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Editorial Brief

It is with great pleasure that we announce the release of Volume 8, Issue 1 of the ASEAN Journal of Engineering Education (AJEE). In this issue, we continue our commitment to disseminating cutting-edge research and perspectives that shape engineering education in ASEAN and beyond.

This issue features articles on innovative teaching, sustainable innovation, and online laboratories. Notably, there are two systematic review articles that delve into innovative pedagogy associated with game-based learning and the development of Industry 5.0 competencies. Additionally, several articles examine innovative pedagogical approaches, including the integration of artificial intelligence, problem-based learning (PBL) in architectural engineering, and project-based learning (PjBL) for first-year students.

Furthermore, this issue presents research on how engineering lecturers certified in the field of engineering can foster innovation in Teaching & Learning (T&L) activities. Producing engineers who can make a significant impact on society is crucial. This is emphasized in one of the articles in this issue that addresses engineering curricula that incorporate sustainable innovation. Another article provides a comparative analysis of engineering education systems across multiple countries.

We express our sincere gratitude to the contributors from Brazil, the USA, and Malaysia for their invaluable contributions to this issue. The diverse backgrounds of the authors are greatly appreciated as they ensure a broad range of perspectives.

Chief Editor

Assoc. Prof. Ir. Ts. Dr. Zaki Yamani Zakaria

Editorial Boards

Contents

Redesigning Course Improvement Plan; A Case Study Based-on Learning Outcomes in Engineering Education

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Abstract

Accreditation of engineering programs requires continuous improvement, and a course improvement plan helps accomplish this aim. Student-centered course design components for a particular course in the architectural engineering program is developed at Missouri University of Science and Technology. Method definition is developed and learning objectives, instruction types, and assessment tools are concluded with learning outcomes. Created course improvement plan meets the accreditation requirements partially. Learning outcomes are studied by the help of Bloom's Taxonomy. Instruction types include traditional lecture learning environment and problem-based learning environment. Content priorities are also help to conclude targeted learning outcomes. Success of proposed curriculum development is measured by survey and the results are used to create course blueprint and assessment matrix. The curriculum for the mentioned course in the case study results in transitioning from the existing learning environment to the desired learning environment which can be used as a sample for similar courses.

Keywords: Bloom's taxonomy, learning outcome, assessment tool, instruction type, course design.

Introduction

Curriculum needs to be improved for the program targeted to get accreditation. Due to the fact that, continuous improvement of engineering education is the primary target of accreditation process, what is known with cognitive science would be helpful to this process (Williamson, 2007). ABET (accreditation board for engineering and technology) in the United States provide competence banks to clarify the process to whom apply for accreditation (Earnest, 2005; Passow, 2007; Walther, 2007; Choudaha, 2008). Due to theoretical background and need for clarification of problem-based learning (PBL) in Architectural Engineering major, PBL was formalized at Missouri University of Science and Technology for building components design education. The proposed educational model includes a definition of the learning environment, formulation of PBL, appropriate building technologies, and a design guide. Boundary conditions with building structural systems in learning environment is specified inside the proposed educational model and discussed in a separate paper. Implementing existing curriculum development methods and educational theories will continuously improve engineering education. Based on the hypothesis, this paper aims to redesign a course improvement plan, provide application methodology, and present a taxonomy of educational objectives of a particular course in architectural engineering. The research question is herein; how a course improvement plan be designed? Moreover, as a result, how the success of this improvement plan shall be measured? A course improvement plan must follow the interaction between learning objectives, instruction, and assessment. The desired improvements on a course curriculum comprise well-regulated classroom activities, education theories, adding diverse teaching methods and better tracking results of teaching activities.

Diverse courses are taught in architectural engineering programs and "architectural materials and methods of building construction" course is one of these courses. Mentioned course is accepted as the case study in this paper. The objective of the case study is to support program accreditation with broader educational goal and increase the retention of knowledge for students in particular.

