the final year. The capstone design project represents the culmination of what they have learned.

The main objective of the capstone design project is to provide students with a multidisciplinary experience. It enables them to integrate knowledge gained from core, intermediate, and advanced courses in chemical engineering. The seniors in the fourth-year program will apply the skills and knowledge gained through their culminating design experience to demonstrate their readiness for engineering practice. According to Ocampo-López et al., (2022), various authors discuss the development of capstone design projects with applications to laboratories or process control courses which involve design, instrumentation, simulation, and control.

In the engineering curriculum setting, complex engineering problems are embedded in the capstone

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design project. Unfortunately, students often face well-constrained problems but are expected to graduate with the ability to solve complex problems. On the other hand, studies show that learning through solving real-world problems can provide context, thus it promotes deep and meaningful learning, in addition to enabling students to retain and transfer or use knowledge in other situations (Kamaruzaman et al., 2018). Therefore, it is important to ensure that the university's graduates meet current industry demands and are equipped with real-life engineering skills, enabling them to transition seamlessly into the workforce after graduation.

Although some research focuses on capstone design as the primary sample course, future studies could explore how students in lower-year engineering courses perceive and approach complex engineering problems, particularly in courses involving design (Alexa Ray Fernando, 2022). A successful teaching process relies on the development of appropriate and effective teaching methods, techniques, and strategies. For example, McHenry et al. (2005) introduced constructivism as a learning theory that fosters the development of engineering students' competencies, preparing them for engineering practice and graduate education. In the context of undergraduate engineering education, the teaching and learning approach emphasizes the development of factual knowledge, which, when intellectually combined, enables students to understand engineering principles, scientific laws, and mathematical applications. This foundation is critical for conceptualizing and executing solutions to real-world problems, with a particular focus on design. Importantly, these skills must be developed progressively, starting from the first year and continuing through the final year of study.

To immediately address this instructional approach, a study was conducted among final-year Chemical Engineering students at the Faculty of Chemical Engineering & Technology at the Universiti Malaysia Perlis, Perlis, Malaysia to improve their understanding of the PO. In this study, the capstone design teaching and learning model aims to enhance students' understanding. Throughout the approach, the students' acceptance of this new technique is evaluated. This model can be viewed as a teaching method that includes elements such as objectives, content or program outcomes (POs), teaching and learning strategies (pedagogy), activities, student-centered assessment, and the practice of soft skills.

Consequently, survey questionnaires were employed for data collection in this study. Survey questionnaire is one of the means of collecting standardized quantitative primary data that are consistent and coherent for analysis (Satya & Roopa, 2017). Close-ended questions were used, allowing respondents to select from predetermined responses, which makes the process easier and faster, though it may limit the depth of information gathered. A common example of close-ended questions is those constructed using the Likert scale, which provides a structured way to measure responses (Taghinejad et al., 2023). (Taghinejad et al., 2023).

Methods

The study was conducted in three stages. In stage one, the survey questionnaire was designed according to the purpose of the study. Then in stage two, the set questionnaires were distributed to the target population for pilot testing where the reliability of the survey questionnaires was analyzed using CA. Stage three is where the usability and the effectiveness of the capstone design teaching and learning model were assessed using the survey questionnaires. All the above analyses were done by deploying the Statistical Package for the Social Sciences (SPSS 27) software.

Stage 1: Design of the Questionnaires

For the usability assessment in this study, three main domains were investigated: i) usability of the model, ii) satisfaction, and iii) ease of use (USE). Table 1 presents the three main domains and the set of questions for the investigation.

Table 2 presents the set of questionnaires consisting of 12 PO statements. Two types of close-ended question structures were adopted for this part of the study and the former was set with a 5-Likert scale quantification measurement. The survey questionnaires were created using an online Google form.

Stage 2: Pilot Test and Reliability Test

The pilot study began by distributing a survey questionnaire to 30 students registered for the Chemical Plant Design course. A previous study suggests that a sufficient pilot test sample size can be as minimum as 12 or 30 respondents (Sarmah & Bora Hazarika, 2012). Another study affirms that a minimum of 10 respondents per instrument is recommended (Laura & Stephanie, 2011).

The pilot test was conducted as a preliminary step prior to the actual data collection to ensure the quality and effectiveness of the survey questionnaire. This process helped identify and address potential issues related to the questionnaire's theme, content, grammar, sentence structure, and layout format (van Teijlingen & Hundley, 2002). During the pilot test, respondents' feedback and recommendations were closely monitored and incorporated to improve the questionnaire.

In addition, data cleaning of the survey responses was carried out at this stage to eliminate duplications, incomplete responses, and other errors, ensuring the data's accuracy and reliability. As the data collected is considered prime data, this step is crucial for maintaining the integrity of the dataset prior to further analysis (Mullat, 2011). Data cleaning was performed as a prerequisite for subsequent reliability and validity testing.

After the pilot test, the reliability and validity of the survey results were evaluated using CA and PCA, respectively. Once the reliability and validity of the

Table 1. The Questionnaire Domains and Descriptions for *Usability* (USE)

Domains	Descriptions
Usability 1. The Chemical Engineering Capstone Teaching & Learning Model (CEC) helps me to be more effective. 2. The CEC model increases my efficiency. 3. The CEC model is useful for me. 4. The CEC model made learning the Plant Design Course easy for me. 5. The CEC model allows me to easily make references. 6. I save time studying with the CEC model the learning activities are efficient. 7. The CEC model improves learning skills. 8. The CEC model helped improve my understanding of the Plant Design Course.	This domain reflects the respondents' perception of the usability or usefulness of the CEC model for their specific needs; in the perspective of teaching and learning delivery as well as the assessment method.
Satisfaction 9. The CEC model performs as predicted. 10. I like the CEC Teaching & Learning model. 11. I enjoy using the CEC model in my course. 12. I'll recommend the CEC model to colleagues at other universities. 13. I believe the CEC model is necessary for the Plant Design Course. 14. I am satisfied with the way I learned the Plant Design Course using the CEC model.	This domain reflects the respondents' perception of the satisfaction of the teaching delivery using the CEC model.
Ease of use 15. The CEC model is simple to implement. 16. The CEC model is user-friendly. 17. The CEC model is adaptable. 18. I learned to use the CEC model in learning the Plant Design Course quickly and effectively.	This domain reflects the respondents' perception of the usefulness of the CEC model.

Table 2. The Questionnaire Domains and PO Statements for *Effectiveness* (POs)

Domain	PO Statements
PO1 Engineering Knowledge	Apply knowledge of mathematics, natural science, engineering fundamentals, and an engineering specialization as specified in WK1 to WK4 respectively to the solution of complex engineering problems.
PO2 Problem Analysis	Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
PO3 Design/development of solutions	Design solutions for complex engineering problems and design systems, components, or processes that meet specified needs with appropriate consideration for public health and safety, and cultural, societal, and environmental considerations.
PO4 Investigation	Conduct investigations of complex problems using research-based knowledge (WK8) and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.
PO5 Modern Tool Usage	Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to complex engineering problems, with an understanding of the limitations.
PO6 The Engineer and Society	Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems.
PO7 Environment and Sustainability	Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental contexts.
PO8 Ethics	Apply ethical principles and commit to professional ethics responsibilities and norms of engineering practice.
PO9 Individual and Teamwork	Function effectively as an individual, and as a member or leader in diverse teams

	and in multi-disciplinary settings.
PO10 Communication	Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
PO11 Project Management and Finance	Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
PO12 Lifelong learning	Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

questionnaires are achieved, and the survey questionnaire is ready for distribution to the target populations for actual data collection.

The reliability of the survey results is done to assess the internal consistency of the survey results. CA coefficient is a common indicator to measure the internal consistency of the survey results of the intended purpose. Table 3 displays the list of CA values and their interpretation according to the degree of reliability.

Table 3. The Interpretation of Cronbach Alpha (CA)

Value of Cronbach's Alpha (α)	Degree of Reliability
$\alpha \leq 0$	A serious problem in the design of the questionnaire and the researcher should relook into the format of the questionnaire intended to be used for the survey.
$0 < \alpha < 0.5$	Low internal consistency and hence poor inter-relatedness between items. Should be discarded or revised.
$0.5 < \alpha < 0.7$	Moderate internal consistency and reliability of a given questionnaire. Can be revised.
$\alpha = 0.7$	Adequate internal consistency and reliability of each questionnaire.
$0.7 < \alpha < 0.9$	High internal consistency and reliability in each questionnaire. Can be revised.
$0.9 < \alpha < 1.0$	Some questionnaire items may be redundant, and the researcher has to consider removing some items from the questionnaire that are repeated questions in multiple ways.
$\alpha = 1.0$	Perfect internal consistency in each questionnaire.

(Aithal & Aithal, 2020)

According to Christmann & Van Aelst (2006), CA's value suggested by the subject matter expert should be at least 0.7 to indicate adequate internal consistency and reliability in each questionnaire.

The survey results were further analyzed for their validity using the PCA test. The PCA test is used to measure the principal components of the questionnaires. This test provides empirically robust results and a better indicator of the data variability presentation (Ajtai et al., 2023). The PCA analysis employs factor loadings that determine the common theme of the questions therefore the set questions are valid to be combined in the survey questionnaires. The range of factor loading scale is set by default in the SPSS, between (-ve) 1 to (+ve) 1 value. Generally, Aithal & Aithal (2020) stated that the PCA indicator of 0.6 and above is broadly accepted by many researchers. The qualifying indicator for the PCA test is Kaiser-Meyer-Olkin (KMO) which measures the sampling adequacy and Bartlett's Test which measures the chi-square, degrees of freedom, and p-value of the survey questionnaire or the instrument. The KMO coefficient is expected to be equivalent to or above 0.7(Hair J et al., 2014). Whereas, for Bartlett's Test, the chi-square output is considered significant when the p-value is less than 0.05 ($p<0.05$) (Taherdoost et al., 2014).

Stage 3: Usability and Effectiveness of the Capstone Design Teaching and Learning Model

In Stage 3, the usability and the effectiveness of the capstone teaching and learning model were assessed using the survey questionnaires. The data analyses were done by deploying the Statistical Package for the Social Sciences (SPSS 27) software. The target population answered a research questionnaire on the usability of the model, which includes the domains and descriptions as in Table 1. The domain measured includes USE, which is Usability, Satisfaction, and Ease of use on the model carried out in teaching and learning for the KMJ42003 course. On the other hand, the effectiveness of the capstone teaching and learning model was assessed after the students had answered the survey questionnaires on the domain of PO1-PO12 and the PO statements. It is implemented in a quasi-experimental manner, namely *single-group pretest and post-test.*

Results and Discussions

Reliability and Validity of the Questionnaire

A total of thirty (30) students who have registered for the Chemical Plant Design course participated in the pilot test survey. Table 4 exhibits the processing summary of the pilot test survey response. The case processing summary indicates that all the survey response data are valid and 100% used for the analysis.

Table 4. Case Processing Summary for the Pilot Survey Response

Description		Number of respondents	100%
Cases	Valid	30	100.0
	Excluded[a]	0	0.0
	Total	30	100.0

[a]Listwise deletion based on all variables in the procedure.

Table 5 presents the reliability statistics analysis of the pilot survey response. The number of items in this analysis refers to the number of questions set in the survey questionnaires according to the usability and effectiveness domains (Table 1 & Table 2). Cronbach's Alpha (α), the values 0.891 and 0.884 indicate high internal consistency and homogeneity of the survey questionnaires.

Table 5. Results of the Reliability Test

Cronbach's Alpha (α)		Number of Items
Usability	0.891	18
Effectiveness	0.884	12

Table 6 shows the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test outcomes. The KMO coefficient of 0.690 indicates that the sample size of 30 respondents is sufficiently appropriate for factor analysis. Bartlett's sphericity test is significant with a chi-square value of 375.399 and degree of freedom 153; ($p<0.05$). These results indicate that the sampling data is adequate and fit for the PCA test.

Table 6. Results of KMO and Bartlett's Test

Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy		0.690
Bartlett's Sphericity Test	Approx. Chi-Square	375.399
	degree of freedom	153
	Significance (p value).	<0.001

Usability and Effectiveness of the Capstone Design Teaching and Learning Model

In this part, descriptive statistics were used to analyze the data from the survey. The survey measures responses to statements about the usability and effectiveness of the CEC model in the context of a Plant Design course. The analysis was done in terms of the mean and standard deviation of each item in Tables 7 & 8 below.

Table 7. Case Processing Summary for the Usability (USE) Survey Response

Description		Number of respondents	100%
Cases	Valid	99	100.0
	Excluded[a]	0	0.0
	Total	99	100.0

[a]Listwise deletion based on all variables in the procedure.

Table 7 exhibits the processing summary of the survey response on the usability of the CEC model used for the Chemical Plant Design course session 2023/2024. The case processing summary indicates that all the survey response data are valid and 100% used for the analysis. Meanwhile, the statistics of mean, standard deviation, and the percentage of agreement are shown in Table 8 below respectively.