Active learning methodologies such as; PBL and hands-on learning are targeted to include into this course curriculum. Education of framing and panelized building systems is a component of the architectural engineering program. Early studies of this ongoing research based-on design definitions of framing and

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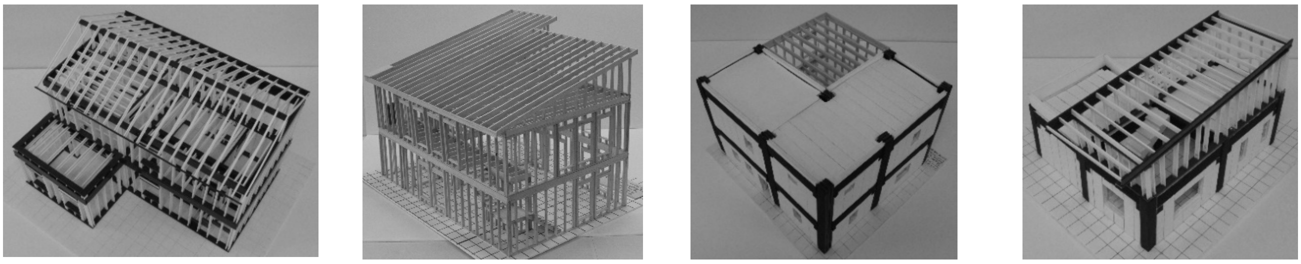


Scaled model assembly of building technologies with teamwork

(a) cold-formed steel framing system (b) timber framing system (c) mix design as precast R.C. system and timber framing system d) mix design as precast R.C system and cold-formed steel framing system

Figure 1. Visual samples for the results of learning event as PBL

panelized building systems are improved and formalized as an educational methodology. This approach can be used on multiple building technologies and particularly stick-built and panelized building systems are the application field of this educational model. Cold-formed steel framing, timber framing, reinforced concrete (R.C.) prefabricated system, autoclaved aerated concrete (AAC) panel system and structural insulated panel (SIP) system are the building technologies investigated inside this course. Visual samples for this learning event are depicted in Figure 1. Visuals are the results of scaled model assembly of building technologies with teamwork in PBL.

The paper is theoretically divided into two sections; first, tools to create a course improvement plan are defined, then curriculum improvement based on this method definition for the case study is introduced. A literature review that include: a methodology for a course improvement plan; a taxonomy of educational objectives; a case study on an existing course, and; a discussion based on research findings are the scope of this study. Targeted audiences are instructors who desire improvement on his/her course curriculum to provide a more effective learning environment in engineering education.

Literature Review and Method Definition

Architectural education is based on getting theoretical and applied information. Hence, experiential learning theory was mostly applied to architecture design courses (Avci and Beyhan, 2022). Architectural design studios are real environment to run inside blended learning pedagogic model (Bregger, 2017). Problem or project based learning (PBL) method has been widely adopted in engineering education as well because of its effectiveness on development of students' professional knowledge. But, PBL implementation has some challenges and little addressed in the current researches. Moreover, less attention has been paid on how these challenges in implementation are related to the diverse PBL practices (Chen, et al., 2020). In most cases, limited implementation of PBL is seen due to the program curriculum offered by educational institutions. PBL frequently adopted inside the existing traditional curricula (Mann, et al., 2020). Intended learning outcomes (ILOs) are created and clearly formulated in the curriculum as PBL competences. In reality, few engineering institutions succeed to adopt PBL method in their curricula at such a level, but there are efforts by several institutions through that direction (Miklos and Kolmos, 2022). In engineering education, implementing active learning methods is becoming popular as a new method of learning process and it is accepted as a prerequisite to get ready to their professional life when they graduate (Sukacke, et al., 2022).

The challenge herein is; how course design components mentioned in Figure 2 will be integrated into the case study. Learning outcomes, instruction types and assessment methods shall be re-evaluated according to the context of the case study. When the literature review is performed, method definition is mostly introduced generic samples. Instead of generic samples, figures and tables are reproduced according to the case study. Due to the fact that, literature review focus on creation of a method definition for the case study in this section. Figure 2 is also accepted as backbone of course improvement plan for the case study. The methodology of instructional design stages is suggested as analysis, design, development, implementation and evaluation (ADDIE) in another study (Sukacke, et al., 2022).

In order to partially meet the program accreditation, a course curriculum is intended to be improved. A course improvement plan can be designed by defining the taxonomy of learning objectives, learning outcomes, instruction types, content priorities and assessment tools. The improvement plan needs a careful analyze of course curriculum and an improvement methodology and measurement of success on applied educational model. Efforts required in three sections to succeed intended learning outcomes are depicted in Figure 3(b) (Felder, 2003). A template to document course design and to create a taxonomy of educational objectives is selected as

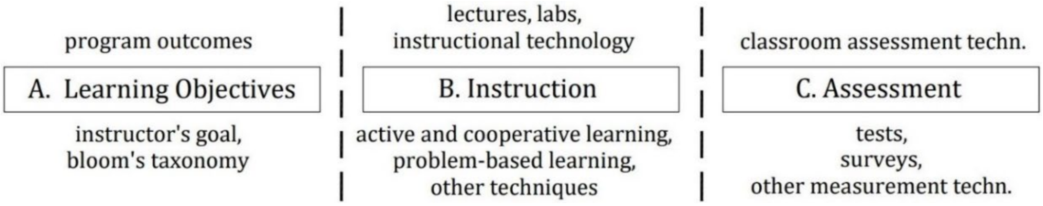


Figure 2. Student-centered course design components; learning objectives, instruction, and assessment (Felder, 2003)

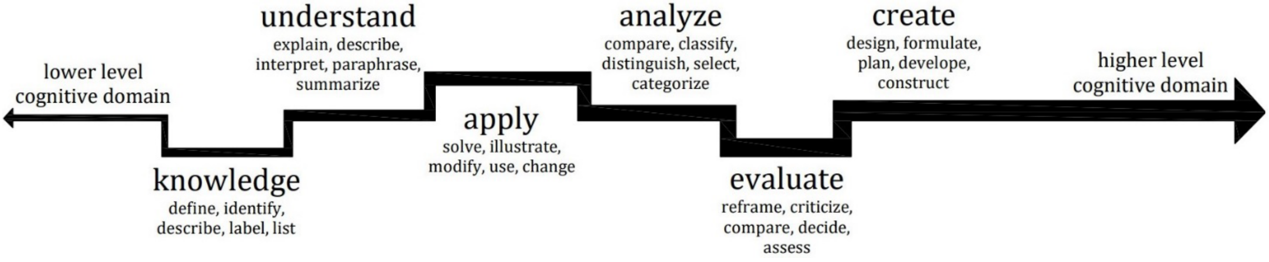
course blueprint (Felder, 2016). Learning objectives with higher and lower cognitive domains are defined by using necessary action verbs in Bloom's Taxonomy. Producing a course assessment matrix presenting outcome-related learning objectives is also beneficial during course curriculum design.

Learning Objectives

As a result of a learning activity, knowledge and the ability of learners can be specified by defining learning outcomes. The learners' actions which is specified shall be observable and measurable. Clear expectations must be stated by learning outcomes used at course level (Figure 3(a)) (Osters & Tiu, n.d.). Knowledge, skills, or attitudes are introduced in outcomes. When planning a course, it is also recommended to take into consideration adjoining a couple of critical targets such as; communication skills including oral and written, interpersonal skills including teamwork, problem-solving skills in a variety of contexts, critical thinking skills in a variety of contexts, information competency skills: the ability to access information in various formats.

A taxonomy, specifically the preferred terms, can aid researchers search the literature by linking and suggesting related terms and proposing a hierarchical structure that helps in navigation (Finelli, 2015). The taxonomy of educational objectives is a scheme for classifying educational goals, objectives, and, most recently, standards. (Felder, 2016; Krathwohl, 2002). Bloom's Taxonomy, SOLO (the structure of observed learning outcomes) Taxonomy, EER (the engineering education research) Taxonomy, and Fink's Taxonomy were developed to be used in tertiary education. Bloom's taxonomy has been widely accepted for engineering education with a universal agreement that engineering graduates should be competent at analysis, synthesis, and evaluation (Bloom, 1956; Braband, 2009; Williamson, 2007). Bloom developed the taxonomy (hierarchy) of cognitive learning skills, allowing educators to systematically evaluate students' learning (Barrett, 2009; Schultz, 2005). Bloom's taxonomy was revised due to need in the course of the time (Anderson, 2001). Sample of wording is as following; define, explain, solve, analyze, criticize, design, etc. (Osters & Tiu, n.d.; Tulane University, n.d.). Figure 3(a) shows the action verbs (partially) in revised bloom's taxonomy based-on Anderson (2001) explanation. Improving the faculty's teaching ability is possible by using active learning methodology and a learning taxonomy can be developed to meet this target. Providing continuous improvement based on the accreditation process and establishing a standard terminology – a taxonomy of terms – aids in navigating diverse teaching methods and measuring learning outcomes in engineering education is the primary motivation for this research.