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Table 8. Descriptive Statistic Summary for the Usability (USE) Survey Response

Item USE	N	Mean statistic	Std. deviation statistic	Frequency of agreement (N/%)	
				n	%
U1	99	4.33	.655	93	93.9
U2	99	4.26	.790	87	87.9
U3	99	4.29	.918	85	85.9
U4	99	4.17	.904	78	78.8
U5	99	4.23	.831	83	83.8
U6	99	3.68	.946	59	59.6
U7	99	4.26	.864	89	89.9
U8	99	4.54	.660	92	92.9
S9	99	3.87	.933	68	68.7
S10	99	3.85	.908	69	69.7
S11	99	3.85	.850	70	70.7
S12	99	4.01	.985	70	70.7
S13	99	4.44	.772	89	89.9
S14	99	4.15	.861	83	83.9
E15	99	3.91	.797	69	69.7
E16	99	4.04	.856	75	75.7
E17	99	4.09	.834	78	78.7
E18	99	4.09	.744	88	88.8

The data provided in Table 8 consists of responses from 99 respondents about their experiences with the CEC model in the context of a Chemical Plant Design course. Figure 1 shows a bar chart plotted from the above data that compares the Mean Statistic and Frequency of Agreement (%) for each item. This visualization allows for a clear comparison of how each item performed in terms of average score and agreement frequency among respondents.

The items measure various aspects such as effectiveness, usefulness, time-efficiency, usability, implementation and usability, learning experience and understanding, enjoyment, necessity, and satisfaction with the model. In general observation, there are overall positive responses. Across almost all items, the mean scores are above 3.5, indicating that respondents generally feel positive about the CEC model's impact on their learning. This suggests that the CEC model can be used and is perceived as effective, useful, and enjoyable.

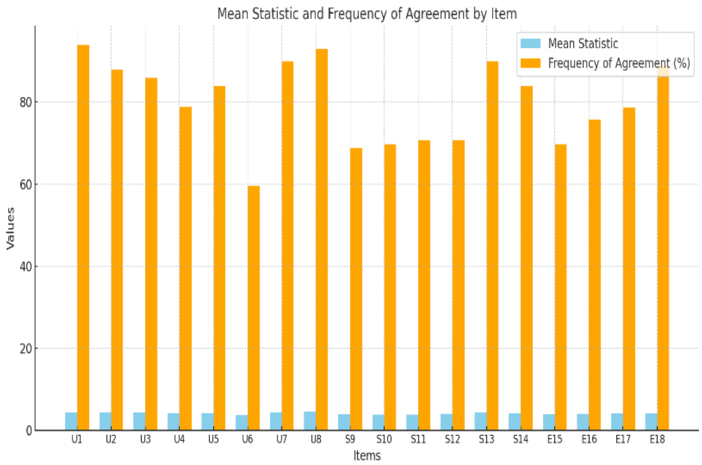

Figure 1. Mean Statistic and Frequency of Agreement (%) of the Usability (USE) Survey Response

The highest mean is 4.54 (for the item "*CEC model helped improve my understanding in the Plant Design course*"), and the lowest mean is 3.68 (for "*I save time studying with the CEC because the learning activities are efficient*"). There are also findings that high variability in responses. Many items have moderate to high standard deviations (ranging from 0.655 to .985), suggesting that responses varied among participants. For instance, the item "*I save time studying with the CEC model because the learning activities are efficient*" has a relatively high standard deviation of 0.946, indicating that there are mixed opinions on the time-saving aspect of the CEC model. For the terms of necessity and satisfaction: "*I believe a CEC model is necessary for the Plant Design Course*" received a high mean of 4.44, indicating strong agreement that the CEC model is necessary. Similarly, *"I am satisfied with the way I learned the Plant Design course using the CEC model"* (Mean = 4.15) indicates general satisfaction with the learning experience using the model.

Additionally, skewness and positive perception summarized that a significant number of items show negative skewness, which suggests that the data is skewed toward the more positive responses (i.e., respondents tended to agree more strongly than disagree). For example, the item "*CEC model improves learning skills"* has a skewness of -1.799, suggesting a strong tendency for respondents to rate it positively. This positive skew across items indicates that the CEC model is viewed favorably overall by participants, with a larger proportion of responses leaning toward agreement. However, there were mixed views on time efficiency. While many respondents feel that CEC is effective, there is more variability in terms of its time-saving aspects. Some respondents may not find the model as efficient for saving time. This suggests that while some participants find the model time-saving, others may not. This might indicate a difference in how participants perceive the efficiency of the learning activities or how well the model fits their study styles.

On the other hand, the effectiveness of the CEC model has been determined by using a quasi-experimental design namely Single-Group Pretest Post-test. Respondents answered the questionnaire for the measurement of PO before and after using the model in the Chemical Plant Design course. The case processing summary and the descriptive statistics in mean, standard deviation, and frequency of agreement are shown in Table 9 and Table 10.

Table 9. Case Processing Summary for the Effectiveness (PO) Survey Response

Description		Number of respondents (single group)	100%
Cases	Valid	99	100.0
	Excluded[a]	0	0.0
	Total	99	100.0

[a]Listwise deletion based on all variables in the procedure.

Table 9 presents the processing summary of the survey response on the effectiveness of the CEC model used for the Chemical Plant Design course session 2023/2024. It indicates that all the survey response data are valid and 100% used for the analysis. However, the data was analyzed and the descriptive statistic of Pretest and Posttest is shown in Table 10. During the *pretest* and *posttest*, the data was collected from 99 respondents. This item measures the understanding of respondents toward PO through the CPDII course. A bar chart graph was plotted using the above data to see the comparison between the Pretest and Post-test mean scores for each PO (Figure 2).

From this finding, in the Pretest session, students had a relatively poor understanding of Program Outcomes and some of them did not agree with the PO statements. In this descriptive analysis, the mean score for each competency shows the average level of each item. The highest mean is for PO1 *"Engineering Knowledge"* (3.28), indicating that on average, participants rated this competency the highest. Meanwhile, PO8 "Ethics" has the lowest mean (2.72), indicating a relatively lower perceived level in this area of knowledge. However, the standard deviation reflects how much individual scores vary from the mean.

It was shown that PO5 *"Modern Tool Usage"* has the highest standard deviation (0.836), indicating that there is more variation in how participants rated their proficiency in this area while the lower values, while PO2 *"Problem Analysis"* (0.631), indicate more consistent responses. Overall, we can conclude that the item that has the highest mean scores indicates that respondents rate themselves more highly in these areas. However, for item that has the lowest mean, suggests that they feel less proficient in this competency.

Table 10. Descriptive Statistic Summary for the Effectiveness (PO) Survey Response

Item PO	N	Mean statistic	Std. deviation statistic	Frequency of agreement (N/%)	
				n	%
Pretest					
PO1	99	3.28	.756	46	46.4
PO2	99	3.01	.631	20	20.2
PO3	99	2.90	.721	70	70.7
PO4	99	2.91	.716	21	21.2
PO5	99	3.21	.836	27	27.3
PO6	99	2.75	.747	10	10.1
PO7	99	2.96	.781	17	17.2
PO8	99	2.72	.671	6	6.0
PO9	99	2.87	.723	12	12.1
PO10	99	3.19	.841	46	46.4
PO11	99	2.93	.732	15	15.1
PO12	99	2.73	.753	10	10.1
Post-test					
PO1	99	4.79	.411	99	100
PO2	99	4.90	.303	99	100
PO3	99	4.81	.467	96	96.9
PO4	99	4.90	.364	97	98.0
PO5	99	4.68	.620	91	92.0
PO6	99	4.19	.710	88	88.9
PO7	99	4.39	.740	88	88.9
PO8	99	4.20	.622	90	90.8
PO9	99	4.93	.258	99	100
PO10	99	4.65	.611	94	94.9
PO11	99	4.60	.669	93	94.0
PO12	99	4.52	.774	90	91.0

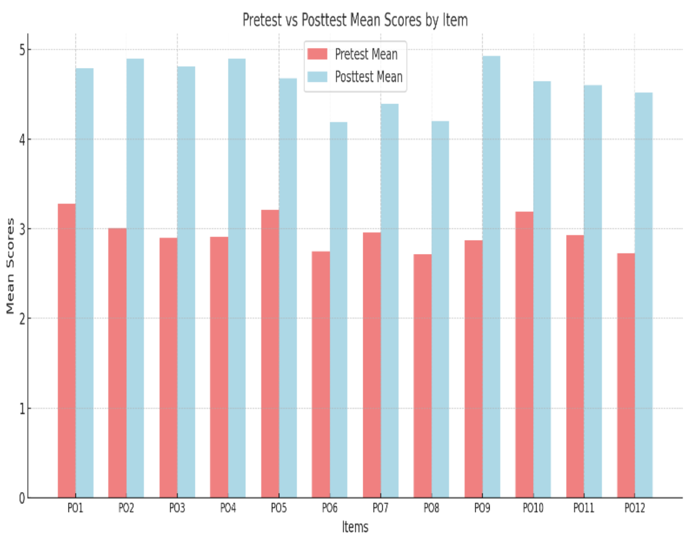

Figure 2. Comparison between the Pretest and Posttest Mean Statistic of each PO.

However, in the Post-test session, the understanding of respondents toward Program Outcomes through the Chemical Plant Design course was much better. It was proven when the mean scores for each item ranged between 4.19 (PO7 Environment and Sustainability) and 4.93 (PO9 Individual and Teamwork), suggesting high ratings across all PO statements. The lowest-rated item appears to be "PO7 Environment and Sustainability" (Mean = 4.19). In terms of the spread of scores, standard deviations ranged from 0.258 (PO9 Individual and Teamwork) to 0.774 (PO12 Lifelong Learning), indicating some variation in responses. Items like "PO9 Individual and Teamwork" and "PO10 Communication" show low variance, suggesting consistently high ratings, while "PO5 Modern Tool Usage" and "PO12 Lifelong Learning" show relatively higher variability. To enhance consistency, consider more personalized or differentiated instruction for these competencies, such as individual feedback sessions or small group discussions to address specific areas of misunderstanding. Overall, scores are high indicating a focus on improvement efforts. Skewness values are negative for all competencies, meaning distributions are left-skewed with a higher concentration of high scores. Negative skewness across competencies suggests an overall positive perception or self-assessment among respondents.

Conclusion

The pilot test provides a decisive view of the survey questionnaire's conformity for the intended purpose. The CA value of 0.891 exhibits a high internal consistency of the survey questionnaires. In addition, the reliability and validity were acceptable. In terms of usability findings, we can conclude that the CEC model is perceived positively in terms of usefulness, satisfaction, and efficiency. Most respondents agree that it helps them become more effective and improves their understanding of the course. From the survey also, we can conclude that respondents express high satisfaction with the CEC model and indicate they would recommend it to others, suggesting that the overall experience is positive, and they found that the CEC model was conducive to learning.

Overall, from a usability point of view, the CEC model seems to have a positive impact on student learning, though there's room for improvement in terms of its time-saving efficiency and ease of implementation. It may be worth exploring how the model could be adjusted to better support time management, or if different types of users have varying perceptions about its efficiency. In terms of the implementation process, some participants could find the model more challenging to apply than expected. As a result, more detailed feedback on this aspect will be collected to help improve its implementation or make the process more seamless for future users.

From the point of view of the effectiveness of the model, the mean scores improved significantly from the pretest to the posttest across all items of Program Outcome. It indicated an overall positive effect and showed substantial improvement from the intervention or learning experience using the CEC model in the CPDII course. The standard deviations in the posttest were decreased for most items compared to the pretest. This indicates reduced variability in responses, which means that more respondents achieved a better understanding. They achieved higher and consistent scores in the posttest. Additionally, the frequency of agreement also increased significantly from the pretest to the posttest, with several items reaching 100% agreement in the post-test, indicating that almost all respondents achieved high scores after the intervention. In the pretest, items like PO8 (6.0%) and PO6 (10.1%) showed particularly low frequencies of agreement. It might be that the respondents have initial weaknesses like initially they felt less confident before intervention. However, in the posttest, several items reached 100% agreement (PO1, PO2, PO4, PO9). This indicates strong learning outcomes or significant improvement in their understanding across the POs. Overall, this study showed impressive improvements across all items reflecting effective learning interventions. This can also help to identify areas of strength and potential gaps in the group's skill set. For example, training programs and improving teaching and learning strategies can focus on improving understanding in "PO6 *Engineering and Society*" or "PO8 *Ethics*," where scores and consistency are lower. In addition, opportunities for continuous learning and feedback should be provided. Continuous improvement measures should also be taken to ensure that the positive reflections observed are sustained and further enhanced.

Significance of the Research

By focusing on the capstone design project course for chemical engineering students at UniMAP, the study addresses a gap in engineering education. Traditionally, engineering programs have struggled to fully integrate theoretical knowledge with practical industry skills, but this research offers a comprehensive approach to bridge that gap. The core importance of the work lies in the methodology for evaluating and improving educational practices. Through statistical analysis, including PCA and CA testing, the researchers developed a robust framework for assessing educational outcomes. The high reliability of their survey instrument (with a Cronbach Alpha of 0.891) provides a scientifically validated method for understanding and improving student learning experiences.