a. Action verbs (partially) based-on revised bloom's taxonomy (Anderson, 2001)



b. Targeted learning outcomes based on revised Bloom's taxonomy

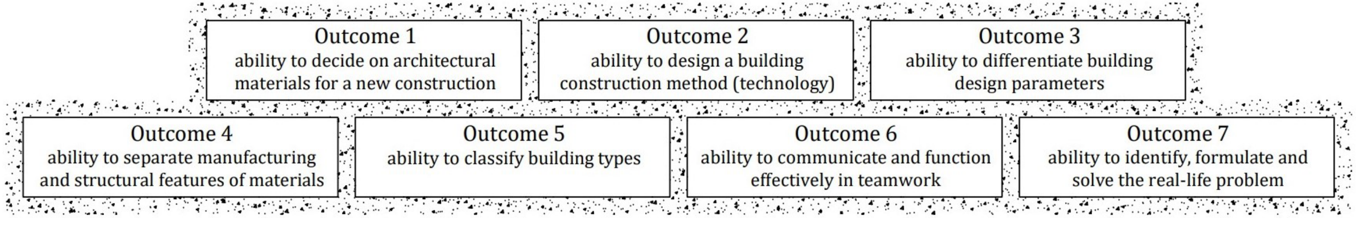


Figure 3. (a) Action verbs (partially) based-on revised bloom's taxonomy (Anderson, 2001), (b) Targeted learning outcomes based on revised Bloom's taxonomy

Based-on the course content and instruction types of case study, seven outcomes are decided and included in the method definition as a sample. Targeted learning outcomes of the "architectural materials and methods of building construction" course based on revised Bloom's Taxonomy are depicted in Figure 3(b).

Instruction Types

The curriculum, the teaching methods, and the instructional tools shall be studied in depth to integrate technology into the tertiary education. David Kolb had introduced experiential learning which is the most widespread teaching theory (Ghaziani, 2013). Kolb's learning cycle includes quadrants showing a set of activities and assist the instructor. Teaching in each quadrant promotes retention, encourages recognition of applications, and serves the diversity of students' learning styles (Williamson, 2007). Kolb developed a system of selecting classroom activities based on his research related to adult learning (ASCE, 2004; Kolb, 1984; Williamson, 2007). Furthermore, students use different ways to get information and active learning is one of them. Active learning and PBL methods are mostly interchangeable. However, using any of them in engineering education is highly promoted due to the need for highly competent graduates with problem-solving skills in the workforce.

Graduates of architectural engineering programs are expected to ensure competence in technical and managerial levels, effective communication, continuous professional progress, ability in teamwork and responsible professional behavior (ASCE, 2004; Earnest, 2005). The hands-on learning experience with teamwork is also highly promoted to meet program objectives. The educational model for this course does not meet a program's whole objective but contributes to meeting some of the objectives. Delivery of course material as a teaching method can be organized in different ways, and it is named "instruction" herein. These instructions include traditional classroom lectures, online lectures, and lab activities. On the other hand, active, cooperative, or PBL can be included in any part of these instructions. The effectiveness of these instructions is different from each other; basically, longer retention of knowledge is desired by using diverse teaching methods.

Design parameters, manufacturing features, and building types are influential factors in understanding the design and building process. These are the primary course content for the "architectural materials and methods of building construction" course. Course content is split into five fundamental sub-title, some of which need enduring understanding. Wiggins (2005) presented that how content priorities shall be linked to the student learning outcomes. During the curriculum design of the course, content priorities shaped the necessary teaching methods based on the level of understanding. Figure 4 depicts the course's targeted level of understanding and content priorities based-on Wiggins (2005) explanation.

Contents of architectural materials and methods of building construction are defined as having content priority and need enduring understanding. Also, the first two items in learning outcomes require a higher cognitive domain. Consequently, the action verbs "decide" and "design" is selected for these learning outcomes. In order to achieve these learning objectives, a learning event is defined as PBL in a term project.

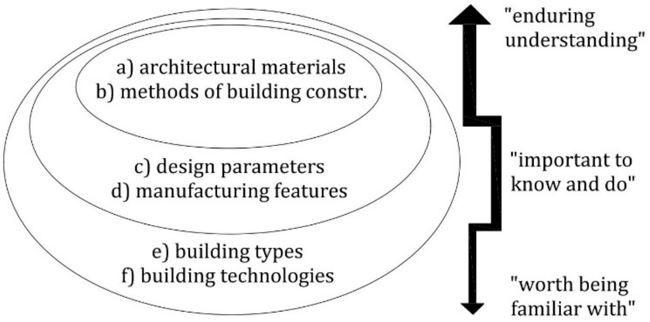


Figure 4. Clarifying content priorities for "architectural materials and methods of building construction" course