The research also directly impacts student development. By carefully designing a teaching and learning model that comprehensively addresses the program outcomes, the study demonstrates a holistic approach to engineering education. The results show significant improvements in students' understanding of professional expectations and their career preparedness. The research provides a replicable model for other educational institutions seeking to align academic curricula with professional requirements. By offering detailed insights into course design, assessment, and student feedback mechanisms, the study presents a more effective engineering education. It underscores the importance of continuous evaluation and adaptation in educational approaches, highlighting how carefully designed pedagogical methods can substantially improve student learning outcomes and professional readiness.

The broader implications of this research extend to addressing the ongoing challenge of preparing engineering students for rapidly evolving industry landscapes. By creating a more dynamic, responsive approach to education, the study contributes to closing the gap between academic learning and real-world professional expectations, ultimately benefiting students, educational institutions, and the broader engineering industry.

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Conflict of Interest

The authors declare no conflict of interest.

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Automating Peer Evaluation and Attendance in Chemical Engineering Education: A Google-Based Approach

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Abstract
Teaching and learning processes not only involve activities, but class preparation management and pedagogies also play an important role in ensuring quality education is delivered properly. With high-performance indicators to be achieved by academicians, teaching and learning management must be automated to reduce the time spent on these processes. Thus, the one-stop center on content management, automated peer evaluation form (APEF), and attendance management system (AMS) were developed to assist educators in managing academic duties. To date, three chemical engineering courses have been fully developed under the one-stop center which consists of lecture notes, videos, tutorials, past year questions, and any scaffolding activities. APEF and AMS were developed in a Google environment combining Google Site, Sheet, Form, Docs, and Scripts. The APEF was designed to reduce errors in data management and data population of the peer evaluation marks. Meanwhile, the motivation for AMS is to ensure paperless and seamless attendance monitoring can be conducted on real time basis. The output is a fully automated peer evaluation form and attendance monitoring system that can monitor student peer evaluation submission in real-time, providing automated data population and calculation, tracking student attendance, and serving as an evidence collection tool. These tools have had a great impact on the instructors as well as the students in managing their classroom as shown in the 100% agreement in the user satisfaction survey. Although the implementation of these tools as a department practice is not yet in place, the potential of mass adoption is profound due to its simplicity, applicability, and scalability.

Keywords: Teaching and learning tools, one stop center, peer evaluation, attendance monitoring, quality education.

Introduction

Quality education is the bedrock of any nation that strives to be a developed country. It is even highlighted in The Global Goals by the United Nations (UN) focusing on Quality Education as explained in theme 4. It ensures inclusive and equitable quality education. Furthermore, the initiative promotes lifelong learning opportunities for all. Under target 4.4, it is expected that by 2030 the initiative will be able to increase the number of people with relevant skills to increase their earnings and obtain financial success (Nations & Affairs, 2021).

However, there are still challenges in providing quality education by knowledge providers. With the abundance of information and unchecked quality from unqualified subject matter experts. Furthermore, higher non-teaching deliverables expected to be delivered by the university lecturer hinder a higher quality of teaching and learning (T&L) activities. The repetitive process of managing T&L activities should be reduced to provide space and time for lecturers to focus on developing impactful learning experiences for the students as well as other non-teaching deliverables.

Aligning with the SDG initiatives, the main stakeholders of quality education are the students. Quality information, delivery, and experience need to be provided to ensure full engagement can be made with the students. Staying with a teacher-centric approach has proved to be ineffective in providing a holistic experience. Utilizing any student-centric approach on the other hand has shown a significant improvement in student cognitive, psychomotor, and affective development (Howell, 2021; Ruslan et al., 2021; Wu, 2016). However, developing an impactful T&L experience for the student requires the time and creativity of the instructor. To assist this, the repetitive T&L management needs to be automated.

The current learning management system (LMS) focuses more on content management, group management, and assessment management, providing a platform for online discussions and meetings. To the best of our knowledge, other LMSs only allow for the current students who are enrolled in the course to access the learning materials. Thus, the development of

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a one-stop center allows for a better reach and accessibility to those who wish to use it be it as a learner or as an instructor. Moreover, other features such as peer evaluation that was heavily used in team projects are not available in any LMS that the author has encountered. Even though peer evaluation has been around for years, an effective tool that is incorporated into a learning management system or tools has yet to be developed

Thus, this innovation, aids both main stakeholders, instructors, and learners, by developing a system to automate the T&L process by providing features such as a learning platform, automated peer evaluation system, and attendance monitoring system developed using the Google environment.

Innovation Details

One Stop Centre

The development of a Google Site for certain core chemical engineering courses is relevant and crucial to help both major stakeholders in T&L. Rather than only obtaining the knowledge from the instructor alone, an open-source learning material was developed to facilitate student learning. Together with the learning material, sample questions including past year questions for quizzes and final exams were also integrated into this one-stop center for learning material. Google Site was selected to be a content management site due to its simplicity and accessibility by the target market which is UiTM students. Not only is it accessible for students taking the course from the instructor, but it is also open to all who are keen to learn. Moreover, the material will also be useful for final-year students who will be developing their plant design. Conventionally, learners would consult with the lecturer and hope to be spoon-fed on the solution. However, with the availability of this one-stop center, it is expected that the learner can come to the discussion with basic knowledge in hand. This will make the discussion more meaningful and not depend entirely on the instructor. These are aligned with the active learning and flipped classroom initiative that will be discussed further in the learning theory applied in the next topic. Figure 1 shows the Google Site framework for easier reference.

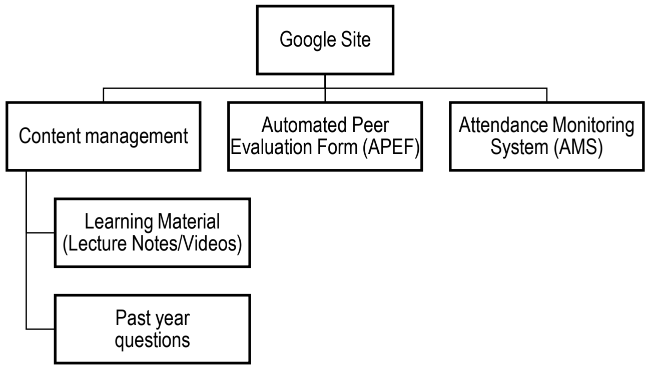

Figure 1. Google Site framework and main components of the innovation

Automated Peer Evaluation Form (APEF)

Included in the Google Site is an Automated Peer Evaluation Form (APEF) that can be used for subjects that utilize group work as a form of assessment. Peer evaluations are essential to ensure the weightage of work done by each team members are given appropriately. The APEF was developed using the available Google features (Google Forms and Google Sheet). The two apps ensure seamless experience for the user, administrator, and developer. This allows the data to be traced in real time and makes monitoring much easier compared to conventional methods. The APEF is equipped with security features to ensure that the learners are utilizing the correct link and reduce error by the student. On top of that additional features such as pre-filled form are the corner stone of the product. The framework of the APEF is illustrated in Figure 2.

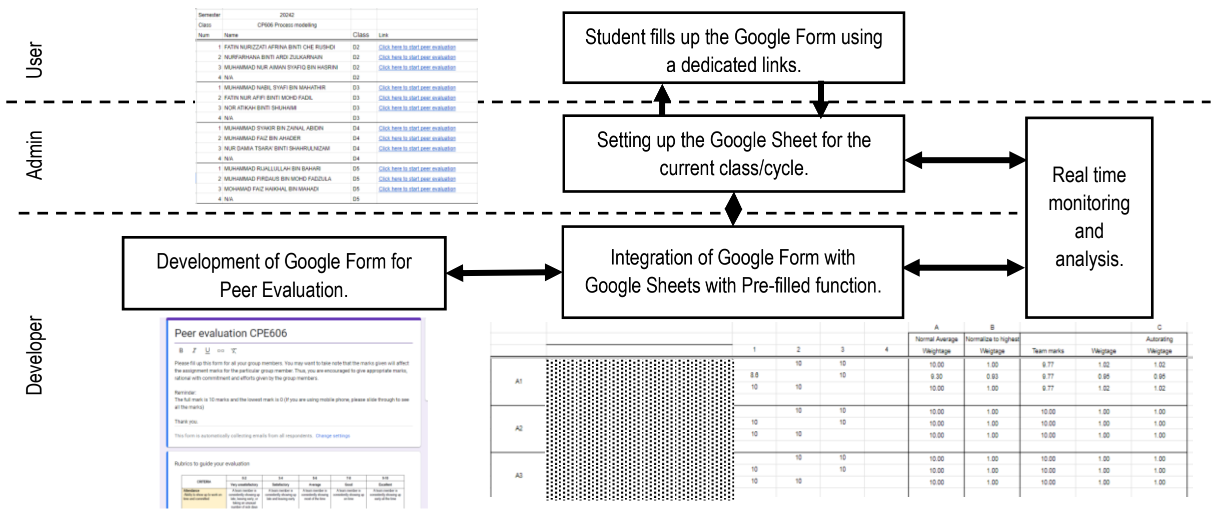

Figure 2: Working Framework of the Automated Peer Evaluation Form (APEF)

The completed peer evaluation form will be integrated with Google Sheets. The equations, coding, and hyperlinks have been embedded in the Google Sheet to ensure the pre-filled forms can be utilized by the user and the admins. Next, the admins are required to fill in the student's name and group that tally up with the class that will be using the form. After that, the dedicated link will be shared with the students as the user of the form. The user will have to log in using their institutional account to ensure they are selecting the correct links, and that it is matched with their user ID. After the data has been submitted, it will be recorded in the same Google Sheets. A series of equations and coding embedded on the sheets will calculate and populate the data in real-time to the peer evaluation marks table. This APEF provides 3 types of calculation which were normal average, normalization to highest, and autorating method. Conventionally, instructors will need to tediously extract individual marks before calculating the respective values for each person involved. Using this APEF, values are automatically calculated and instructors can simply extract the values needed. Additionally, administrators can monitor students who have not completed the evaluation or even those who did make an error in the evaluation using the analysis tab in the Google Sheets. Any anomalies in the table can also be cross-checked with the user's reasoning for every mark provided.

Attendance Monitoring System (AMS)

Other features that were added to the Google Site are the attendance monitoring system (AMS). Utilizing the same features as the APEF, learners can clock in using the personalized Google Form. This reduces the dependency on physical attendance form and transitions to a simplistic paperless system. On top of that, student attendance frequency can be made and to ensure the compliance toward Engineering Accreditation Council (EAC). The framework for the AMS is shown in Figure 3. Moreover, utilizing a Google Script, a warning letter can be generated seamlessly by comparing the attendance percentage to the compliance value. This aids instructors in not manually monitoring the students' attendance and being caught up with administrative tasks of making individual warning letters.

To date, the implementation of AMS has not been very wide, and it is currently exclusive to the author's class only. The practice has been ongoing for 2 semesters and a positive impact has been observed in the attendance monitoring practice. The author feels that attendance collection has been easier compared to manual form, easier collection of medical certificates submitted by absent students, and proper monitoring can be made by utilizing AMS. The most significant feature was the warning letter generation which includes a Google Script development to be integrated with the Google Sheets. Only with a click of a button, a warning letter for multiple students can be generated hassle-free. Embedded to the warning letter was an intelligent code that could be adapted to the date of the letter being generated to ensure an updated version of the letter was generated. The AMS system was not made available to the public due to several documentation that needed to be made before launching it to the masses such as an instruction manual for users and administrators.

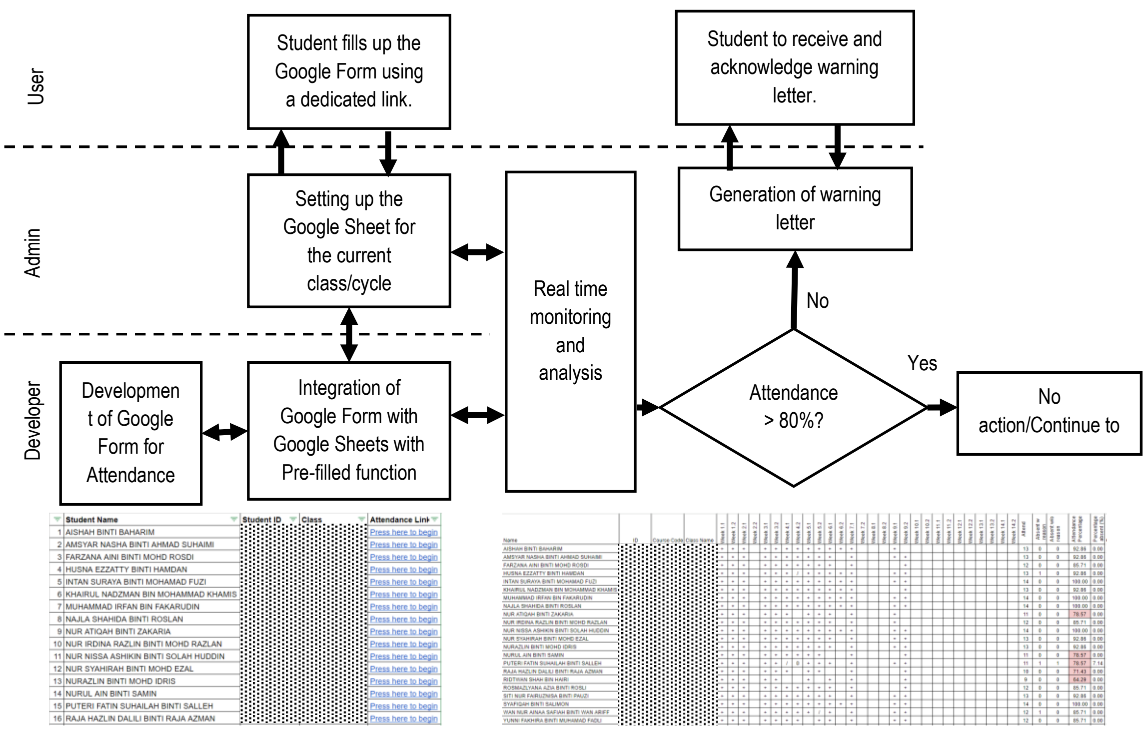

Figure 3: Working Framework of the Attendance Monitoring System (AMS)

Learning Theory and Pedagogical Approach

Student-centred learning theory was applied to ensure learners gain the most out of the learning experience. The learners oversaw their learning while the instructor was facilitating the learning process. Furthermore, the instructor must heighten the learning experience by developing activities that can engage the learners not just cognitively but also psychologically and emotionally. Developing the learning activity according to several principles such as constructivism approach (Do et al., 2023; Pande & Bharathi, 2020), how people learn (HPL) framework (Funes-Lora et al., 2022) and constructive alignment (Yusof et al., 2012) allows a proper mapping between the intended learning outcomes, learning activities, and assessment. Several studies has shown the effectiveness of active learning and flipped classroom approaches in several disciplines such as engineering (Lewin & Barzilai, 2022; Ożadowicz, 2020), computer science (Mirkouei et al., 2016), medical (Phillips & Wiesbauer, 2022; Scholte & Strehler, 2025), business (El-Bassiouny & El-Naggar, 2023), and psychology (Wittmann & Wulf, 2023).

Active learning has shown its capabilities to increase the student level of understanding and motivation in engineering (López-Fernández et al., 2019; von Blottnitz, 2006). It leverages in making the learner actively engaged during the learning session. Activities such as think-pair-share, focused listing, active listening, and one-minute paper were conducted to engage the learner. The implementation is quite straightforward and does not require much resources.

Conversely, a flipped classroom requires the learners to learn before the class starts. Instructors will have to provide additional resources such as books, and videos for the learners to learn so that the discussion and activity in class would be lively and engaging. The resources to the learning materials were provided in the learning management system (LMS) or any content management system available such as Google Classroom, Moodle, and Microsoft Teams to name a few. Instruction was made for the students to prepare peer teaching notes or summaries of the material to be presented and discussed in class. The framework for the flipped classroom was discussed thoroughly by Abdullah and Azizan 2018 and Ruslan et al. 2022. The synchronous and asynchronous sessions were adopted in the implementation plan of the approach. It was designed to engage higher cognitive levels during the discussion with the instructor Many studies have successfully shown that a flipped classroom is often the choice to enhance the learning experience, especially during pandemic times (Awuor et al., 2022; Lewin & Barzilai, 2022; Ożadowicz, 2020). Even though the preparation for the flipped classroom approach is demanding to learners and instructors, the outcome speaks volumes as it is more impactful.

Additionally, proper scaffolding activities were included in the learning process to ensure learners at a lower level were able to understand and appreciate the course. Scaffolding activities such as peer teaching, team quizzes, and formative assessments were included in the lesson plan and executed. Several studies have shown that scaffolding activities can increase learners' engagement. (Bill Ferster, 2014; Mirkouei et al., 2016; Yusof et al., 2012).

Besides that, project-based learning was also embedded in the learning process. Subjects such as process modelling and process simulation which emphasis project delivery were considered for this approach. The framework applied was according to previous researcher (Ruslan et al., 2022). All the necessary materials and steps such as personality checks, team formation, peer evaluations, reflections, and assessments were embedded in the Google Site and APEF to ensure the smooth operation of the learning pedagogy.

Problem Solutions

Conventionally, the learning materials were provided depending on the pace of the instructor. It can be provided either physically or digitally to the learner according to the instructor's lesson plan. In view of the learning management of these learning pedagogies, the availability of learning materials is critical. Accessibility to question banks as scaffolding and formative assessment allows for a better understanding and engagement during the learning activities. Furthermore, digitalized learning material such as lecture notes, online quizzes, lecture videos, and guest lectures is an additional plus point, especially for flipped classroom implementation.

Thus, the one-stop center serves as a library of learning materials to ease up the learning management process by the instructor. Availability and accessibility to the learning materials, question banks, and formative assessment tools such as ‘Quizziz’ and ‘Padlet’ allow for on-demand activities to be conducted. The AMS acts as a tool to ease up the attendance monitoring process making it paperless and seamless. Generation of warning letters can be done with a click of a button. Furthermore, for team-based assessment, APEF assists the instructor in automatically collecting, populating and calculating the peer evaluation provided by the learners. This ecosystem allows for peace of mind for the instructor because some of those processes have been automated. Instructors can focus on delivering and designing an impactful learning experience for the learners.

Current Limitation of the Innovation

Although the ecosystem has been automated, there are still flaws and limitations. The one-stop center and AMS are easy to use due to their intuitive nature. All information is readily accessible to the user. The information and syllabus will have to undergo revision over the years to ensure the information is valid, relevant, and upgraded in terms of presentation and look and feel of the site.

However, the APEF system requires the user to pay close attention to the instruction. Since the form was pre-filled, some users tend to re-fill the name of the student. This can cause mismatches in the system and problems during the data population process. To solve this issue, proper instruction and explanation was given to the user to reduce this error.

Results and Discussion

Google Site Case Study

Using the Google Site developed, active learning and flipped classroom (FC) approach were utilized for two cohorts of students. The first cohort in March 2021 was the process simulation class which utilizes software (Aspen Hysys). The learning material was made public to the students and FC was applied to this group of students. A comparison was made between the students who underwent the FC approach and those who did not. Results in Figure 4 show a significant difference between the two groups. The *t*-test analysis comparing the method shows a *p*-value of 0.01. This shows that the introduction of the FC approach coupled with the digital content is significantly different compared to conventional delivery with a conference level of at least 95%. In this case study, the FC method with digital content has been shown to improve learner performance. The average marks for the conventional group and the FC students are 70.73% and 74.23%, respectively. The data shows that 32.29% of FC students achieve A and A- while 19.33% of the students with the conventional method achieve the same grade. This shows that the Google Site coupled with an effective learning pedagogy can increase student performance. Some reflection by the students did mention that they are able to explore more on the software as shown below:

"The pros from this experience is I actually push myself to explore more about the Aspen HYSYS and read more the research paper."

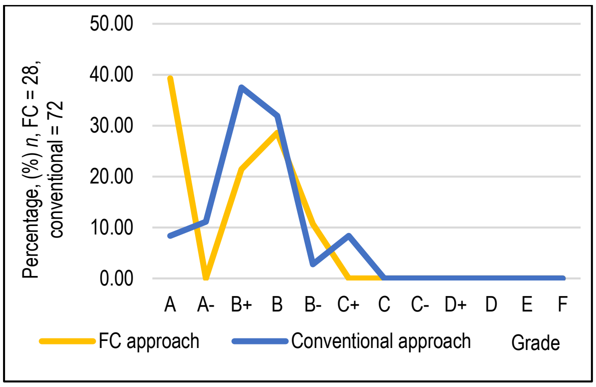

Figure 4. Students grade based on method of delivery utilizing the Google Site.

The same Google Site was applied to 24 repeating students for the process integration course in September 2022. The course is well known to be a tough subject and has a high failure rate amongst chemical engineering students. This provides the perfect opportunity for the implementation of student-centered learning. Since the student background is repeating students and normally being taken by final year students, active learning was selected for the learning pedagogy as it is not too demanding to the students. However, the engagement during the class is maximized to ensure that students can get the full experience. Activities such as jigsaw, peer teaching, gallery walk, reflection, think-pair-share, and one-minute paper were utilized. The student performance between the 2 semesters was evaluated and illustrated in Figure 5. Data shows 22 out of 24 students who retake the class managed to pass the course with 1 student able to score an A. The median increased from 40.01% to 58.40% and a 4-grade leap was observed from D to C+. A one-tailed *t*-test analysis of the result shows that the two data are significantly different with a *p*-value of 2.73 × 10-9 which is way lower than the threshold value of $\alpha = 0.05$. This means that the method is significant in improving student performance. This shows an engaging learning method with a proper content management setup can increase learners' performance and keep the student motivated for the course as mentioned in the reflection of the student: *"Studying is stressful, especially when you're taking more than 1 subject per semester. The fact that I got excited and anticipate to be in Sir XX's class speaks a lot of volume. His classes are very entertaining and insightful."*

Figure 5. Comparison of student performance utilizing two different learning methods of delivery.

Furthermore, data collected from student reflection as shown in Figure 6 also shows that 100% of the learners exposed to the Google Site agree that the platform was easy to navigate and accessible. The student also agrees that the content provided on the site is easy to follow, the duration is decent, and they can prepare before attending class. In the context of T&L automation, having the learning material ready for student accessibility coupled with proper instruction and planning, the teaching and learning process can be more effective. As the materials are readily available for the students, it is expected that the students come to class with a general idea of the topics. Instructors take the role of reinforcing the learners understanding. The automation process was initiated when the learning process became a norm that learners seek information through questioning, inquiries, and discussion in the classroom making it cognitively engaging. Moreover, scaffolding and interactive activities can be introduced such as in-class discussions, gallery walks, and team quizzes. These activities have been shown to increase student motivation and knowledge attainment.

APEF Case Study

The development of APEF aims to reduce the instructor's workload by having an automated collection, calculations, and monitoring system. The first draft of the system was proposed in August 2023 whereby students were given links to evaluate each team member. However, this approach was not fully optimized and received a lot of criticism regarding the system by the students. Comments such as requests to add reasoning for the rating, adding the evaluation rubrics to the form, and combining the link so that each person is only provided with one link were addressed. Additionally, 19 out of 94 students (20.21%) face difficulty utilizing the system. Inputs provided are not in the right field or even changing the information that has been pre-filled for them.

Consequently, an improved and optimized system was introduced to the students. For this cycle, all the previous comments were addressed accordingly. The rubrics were provided at the beginning of the Google form, clear instructions were provided to the user, reasoning for the evaluation was also added to the form and verbatim analysis were conducted. In January 2024, the APEF system was handed to users to cater for 295 students which obtained more than 1200 data points for the calculation. Utilizing real-time monitoring and proper instruction to the students, only 2 input errors were found (0.002%). The adjustment has shown a significant improvement in the APEF system. Additionally, the response from the users was extremely positive as it reduced their days' work to only a few minutes of analysis. This shows an increase in productivity and reduces the data management procedures.

Based on the user experience survey that has been conducted on the user (students) as well as the administrator (lecturers), all the respondents agree that the APEF is performing better than the current peer evaluation form as shown in Figure 7. A total of 90 users were surveyed for this study and the data shows that 93.33% of the respondents strongly agree that the form can easily be used, 89.89% of the respondents strongly agree that the APEF is intuitive and can be used with minimal instruction and 95.51% of respondents strongly agree that the APEF form can be completed faster compared to the conventional forms. From the administrator perspective, 60% of the respondents strongly agree that by using the APEF system, the form is easier to manage, the analysis is seamless, the reporting of the form is easily understood, and they did not utilize as much time to analyze the peer evaluation compared to the previous practice. Note that even though 60% rate the form in the "Strongly agree" region on the Likert scale, the remaining maintained on the "Agree" region, and no negative response was received throughout the study. However, some constructive comments were received such as it is hard to find their names in the APEF list. This can be easily addressed by using the filter function in Excel to find their personalized links. Thus, it is believed an instruction to utilize the filter or search function can be introduced to cater to this issue.

Conclusion

This study shows that the Google Site developed is a learning tool that may assist lecturers and instructors in delivering an impactful learning experience to the learners. The development of a simple and intuitive one-stop center is key to having it be used by the users. On top of that, the development of additional tools such as AMS and APEF is important to improve the learning experience for the learners and the instructor. Continuous quality improvement and feedback are most important in ensuring the Google Site is up-to-date and relevant to the current demand. More courses can be included together in the one-stop center to increase the number of courses that can be offered. Moreover, a complete collection of chemical engineering courses can foster a learning community and provide learners with a comprehensive knowledge of the program. Additionally, implementing APEF and AMS as standard practice in the institution is projected to assist academician in managing their classroom. However, the current limitation on the number of instructors involved, storage limitation as well as lack of exposure to the community contributes to the setback of the initiative. These are the challenges that if can be solved can propel the implementation of Google Site to the departmental or institutional level.