Assessment Methods

Assessment efforts are categorized as direct and indirect measures in order to collect evidence of student learning. These methods provide adequate feedback to the program to identify strengths and weaknesses (Maki, 2004). The two most used research instruments in quantitative research studies include questionnaires (surveys) and tests (Bachman, 2009). Students' performance cannot be measured by only focusing on grades. But, if grading is linked with rubrics, it is a much better tool to identify the strengths and weaknesses of student performance. Two methods of assessment can be categorized as direct method with standardized exams and indirect method with survey (Osters & Tiu, n.d.). Learning activity has been measured in two methodologies, as depicted in Table 1. The first is a direct method based on a grading system using a rubric and peer assessment. The second is used indirectly to measure the effectiveness of learning activity through pre-post surveys.

Direct measurements of student learning and relation of these data with program outcomes are focused during accreditation process. (Williamson, 2007). Direct assessment methods include paper-based exams, multiple-choice tests, essays, assignments, and homework as course-embedded assessment, portfolio evaluation (presentation), and class projects (term project) as shown in Table 2. Indirect measurements of student learning, such as surveys, provide reliable feedback and can be used long-term to monitor the effectiveness of the teaching method. As an indirect assessment method, the survey is intended to monitor the performance of PBL tools and other course materials. Success of the learning environment is also measured by student surveys. Pre and post surveys can be included for term-based performance measurement.

Table 1. Direct and indirect assessment methods

	direct	indirect
method	**rubric** instructor assessm. peer assessm.	**survey** pre-survey post-survey
source	instructor & student	student
record	on-grade system	off-grade system
tools	percentage	percentage
period	term based	term based
graphic	table & quadrant	table & quadrant

The usage of the quadrant in Kolb's learning cycle (ASCE, 2004; Kolb, 1984) and Webb's depth of knowledge (DOK) (Hess, 2006; Hess, 2013; Webb's Depth of Knowledge Guide, 2009; Webb, 1997) is inspired to create a course-based assessment quadrant as an indirect method of the assessment tool. Cerovsek and others (2010) also suggest a quadrant to measure the performance of design competencies in the AEC domain.

Table 2. Assessment tools as direct method

Assessment Type		Frequen. (number per term)	Formative or Summative	How quickly students receive feedback from this assessment
Exams (paper based)	Short answer	3	summative	a week later
Quizzes (online)	Multiple choice	5	summative	instant
Essay	Short essay	1	formative	a week later
Lab Projects	Lab assign.	3	formative	a week later
	Lab activity	2	formative	a week later
Term Project	Present.	1	summative	a week later
	Hands-on activity	1	summative	a week later

Curriculum Improvement Plan for an Architectural Engineering Course

Curriculum improvement for an architectural engineering course needs a specific methodology which is defined in method definition by the help of literature review. But it is not only a review but to create a variation of existing methodology through architectural engineering education. Student-centered course design components in Figure 2 is the primary method to be used to redesign course improvement plan in this study. Learning objectives and instructions are redesigned and reproduced as course blueprint. Course assessment matrix links the course outcome with the program outcome. On the other hand, effectiveness of learning activity is also measured to verify the necessity of constant development effort on engineering education. Instruction types are not discussed in depth in this study due to the fact that being a separate topic out of the scope of this paper. This paper is particularly focus on redesigning course curriculum based on the learning outcomes and assessment of learning activity. To accomplish this task, course blueprint and assessment matrix are produced for the case study.

Course Blueprint and Assessment Matrix

The course blueprint includes mapping the course goals with the objectives, learning events, and assessment tools. This approach is used herein to classify learning events by dividing the course into modules as Module 1; preparatory blocks, and Module 2; PBL block. Learning objectives and course goals are prepared as per revised Bloom's Taxonomy. Student-centered course design components are derived from Figure 2 which are referring the outcome 1 to 5. Student learning objectives reflect the course content. Learning event is related with instruction types. Assessment tool is tied with rubric. Moreover, the course blueprint reflects the direct assessment method for this case study. In summary, the course blueprint, including partial course goals, learning objectives, learning events, and assessment tools for the

Table 3. Partial course blueprint; items (a and b) are derived from Figure 4

Course Goals		Student Learning Objective	Learning Event				Assesm. Tool		
			Lecture	Demonstration	PBL	Hands-on/PBL	Exam (short answ.)	Quiz	Team project
a)	Students will decide architectural materials for a new construction	Compare different finishing materials	X	X			X	X	
		Examine thermal & fire related properties	X	X	X		X	X	X
		Use different types of windows, doors, roof & stair	X		X		X	X	X
b)	Students will design a building construction method (technology)	Plan a light framing system	X	X		X	X	X	X
		Plan a prefabricated building system	X	X		X	X	X	X
		Plan a conventional building system	X				X	X	

"architectural materials and methods of building construction" course, is depicted in Table 3. Course description is mentioned in the course syllabus as the origin and the properties of architectural materials, methods of building construction and installation principles.