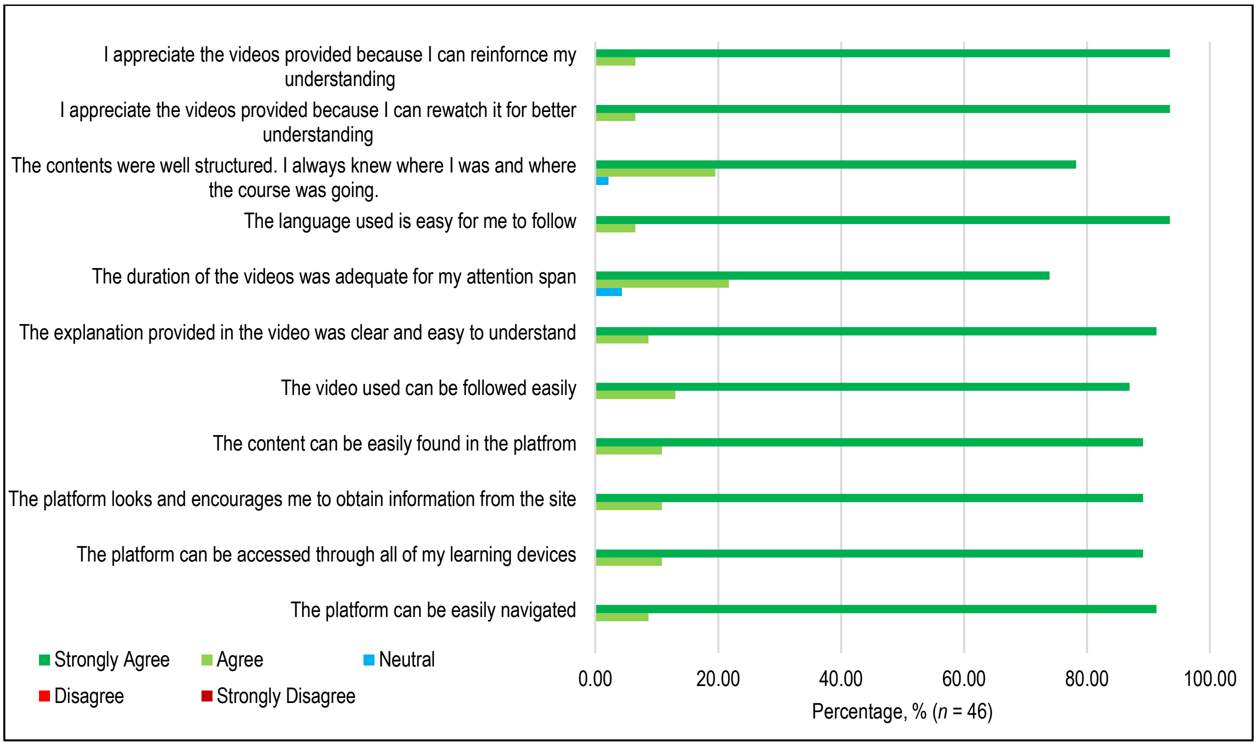

Figure 6. Student reflection and course exit survey after using the Google Site.

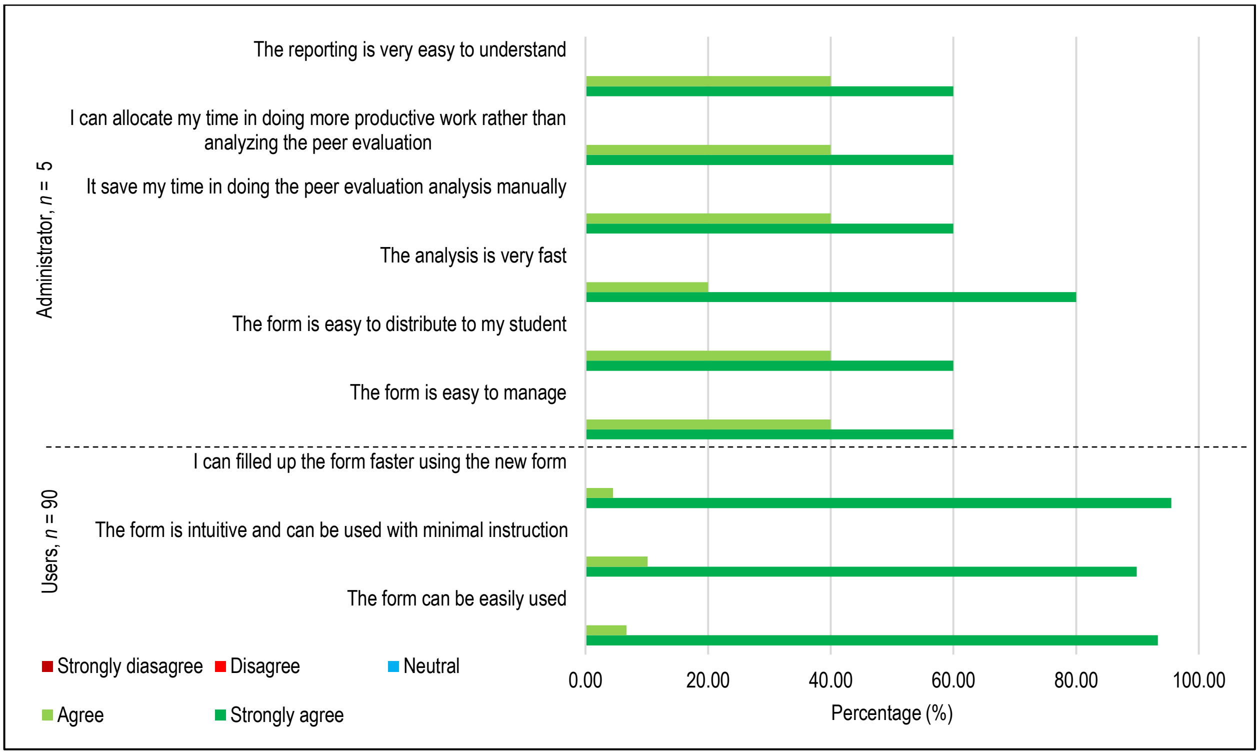

Figure 7. APEF user experience survey analysis

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Conflict of Interest

The authors declare no conflict of interest.

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The Effect of Six Sigma on TVET Course Syllabus Development Learning Institutions in Pasir Gudang, Johor

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Abstract
There are a few major components learning institutions would look out for in their course syllabus while playing a vital role in the performance of technical and vocational education and training in any academic or student outcome. The process structure determines whether the students gaining knowledge and skills are in the condition of improvements from the previous syllabus or have the ability to adopt the knowledge in the future. The Six Sigma methodology has extensively been used as a structured approach to problem-solving, and it shall be used to test the potential effects of improvements obtained from the previous syllabus. This study was conducted in educational institutions in Pasir Gudang, Johor, to observe how Six Sigma implementation applies in affecting the structural processes in the syllabus. A sample of 176 members of the academic department were randomly selected and requested to complete a questionnaire on how the Define-Measure-Analyze-Improve-Control (DMAIC) method has influenced the structural procedures of their course syllabus. By using Statistical Package for the Social Sciences (SPSS), more time is available for the researcher to appreciate the underlying assumptions of the various methods utilized in carrying out the correlation and regression studies. The findings indicated that the core field of study and knowledge of standard requirements significantly affect course syllabus process structure and Six Sigma. It is recommended by the researcher that other organisations, especially in the Technical and Vocational Education and Training (TVET) institutions, to apply the DMAIC strategy in the course syllabus process structure. Six Sigma is applicable to be used to improve the course syllabus process structure.

Keywords: TVET, Six Sigma, DMAIC, course syllabus, learning institutions.

Introduction

Technical and Vocational Education and Training (TVET) programs are essential for providing learners with the practical skills required to fulfil industrial needs. Nonetheless, their efficacy is frequently compromised by various obstacles, such as obsolete curriculum, inadequate alignment with industry benchmarks, and insufficient incorporation of developing technology (Khalid et al., 2021). The inefficiencies yield graduates inadequately equipped for the job market, raising questions over the relevance and efficacy of TVET programs in mitigating skills shortages (Renaud, 2009). This necessitates the identification of systemic barriers and the formulation of initiatives to enhance TVET outcomes.

Numerous structural problems impede TVET institutions from achieving their maximum potential. Resource limitations, the absence of standardised quality assurance protocols, and inadequate teacher preparation intensify these issues (Amudalat & Yusuf, 2024). Moreover, stakeholders, such as policymakers and administrators, frequently have difficulties in ensuring coherence between educational programs and labour market demands (Joo, 2018). Consequently, comprehending the determinants influencing TVET success is essential for formulating effective solutions.

Innovative approaches such as Six Sigma's Define-Measure-Analyze-Improve-Control (DMAIC) framework provide a systematic strategy for tackling these inefficiencies. Although widely utilised in manufacturing and service industries, the application of DMAIC in the educational sector, especially for enhancing TVET performance, is yet inadequately investigated (Sabtu & Matore, 2023). The deficiency in the research highlights the necessity to examine the particular effects of DMAIC on curriculum design, instructional quality, and program efficiency (Jayamohan & Bhasi, 2024).

The incorporation of Six Sigma methodologies into the development of TVET syllabuses has garnered considerable interest as a strategy for enhancing educational quality and relevance. The structured approach of Six Sigma, especially the DMAIC model, is gaining traction in education to improve teaching-learning processes, optimise resource use, and align curricula with industry standards (Jayamohan & Bhasi, 2024).

Research demonstrates that the application of Six Sigma in higher education can result in systematic enhancements in curriculum design and delivery, therefore improving teaching effectiveness and students' satisfaction (Toqir et al., 2024). By utilising quality control techniques inside the Six Sigma framework, educational institutions can gain a comprehensive understanding of their operations and make specific enhancements to rectify inadequacies (Sabtu & Matore, 2023).

Furthermore, the implementation of Six Sigma in TVET has demonstrated an enhancement in operational efficiency and the cultivation of a dynamic learning environment that more effectively addresses the requirements of stakeholders, including students and employers (Haerizadeh & Sunder, 2019).

Traditional curriculum framework and the TVET curriculum syllabus model can exhibit parallels and differences. This study aims to address this gap by examining the application of DMAIC in improving TVET learning, and identifying strategies to align educational offerings with industry needs.

Although it holds promise, implementing DMAIC in educational settings poses distinct problems. Cultural opposition, insufficient knowledge in quality management, and misaligned institutional objectives frequently obstruct successful implementation (Haerizadeh & Sunder, 2019). Furthermore, the absence of customised frameworks for implementing DMAIC in TVET environments needs study to investigate adaptations that can efficiently overcome these obstacles.

This study seeks to fill existing gaps by analysing the implementation of DMAIC in enhancing TVET outcomes, exploring systemic barriers to performance, and identifying strategies to align educational programs with industry requirements. The findings will enhance the relevance, efficiency, and impact of TVET programs, ensuring the production of industry-ready graduates who can contribute to economic growth.

Addressing these challenges requires an examination of the integration of structured methodologies, such as DMAIC, into the operational framework of TVET institutions. Research must concentrate on identifying optimal practices, quantifying the concrete advantages of DMAIC implementation, and investigating strategies to address potential challenges. This research seeks to connect theoretical frameworks with practical applications, thereby improving the ability of TVET programs to produce graduates who are prepared for industry. It addresses the question of how DMAIC and similar tools can be adapted to tackle the practical challenges that TVET programs encounter in aligning educational outcomes with industry needs.

Literature Review

TVET programs are acknowledged worldwide for their crucial role in providing individuals with skills that are pertinent to industry needs, enhancing employability, and responding to the requirements of the labour market. The performance of TVET programs frequently falls short, influenced by systemic challenges including outdated curricula, inadequate industry alignment, and restricted resource allocation (Khalid et al., 2021). Research shows that these inefficiencies result in graduates who lack adequate preparation for the job market, which diminishes the significance of TVET in achieving economic and social objectives (Renaud, 2009). Although certain institutions have progressed in refining their methodologies, numerous others continue to face challenges in ensuring quality and consistency in program delivery (Amudalat & Yusuf, 2024).

In addressing these problems, organised quality management approaches such as Six Sigma, namely its DMAIC framework, have been suggested as viable solutions. The DMAIC paradigm offers a structured approach for detecting inefficiencies, quantifying results, and executing enhancements. Research has shown the relevance of Six Sigma in educational settings, including improvements in curriculum quality, teaching methods, and operational efficiency (Jayamohan & Bhasi, 2024). Integrating DMAIC into educational processes has led to increased student satisfaction and enhanced program outcomes (Sabtu & Matore, 2023). Implementing Six Sigma in educational institutions faces obstacles due to cultural opposition and insufficient skills in quality management, which often hinder acceptance (Haerizadeh & Sunder, 2019).

TVET programs exist inside intricate institutional frameworks where resource limitations, organisational culture, and industry dynamics converge to affect outcomes. To effectively implement Six Sigma, institutions must consider these contextual aspects while aligning their tactics with overarching educational objectives. Models such as Tinto's Institutional Integration Theory and the Theory of Planned Behaviour have been utilised in TVET research to comprehend the relationship between institutional practices and student results (Renaud, 2009). These models indicate that synchronising institutional initiatives with student expectations and industry requirements is essential for success. Nonetheless, deficiencies remain in the adaptation of these ideas to include structured quality improvement methodologies like DMAIC into institutional practices.

The current literature emphasises the potential of Six Sigma approaches in mitigating inefficiencies in TVET while also identifying considerable obstacles. Research on the use of DMAIC in various educational contexts, especially in resource-limited settings, remains sparse (Sabtu & Matore, 2023). Addressing these problems necessitates a twofold strategy: enhancing institutional capacity for quality management and formulating context-specific frameworks that connect theoretical models with practical applications.

Hence, it can be deduced that TVET programs and Six Sigma can reduce educational inefficiencies, but their combination faces structural and operational challenges. This study examines possible Six DMIAC integration methods for TVET contexts and proposes a framework that aligns institutional practices with industrial needs to improve education quality for students. The capability of Six sigma DMIAC flow is tabulated in Table 1.

Table 1. The DMAIC Phases adopted (Abdulla & Kavilal 2022).

Phase	Details
Define (D)	Educational institutions identify key problem and goals areas that need improvement, such as suitable course syllabus, structure program, and program learning outcome.
Measure (M)	Institutions collect data on various performance metrics, such as assessment of internal academic and industry, evaluations of program structure and industry feedback. This data provides a baseline for assessing the course syllabus development for the program.
Analyse (A)	Examining the collected data to identify root causes of performance issues. This may involve analyzing trends, correlations, and patterns in student performance data.
Improve (I)	Implementing solutions to address the identified root causes. This could include revising the curriculum, enhancing teaching methods, and taking industry advise on new program development.
Control (C)	Sustaining the improvements made. This involves setting up monitoring systems, regular reviews, and continuous feedback mechanisms to ensure that performance gains are maintained.

Table 1 illustrates that Six Sigma can significantly influence TVET and education, enhancing performance and outcomes. Educational institutions can identify and rectify issues systematically through the DMAIC methodology, resulting in increased student satisfaction, higher retention rates, and improved employment opportunities. Previous studies indicate that Six Sigma can enhance various aspects of education, including the development of course outlines, the improvement of facilities to facilitate student learning and performance, the formation of collaborative learning groups, and the overall enhancement of teaching and learning processes (Abdulla, A., & Kavilal, 2022; Arafeh, M., et al., 2021; MacIel-Monteon et al., 2020). Six Sigma's systematic approach guarantees that improvements are based on data, remain uncomplicated, and yield enduring solutions. It serves as a valuable resource for educational institutions aiming to improve their programs.

This article seeks to examine the implementation of Six Sigma methodology in the formulation of TVET course syllabi, highlighting its capacity to reconcile discrepancies between academic training and industry requirements while maintaining quality and relevance.

Specifically, this study aims to identify key factors influencing TVET performance, examine the application of Six Sigma methodology, and improve institutional performance in delivering these programs. This study aims to examine the concrete implementation of the DMAIC phases of Six Sigma in addressing performance issues related to course syllabus development at TVET institutions in Pasir Gudang, Johor.

Methodology

This study utilised a quantitative research design, crucial for producing evidence-based knowledge and enhancing practice. Quantitative methods establish a structured approach for the collection and analysis of numerical data, yielding essential insights into the relationships among variables (Sousa et al., 2007). This study employed a survey method, a well-established technique for collecting structured data. Surveys are widely utilised across various disciplines for their systematic and efficient data collection capabilities, aiding in the understanding of complex phenomena. This research employed a questionnaire, a standardised instrument that guarantees uniformity in responses, facilitating rigorous statistical analysis (Collins, 2003; Artino et al., 2014; O'Rourke, et al., 1988).

The questionnaire was developed through a rigorous process to ensure its reliability and validity. Expert validation was performed to enhance the instrument, confirming its effectiveness in measuring the intended constructs. The process involved face and content validation, as suggested by Elangovan & Sundaravel (2021), incorporating feedbacks from experts and scholars in the discipline. This validation establishes the questionnaire's relevance and adequacy for capturing the study's nuances. The comprehensive approach employed is consistent with established best practices for survey design, as indicated by Draugalis et al., (2008). This survey targetet stakeholders involved in TVET programs at higher education institutions (HEIs) around Pasir Gudang, Johor, Malaysia.

A total of 300 questionnaires were distributed, yielding 176 completed responses. The data were analysed utilising IBM's Statistical Package for the Social Sciences (SPSS), Version 27. SPSS is a well-established tool utilised in social sciences, business, and health research for data management and analysis (Alili & Krstev, 2019). It enables diverse statistical analyses and data manipulation, yielding outputs that are essential for researchers.

SPSS V.27 provides various advanced features such as multidimensional scaling, factor analysis, MANOVA, and a priori power analysis. These functions allow researchers to investigate intricate relationships between data variables and guarantee strong statistical interpretation. The revised software version offers improved tools for power analysis, which are especially beneficial for complex study designs, including repeated measures and longitudinal studies (Muller, 1992). Essential statistical methods to be utilised comprised of ANOVA, correlation tests, and factor analysis, which aid in recognising patterns and relationships within the data.

This research seeks to elucidate the elements influencing TVET performance by utilising the functionalities of SPSS V.27. The stringent quantitative technique, along with sophisticated analytical instruments, guarantees that the results are both dependable and practical, enhancing the current dialogue in TVET and higher education research.

Results and Discussions

A series of questionnaires were used to gather the data, and SPSS V.27 Statistics programme was used to examine the results. To fulfil the project's objectives, the researcher the data will be analysed and and conclusions will be drawn from the investigation.

Pearson's correlation coefficient r in relation to the P-value. The Pearson correlation coefficient ranges from -1 to 1. In general, the correlation expresses the degree to which two variables vary similarly on average. A positive correlation exists when one variable increases while the other increases. The correlation coefficient will be closer to 1 in this situation. When one variable decline while the other increases, there is a negative connection and the correlation coefficient approaches -1. To interpret the correlation, it can be determined by observing on the aspects such as direction of the relationship and level of significance.

The null hypothesis is being tested to determine whether there is any or no evidence to imply correlation exists based on this sample. The data indicates which of these opposing hypotheses is more likely to be accurate. If it is the Pearson Correlation Coefficient, we may express this test using a hypothesis (H1) as follows:

H1: Six Sigma DMAIC has an effect on TVET performance

Some evidence have been observed to display that all the service quality components are monotonically associated in the sample and that strong evidence also exists for H1 to be accepted as the SPSS displays the p-value for this test as .001.

Table 2 shows the descriptive statistic to assess H1. The correlation coefficient value indicates how strongly the value correlates with another variable. It also implies that there is correlation between variable because according to the Pearson Correlation Scale, the p value is less than 0.05. Thus, it can be assumed that all the constructs have hook connections. Moreover, the p value of $p < .001$ indicates that the result is highly significant and it is very unlikely to have occurred by chance alone.

The Pearson Correlation value confirms that there appears to be a strong positive correlation with other factors, since at the value .793 there is no negative symbol. There is significant positive relationship between Six Sigma DMAIC and TVET performance, r (174) = .793, p = .001.

Table 2. Descriptive Statistics

Correlations			
	DMAIC		Technical and Vocational (TVET) performance
DMAIC	Pearson Correlation	1	.793**
	Sig. (2-tailed)		.001
	N	176	176
Technical and Vocational (TVET) performance	Pearson Correlation	.793**	1
	Sig. (2-tailed)	.001	
	N	176	176

A regression test was also employed to analyze how the independent variables affect the dependent variable. The regression analysis determined how much the predictor factors affected the criterion variable (Davison & Davenport, 2002). Bivariate Regression Analysis is a sort of statistical analysis that can be utilised in quantitative market research during the analysis and reporting stages. Bivariate Regression Analysis is examining two variables to determine the strength of their relationship. The two variables are commonly labelled as X and Y, with the first being an independent variable (or explanatory variable) and the second being a dependent variable (or outcome variable).

The Model Summary provides key insights into the regression analysis. The correlation coefficient RRR is 0.793, indicating a strong positive relationship between the predictor and the dependent variable. The R2R^2R2 value of 0.626 suggests that approximately 62.6% of the variability in the dependent variable can be explained by the model. The adjusted R2R^2R2 value of 0.628 takes into account the number of predictors and provides a more accurate assessment of the model's explanatory power.

The Standard Error of the Estimate is 0.793, reflecting the average distance that the observed values fall from the regression line. The significant FFF change (p = .000) reinforces the finding that the inclusion of the predictor variable significantly improves the model's fit compared to a model without it. Additionally, the Durbin-Watson statistic of 1.633 suggests that there is no strong autocorrelation in the residuals, indicating the model's reliability. Overall, these findings highlight the model's effectiveness in capturing the relationship between the variables.

The ANOVA results indicate that the regression model significantly explains the variability in the dependent variable. With an F-statistic of 294.186 and a p-value of .000, the model demonstrates a highly significant relationship between the predictor and the outcome, suggesting that the predictor variable is effective in explaining changes in the dependent variable. The regression accounts for 59.828 units of variability, while the residuals reflect an unexplained variability of 35.386 units, highlighting the model's overall adequacy.

Additionally, the total sum of squares amounts to 95.214, indicating the combined variability in the dependent variable. The degrees of freedom for the regression (1) and residuals (174) suggest a well-structured model with a sufficient sample size. Overall, these results imply that the regression analysis has effectively identified a meaningful relationship, warranting further exploration or application in predictive modelling.

The main finding from the ANOVA analysis is that the regression model is statistically significant, as indicated by the F-statistic of 294.186 and a p-value of .000. This suggests that the predictor variable has a strong effect on the dependent variable, explaining a substantial portion of the variability (59.828 out of a total of 95.214). The results imply that the model is effective and that the predictor can reliably be used to forecast changes in the outcome variable.

Table 3. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	df1	df2	Sig. F Change	Durbin-Watson
1	.793[a]	.626	.628	.45.793	.628	1	174	.000	1.633

a. Predictors: (Constant), Six Sigma DMAIC

b. Dependent Variable: technical and vocational (TVET) performance

Table 4. Shows ANNOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
1Regression	59.828	1	59.828	294.186	.000[b]
Residual	35.386	174	.203		
Total	95.214	175			

a. Predictors: (Constant), Six Sigma DMAIC

b. Dependent Variable: technical and vocational (TVET) performance

Table 5. Coefficient Test

Model	B	Std. Error	Beta	Lower Bound	Upper Bound	Model	Tolerance	IVF
1 (Constant)	.842	.170	4.947 .000	.506	1.178	1 Constant)		
Six Sigma DMAIC	.729	.042	.793 17.152 .000	.645	.813	Six Sigma DMAIC	1.000	1.000

a. Dependent Variable: technical and vocational (TVET) performance

The Coefficients table presents the regression analysis results for the model. The constant (intercept) is 0.842 with a standard error of 0.170, indicating that when the predictor (Six Sigma DMAIC) is zero, the dependent variable is expected to be approximately 0.842. This value is statistically significant, with a p-value of .000.

For the predictor variable, Six Sigma DMAIC, the coefficient is 0.729 with a standard error of 0.042, resulting in a standardized beta of 0.793. This strong beta value suggests that Six Sigma DMAIC has a substantial positive effect on the dependent variable. The p-value of .000 further confirms the statistical significance of this predictor. The confidence interval for the coefficient ranges from 0.645 to 0.813, indicating that we can be confident that the true effect of Six Sigma DMAIC lies within this range. The tolerance value of 1.000 suggests that multicollinearity is not a concern in this model. Overall, these results underscore the importance of Six Sigma DMAIC in predicting the outcome variable effectively.

The findings from the Coefficients table indicate that the Six Sigma DMAIC variable has a strong positive impact on the dependent variable, with a coefficient of 0.729. This suggests that for each unit increase in Six Sigma DMAIC, the dependent variable increases by approximately 0.729 units. The standardized beta of 0.793 further highlights the strength of this relationship, indicating a substantial effect.

The statistical significance of this predictor is reinforced by a p-value of .000, confirming that the relationship is not due to chance. The confidence interval for the coefficient (0.645 to 0.813) suggests that the true effect is likely to fall within this range, providing further assurance of the model's reliability. Overall, these findings emphasize the effectiveness of Six Sigma DMAIC as a significant predictor of the outcome variable.

The Regression Test table outlines the main results about the idea that DMAIC has an impact on TVET performance. The regression weight for this connection is 0.729 showing a big positive effect of DMAIC on how well TVET does. The Beta coefficient of 0.628 backs up how strong this effect is hinting that DMAIC can predict performance outcomes in this area.

A p value of < .001 with an F = 294.186 000, relations are statistically significant (p < 0.05) and indicate that your hypothesis is supported. If DMAIC methodologies improved educational performance in technical and vocational education as suggested by this meta-analysis, their wide-spread implementation has the potential to be of relevance due to its consequences on skill formation. Implications - These findings provide evidence to support the effectiveness of DMAIC for improved TVET performance.

For the hypothesis of whether Six Sigma DMAIC has a significant effect on TVET performance, Model 2 was used to assess TVET performance → Six Sigma DMAIC (to test H1) DV PredictingDfFp-valueR^2Adj. Operational Performance was significantly predicted by Six Sigma DMAIC; F (1,174) = 294.186, p < .001.

This means that the Six Sigma DMAIC can be critical in developing TVET performance (b =. 729, p <. 001). These results plainly indicate that the Six Sigma DMAIC has a positive impact.

The value of R = .628 depicts that the model explains 62.8% of the variance in TVET performance.

Conclusion

This research has investigated the application of the Six Sigma DMAIC methodology in improving the performance of TVET programs within educational institutions in Pasir Gudang, Johor. The study findings demonstrated that the core field of study and the understanding of standard requirements play a critical role in shaping the structure and processes of course syllabi. The implementation of the DMAIC strategy was shown to significantly enhance the effectiveness and efficiency of these processes, highlighting its applicability as a quality improvement tool in the context of TVET.

The results underscore the potential of Six Sigma methodologies, particularly DMAIC, to improve the structure and delivery of course syllabi in TVET institutions. By addressing inefficiencies and aligning curricular processes with standardized requirements, DMAIC can foster improved academic and institutional outcomes. These findings contribute to the growing body of evidence supporting the integration of structured quality management tools in educational contexts.

Based on these insights, it is recommended that other organizations, particularly TVET institutions, consider adopting the DMAIC framework to optimize their course syllabus development and related processes. This approach not only enhances the quality and alignment of educational offerings but also supports broader institutional goals of efficiency and relevance.

Table 6. Regression Test

Hypothesis	Regression weight	Beta Coefficient	R	F	p- value (p< 0.05)	Hypothesis supported
H_1	DMAIC on technical and vocational (TVET) performance	.729	.628	294.186	.000	Yes

Furthermore, the conclusions derived from this research provide a valuable framework for future studies. Researchers are encouraged to build on these findings to explore the application of Six Sigma in diverse educational settings and across varying institutional contexts. Expanding the scope of investigation will deepen the understanding on how quality management tools can be tailored to address specific challenges in technical and vocational education.

Recommendation

From the findings gathered, some recommendations can be suggested. It was found that the syllabus cannot be formulated very easily or effectively. One of the objectives is to determine the relationship between Six Sigma DMAIC and TVET performance at Pasir Gudang Johor. It can be seen that that Six Sigma DMAIC did have an effect toward TVET performance. Therefore, it is recommended to implement DMAIC approach in course syllabus development as well as for other organizations particularly related to education institution.

This approach significantly contributes to enhancing student knowledge, reducing program development time, and increasing productivity. For instance, implementing systems like DMAIC or Failure Mode and Effects Analysis (FMEA) can help improve efficiency. Therefore, other educational institutions, particularly those involved in TVET program development, should consider adopting this approach to reap its benefits.

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Conflict of Interest

The authors declare no conflict of interest.

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A Study on the Gap Between the Competencies of Industrial Engineering Undergraduate Students and the Competency Requirements of the Job Market in Indonesia

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Abstract

This study examines the gap between industry expectations in Indonesia and the current competencies of undergraduate Industrial Engineering students at Universitas Sebelas Maret. The findings of this study can serve as a guideline for improving the existing Industrial Engineering program at Universitas Sebelas Maret. The research employs web scraping methods to identify appropriate indicators for assessing competency requirements in Indonesia's industrial sector. The curriculum expert team of Industrial Engineering at Universitas Sebelas Maret reviewed these indicators. Thirty-one competency performance indicators were adopted and distributed via questionnaires to 33 industry employees and 91 Industrial Engineering students from Universitas Sebelas Maret to rate the competency indicators on a scale of 1-5. We collected data and analyzed it to determine the gap between industry expectations and the current competencies of the students. The results show a significant gap between the competencies of undergraduate Industrial Engineering students at Universitas Sebelas Maret and the demands of the industry in Indonesia across all analyzed variables. The competencies with the highest gap are in the variables of Information & Communication, with a gap value of 436.8. The Information & Communication variable relates to the scope of technical skills, information system design, and programming. Conversely, we found the lowest gap in the management variable, with a gap value of 261.6. These variables are cost analysis, organizational management, marketing, and product innovation, which indicate that student competencies in this area are closer to industry expectations. This study highlights the urgent need for curriculum adjustments better to align student competencies with Indonesia's industrial sector demands.

Keywords: gap study, Indonesian industry, engineering education, industrial engineer.

Introduction

With the rapid advancements in industry and technology, the need for corresponding competencies in the job market is constantly evolving and increasing. However, there are indications that graduates of undergraduate industrial engineering programs have not yet fully met the competency demands required by the industry. This discrepancy creates a gap between the competencies possessed by graduates and those needed in the workforce.

Competencies combine knowledge, skills, and attitudes necessary to perform a job effectively. Knowledge includes theoretical and practical information relevant to the field of work, skills encompass both technical and non-technical abilities applicable in real situations, and attitudes involve values, motivations, and behaviors that support optimal performance in the workplace. Good competencies enable individuals to complete tasks efficiently and adapt to changes, solve problems, and contribute to overall work quality improvement (Spencer & Spencer, 1993). The industry has specific competency standards that workers must meet to contribute optimally. Therefore, higher education institutions are responsible for preparing graduates who meet industry needs (Kadir, 2017).

The competency gap in Indonesia is evident from the high unemployment rate (BPS, 2023) and feedback from companies regarding the competencies of graduates. Factors contributing to this gap include curricula that are less relevant to industry needs, a lack of practical experience among students, and insufficient mastery of soft skills such as communication and teamwork (Susanto, 2020).

As a potential market, Indonesia has the fourth-largest population globally (BPS, 2023), with a growing middle class (World Bank, 2023). It opens significant opportunities for industrial products and services. On the other hand, the demographic bonus, with 70% of the population being of productive age, is a valuable human resource (BPS, 2023). Despite its vast potential, Indonesia's readiness to face industrial challenges still needs improvement. Collaboration between the

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government, industry, and academia is key to building an ecosystem that supports industrial development (Setiawan, 2021).

The Indonesian government has demonstrated its commitment by launching various programs and policies, such as Making Indonesia 4.0 (Ministry of Industry, 2018). These programs include accelerating infrastructure, promoting technology adoption, enhancing digital talent, and establishing supporting regulations to prepare a digital society.

However, implementing advanced technologies requires skilled human resources capable of quickly adapting to technological changes. Here, the role of higher education, particularly industrial engineering programs, becomes crucial. Industrial engineering plays a vital role in this era. Industrial engineering focuses on the design of integrated systems involving humans and technology to achieve efficient and effective goals (Suharso, 2018). Technological developments like the Internet of Things (IoT), big data, and artificial intelligence (AI) open new opportunities to enhance industrial efficiency and productivity.

The industrial engineering curriculum offers subjects such as systems optimization, supply chain management, simulation, and manufacturing technology, which are highly relevant to Indonesia's industrial development (Arifin, 2019). Additionally, the interdisciplinary skills possessed by industrial engineering graduates, such as understanding business processes and technical capabilities, make them valuable assets for companies seeking innovation and operational efficiency improvements. Industrial engineering professionals must adapt to new technologies and develop innovative solutions to meet industry needs (Wijaya, 2020).

We need to ensure that the competencies and skills of undergraduate Industrial Engineering students at Universitas Sebelas Maret meet industry competency demands. So, this research aims to identify the gap between the competencies of these students and the competency requirements of the job market in Indonesia. The main focus of this research includes determining the competency indicators needed in the industry and assessing the readiness level of Industrial Engineering students at Universitas Sebelas Maret to meet these challenges. This research will give the curriculum team members better insights regarding the necessary education and training to prepare a competent workforce to face industrial challenges (Nugroho, 2021).

The results of this study can be used as a reference for improving the Industrial Engineering curriculum at Universitas Sebelas Maret and provide strategic recommendations for higher education institutions and policymakers in developing educational programs more aligned with current industry needs. Thus, the contribution of industrial engineering programs will not only be limited to technological development but also include enhancing national industrial competitiveness and the economic well-being of Indonesia as a whole (Handayani, 2022).

In this study, we conducted a web scraping method for the Jobstreet job vacancy website to obtain competency indicators reflecting industry demands. We used these indicators to construct a questionnaire distributed to undergraduate Industrial Engineering students at Universitas Sebelas Maret. The curriculum team can use the research findings to analyze and understand the gap between the current competencies of students and industry demands. Hopefully, this research can aid in curriculum development for educational institutions and ensure that students meet the criteria of the industrial sector and possess the quality needed to drive the nation's economy efficiently in the industrial era (Putri, 2023).

Research Methods

Research Model

We modified the research model of Chaengpromma & Pattanapairoj (2022) to conduct this research. The research studied the gap between industry expectations and current competencies of Khon Kaen University's undergraduate industrial engineering in the context of the Industry 4.0 era in Thailand and provided guidelines for program improvement. The research identified indicators to assess readiness for Industry 4.0, with 17 industry experts validated using the Delphi method. The questionnaires were resulted from competency performance indicators distributed to 71 industrial plants and 60 newly graduated engineers.

This research uses web scraping from the job listing website to determine the competency performance indicators. The questionnaires were distributed to 33 industrial professionals and 91 last semester students. Figure 1 illustrates the research model.

Population and sample group

This research is a quantitative research study. The population of this study comprises industrial employees in Indonesia and students from the Industrial Engineering Department at Universitas Sebelas Maret. The students referred to are enrolled in the Undergraduate Program of Industrial Engineering at Universitas Sebelas Maret and have completed all required courses to accomplish the undergraduate thesis.

Research tool

The research tool was questionnaires for data collection. We divide the research into two parts: 1) screening of competency indicators by web scraping and 2) Gap analysis between industry expectations and the student's competencies.

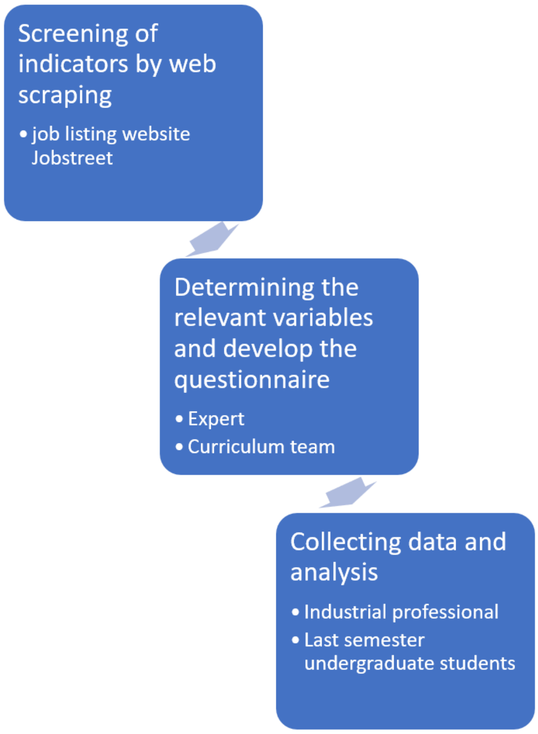

Figure 1. Research model illustration

1. *Screening of indicators by web scraping*

Identifying and determining indicators in this study involved several stages using web scraping from the job listing website Jobstreet, conducted via Jupyter Notebook on the Google Collaboratory platform. Initially, we collected data, cleaned it, and labeled it to ensure consistency, with similar competencies standardized and given uniform labels. Variable items were defined and identified based on expert opinions, followed by the identification and selection of relevant competency variables in consultation with the curriculum team of the undergraduate industrial engineering program. Each variable was assigned unique codes to facilitate systematic categorization and reference. These codes represented different sub-classifications under broader competency categories. Course learning outcomes outline the specific skills, knowledge, and attitudes that students will achieve upon completing individual courses. We developed statement items for the questionnaire considering the identified competency variables.

2. *Gap analysis between industry expectations and the Research tool*

We conducted a gap analysis to compare students' competencies with the Indonesian industry's demands. Data processing involved descriptive statistics and further analysis using SPSS. We conducted descriptive statistics to provide insights into respondents' work divisions and business sector frequency. The Mann-Whitney U Test, a non-parametric test, was then used to compare two independent groups' medians, as it is suitable for non-normally distributed data. This test helped determine if there were significant differences between the groups' medians, with hypotheses testing whether the medians were equal or different. We did a normality test beforehand to ensure the test's assumptions were satisfied.

Quality assessment of the research tool

After collecting data through an online questionnaire, the next step was to ensure the validity and reliability of the questionnaire using SPSS 25. Validity was tested by comparing the calculated R-value to the R table value at a 5% significance level. If the R-value exceeded the table value, the data was deemed valid. Reliability was confirmed with Cronbach's Alpha, where a value above 0.60 indicated that the questionnaire was consistent.

Results and Discussion

Analysis of Industry in Indonesia Competence Demand Indicators

We obtained 320 job vacancies related to industrial engineering, containing information such as job ID, job title, company name, company location, salary, job classification, and competencies in a comma-separated value (CSV) format. Of the 22 available classifications, the Manufacturing, Transportation, and Logistics category had the highest total frequency of 203 instances.

This category includes eight sub-classifications: Procurement, Procurement, & Inventory; Warehousing, Storage, & Distribution; Ergonomics; Management; Quality Assurance & Control; Information & Communication; Job, Assembly, & Processing; and Machine Operator. These sub-classifications were then developed into research variables based on competency-based curriculum (CBC) considerations and the curriculum team's feedback, as shown in Table 1.

Analysis of Industrial Engineering Undergraduate Students' Competence at Universitas Sebelas Maret and Industry in Indonesia Competence Demands

The data collection of the questionnaires sent to each sample group showed that the industries expected industrial engineering graduates to have high skill levels in all eight indicators. The sample of industrial engineering students in the case study university demonstrated moderate current skills in all areas, as seen in Table 2.

Table 1. Questionnaire Framework

Variables	Codes	Statements
Procurement, Procurement, & Inventory	PPI1	I feel that I understand the concepts and basic principles in designing efficient systems and processes.
	PPI2	I feel capable of applying analytical techniques to solve complex engineering problems.
	PPI3	I feel capable of collaborating with various departments to develop comprehensive industrial solutions.
	PPI4	I feel capable of implementing safety procedures in every industrial engineering project I undertake.
	PPI5	I am able to formulate operational problems into linear mathematical models that can be analyzed.
	PPI6	I can analyze relevant data and information to develop predictive models that support operational decision-making.
	PPI7	I feel capable of using analysis results to make optimal decisions related to company operations.
	PPI8	I am capable of developing operational policies based on in-depth data analysis and information processing.
Warehousing, Storage, & Distribution	PPD1	I can develop master production schedules based on sales forecasts and customer demand.
	PPD2	I understand production planning and scheduling to maximize operational efficiency.
	PPD3	I am capable of identifying and solving operational problems related to material management.
	PPD4	I can systematically compile reports and documentation related to inventory performance.
Ergonomics	E1	I am capable of understanding and applying basic ergonomic principles in designing effective work systems.
	E2	I can use anthropometric measurement tools to measure human body parts in work positions.
	E3	I understand human behavior in the context of industrial organizations to enhance productivity and employee well-being.
	E4	I am capable of designing efficient products, processes, or systems considering basic engineering principles.
	E5	I can identify, assess, and control hazards in the workplace by prioritizing handling sequences.
Management	M1	I can develop PPC systems, production strategies, quality procedures, and quality control (QC) to enhance operational efficiency.
	M2	I can comply with applicable industry standards and quality standards in production processes.
	M3	I can monitor sales performance to evaluate the effectiveness of applied sales strategies.
	M4	I am able to analyze market data and trends to improve efficiency and reduce operational costs.
	M5	I can control costs and improve production process efficiency through the application of economic techniques.
	M6	I am capable of implementing training programs for team development.

	M7	I feel capable of analyzing and understanding market trends and performing relevant analysis.
	M8	I can efficiently manage planning and scheduling of goods delivery in the supply chain.
	M9	I feel capable of actively participating in the development of innovative production strategies to enhance product efficiency and quality.
Quality Assurance & Control	PKM1	I feel capable of determining the appropriate probability distribution in the data collection process for statistical analysis.
	PKM2	I feel skilled in conducting production data analysis and processing to support informational decision-making.
	PKM3	I feel capable of implementing effective quality control in production processes.
	PKM4	I feel able to contribute to the development of innovative production strategies to improve quality and efficiency in industrial environments.
	PKM5	I feel capable of preparing comprehensive production quality reports and effectively documenting improvement results for future process enhancements.
Information & Communication	IK1	I feel skilled in using CAD software to design engineering products.
	IK2	I feel capable of developing information system applications (including information system programming and compiling Bill of Materials (BOM)) as needed by the industry to support operational and manufacturing efficiency.
	IK3	I feel capable of writing well and efficiently program code to meet information system needs in the industry.
Assembly & Processing Work	PPP1	I feel capable of understanding and determining standard machine elements and mastering process selection factors for effective product design.
	PPP2	I feel I have strong technical knowledge of products to support development and innovation in product design.
Machine Operator	OM1	I feel capable of understanding and operating machines effectively to support efficient production processes.
	OM2	I feel capable of understanding the basics of electronics and designing IoT systems to enhance automation in product design and operation.
	OM3	I feel skilled in designing mechanical systems that meet industrial specifications and needs to ensure optimal product performance.

Analysis of Competence Gaps of Industrial Engineering Undergraduate Students at Universitas Sebelas Maret Towards Industry in Indonesia Competence Demands

Based on the Mann-Whitney U test results, as shown in Table 3, all variables have p-values below 0.05. The results show we rejected the null hypothesis (equal medians between the two groups), suggesting a significant difference between the two test groups.

These findings reveal a significant gap in three variables: Information & Communication, Assembly & Processing Work, and Machine Operator. On the other hand, the variable with the lowest gap level is management. These results indicate a gap in all variables between industry expectations and the skills currently possessed by students, particularly in Information & Communication. This finding underscores the need for curriculum development that focuses more on these skills to ensure that graduates can meet the industry's evolving demands in the era of Industry in Indonesia.

Analysis Based on Categories of Average Score Differences between Student Competence and Industry in Indonesia Competence Demands

The analysis of differences between the average Industry in Indonesia's competence demands and the level of competencies among industrial engineering students using the Mann-Whitney U Test reveals significant differences across all eight categories at a significance level of 0.01. In all observed categories, the significance value (Sig. 2-tailed) was 0.000, well below the 0.01 significance level, indicating statistical differences. The higher average values of industry expectations in Indonesia compared to student competencies suggest that the industry in Indonesia imposes higher demands than students' current capabilities.

These differences highlight a gap between industrial engineering students and expectations for industry in Indonesia. The Mann-Whitney U Test provides evidence that student competencies do not fully align with the industry demands in Indonesia, calling for improvements in curriculum and educational approaches to bridge this gap. As part of these improvements, variables showing significant gaps will be linked to competency-based curriculum (CBC) groups and aligned with course learning outcomes (CLOs).

This section presents significant research results. The analysis must also be conducted in detail on the results to support the research contribution. Moreover, a good discussion needs to compare the results obtained from other research.

Table 2. Industry in Indonesia Demands and Student Competencies

Industry 4.0 Demands and Student Competencies									
Variable	Industry 4.0			Students			Gap	Z	Sig. (2-tailed)
	Mean	Std. Dev.	Level of Demand	Mean	Std. Dev.	Level of Demand			
Purchasing, Procurement, and Inventory	32.13	2.78	High	24.73	4.487	Medium	333	-7.1855	0.000
Warehousing, Storage, and Distribution	15.88	1.601	High	12.51	2.557	Medium	303.3	-6.2612	0.000
Ergonomics	22.03	2.495	High	18.25	3.749	Medium	272.16	-5.1336	0.000
Management	38.81	4.238	High	32.27	6.154	Medium	261.6	-5.6903	0.000
Quality Assurance & Control	20.78	2.871	High	16.95	3.873	Medium	275.76	-5.2997	0.000
Information and Communication	12.09	1.027	High	8.45	2.731	Medium	436.8	-7.0452	0.000
Assembly & Processing Work	7.94	0.801	High	5.89	1.321	Medium	369	-6.881	0.000
Machine Operators	12.09	1.027	High	9.04	1.833	Medium	366	-7.2268	0.000

Table 3. The Result of Mann-Whitney U Test

Statistics Test[a]								
	Purchasing, Procurement, and Inventory	Warehousing, Storage, and Distribution	Ergonomics	Management	Quality Assurance & Control	Information and Communication	Assembly & Processing Work	Machine Operators
Mann-Whitney U	223.000	443.000	607.500	506.000	560.500	250.500	323.000	220.500
Wilcoxon W	4501.000	4721.000	4885.500	4784.500	4838.500	4528.500	4601.000	4498.500
Z	-7.186	-6.261	-5.134	-5.690	-5.300	-7.045	-6.881	-7.227
Asymp. Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
a.Grouping Variable: Category								

Table 4. Relationship Between Competencies and Course Learning Outcomes (CLOs)

Variable	Área of study	Course	Competency	Indicator	Relevance to CLOs
Information & Communication	Industrial System Design & Optimization	Technical Drawing Computer Programming	Composing Bill of Material	Technical Skill SI Design (System Information Design)	Technical Drawing Course No. 3 Computer Programming Course No. 2
			Using CAD software		
		Information System Analysis and Design	Writing program code	Programming Code Machine Understanding Product Knowledge	Computer Programming Practice Course No. 2 Mechanics Course No. 2 and Materials Engineering Course No. 1 Manufacturing Processes I Course No. 1-3
		Computer Programming Practice Technical Mechanics	Developing information system applications		
			Information System Programming		
		Material Engineering	Writing program code	Machine Operation	Machine Elements Course No. 1 and Manufacturing Processes II Course No. 1
Assembly & Processing Work	Product Planning & Design	Manufacturing Process I Machine Elements	Understanding standard machine elements	Automation Technical Skill	Automation Course No. 1-7 Technical Drawing Course No. 3
			Mastering mechanical system design		
		Manufacturing Process II Automation	Technical Product Knowledge		
			Customer Needs Analysis	SI Design (System Information Design) Programming Code Machine Understanding	Computer Programming Course No. 2 Computer Programming Practice Course No. 2 Mechanics Course No. 2 and Materials Engineering Course No. 1
		Production Aid Design Technical Drawing	Understanding machine operation		
			Mastering process selection factors		
			Product Presentation and Demonstration	Product Knowledge Machine Operation Automation	Manufacturing Processes I Course No. 1-3 Machine Elements Course No. 1 and Manufacturing Processes II Course No. 1 Automation Course No. 1-7
		Computer Programming	Understanding determination of standard machine elements		
Machine Operation		Information System Analysis and Design Computer Programming Practice	Understanding machine operation		
			Mastering process selection factors		
		Technical Mechanics Material Engineering Manufacturing Process I	Mastering automation technology	Technical Skill SI Design (System Information Design) Programming Code	Technical Drawing Course No. 3 Computer Programming Course No. 2 Computer Programming Practice Course No. 2
			Understanding electronics basics		
			Designing IoT systems		

		Machine Elements Manufacturing Process II	Improving operational efficiency	Understanding Machine	Mechanics Course No. 2 and Materials Engineering Course No. 1
			Mastering mechanical system design		
		Automation	Technical Product Knowledge		

Conclusion

This subsection concludes based on the research findings as follows:

1. This study found a significant gap between the competencies of undergraduate Industrial Engineering students at Universitas Sebelas Maret and the demands of the industry in Indonesia. The Mann-Whitney U test showed p-values below 0.05 for all variables, indicating significant differences. Furthermore, based on the hypothesis of mean competence, the average value of industry demands was higher than the upper limit of the interval for the variables, indicating high competency expectations from the industry. In contrast, the average competency value of the students was within the lower and upper interval limits, indicating a moderate level of competence. Therefore, the students' current competencies do not fully meet the industry demands in Indonesia.
2. Based on the gap values obtained, competencies with the highest to lowest gaps are ranked as follows: Information and Communication Variable; Assembly and Processing Work Variable; Machine Operator Variable; Purchasing, Procurement, and Inventory Variable; Warehousing, Storage, and Distribution Variable; Quality Assurance and Control Variable; Ergonomics Variable; and Management Variable. We found the highest competency gap in the Information and Communication Variable, which includes technical skills, information system design, and programming. Conversely, the variable with the lowest gap is management. The aspects covered in the Management variable include the scope of industrial, operational, and strategic elements within the industrial environment, aiming to improve efficiency, productivity, and company competitiveness.

Recommendation

This subsection provides recommendations for further research based on the research findings as follows:

1. The research findings indicate the need for curriculum improvements to bridge competency gaps, particularly in Information & Communication, Assembly & Processing Work, and Machine Operator. Curriculum adjustments should emphasize enhancing technical skills, information system design, programming, machine understanding, product knowledge, machine operation, and automation. Regular curriculum evaluations and stronger integration of digital technology and data analytics in relevant courses will enhance graduates' readiness to meet the challenges of Industry in Indonesia. The curriculum team should conduct periodic curriculum evaluations and stronger integration of technology and data analytics in relevant courses to enhance graduates' readiness to meet evolving industry demands.
2. Further research is recommended to utilize more diverse job search platforms to obtain more representative indicators of Industry in Indonesia. Additionally, for more objective outcomes, measuring student competencies should directly correlate with course grades to accurately depict how existing curricula prepare students to meet industry competency requirements.

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Conflict of Interest

The authors declare no conflict of interest.

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