In order to track program outcomes a course assessment matrix was constructed for the course in case study. Outcome-related learning objectives are depicted in this matrix and the entries 1, 2, 3 are inserted to indicate the targeted level of outcome as slightly, moderately, or substantively. Based on the methodology mentioned herein, the course assessment matrix for the "architectural materials and methods of building construction" course is generated and depicted in Table 4. Targeted learning outcomes are linked to the Figure 3b.

Table 4. Course assessment matrix for "architectural materials and methods of building construction"

Outcome-related learning objectives	Outcome*						
	1	2	3	4	5	6	7
Compare different finishing materials	2						
Examine thermal & fire related properties	2					1	1
Use differ. types of wind., doors, roof & stair	2					1	1
Plan a light framing system		3				3	3
Plan a prefabricated building system		3				3	3
Plan a conventional building system		1					
Discuss structural parameters			3			2	2
Distinguish exterior wall systems			2			2	2
Describe soils & foundation systems			2				
Experiment concrete material				2		1	1
Use brick material				3		3	3
Discover steel & wood materials				2		2	2
Compare resident., commer. & public build.					2	1	1
Discuss low-rise, mid-rise, high-rise buildings					2	1	1
Examine fire-related construction types					1		

* objective address outcome
1= slightly, 2=moderately, 3=substantively

Effectiveness of learning activities

The course curriculum has been divided into modules based on content and type of learning environment. The survey is split into four modules: course content, traditional learning environment, hands-on learning environment, and measurement. The research was run for three years, and surveys regularly provided necessary feedback. The survey is performed two times per semester as pre and post-survey. Students rated the significance of each item using a scale of 1 through 10 (with 1 meaning unimportant and 10 meaning very important). The average rate of the significance of each question is depicted in Table 5 in which pre and post surveys' results belong to third year of the research. Averages of pre and post-survey results are used to create Table 5. To measure the performance of the learning activity, an assessment method using quadrant is generated to provide valid and reliable data, strengthening the findings of PBL activity in architectural engineering. This quadrant consists of modules along with course material. Generated quadrant including results of three successive years presented in Figure 5. Four modules including course content, traditional lecture learning environment, hands-on learning environment and measurement methods are illustrated along with a scale of 1 through 10 in a chart. The scaling is derived from the survey results indexed in Table 5. This radar chart monitors the strengths and weaknesses of learning environments and course materials to enable the instructor to make necessary revisions. Results of three successive years are reflected in Figure 6, which focuses on traditional and hands-on learning environments.

Providing design flexibility resulted in considerable improvement in PBL activity per the radar chart. Efforts to improve the educational model during the time resulted in positive as depicted in the radar chart. Enrolled students are mostly sophomore level due to being an introductory course. Some intern experiences are mainly observed among students. Moreover, many students have 1-2 years of work experience. There is a regular increment in the time in Figure 6 due to improvement efforts of the applied educational model. Cargo container design and main PBL activity are impacted positively due to providing design flexibility at building type and technology. There is a minor declination in item C3 in the year 2 result because of having hardship with model making material of aluminum foil during assembly of the cold-formed steel framing system. This caused a negative thought about the activity, which can be read similarly in item C4's design guide. Hence, material features are directly proportional to the desired learning environment's satisfaction. Despite having difficulty working with multiple building technologies in a PBL environment, the overall study still got a remarkable value, with 7,4 out of 10 in year 2. However, after taking necessary actions on the PBL environment in the following year (year 3), the effectiveness result reached 8.40 in year 3 in item C3. The design guide results are directly proportional to the results of the PBL activity. Considerable improvement in cargo container design in item C2 is also read in the table. On the other hand, masonry wall mock-up activity has the first rank in the table each year, resulting in up to 8.96. 2nd is teamwork in C5, 3rd is site visit in B5 and 4th is PBL activity. Lecture notes in item B2 also received a significant rise up to 8.31. Students in item C5 always welcome teamwork. When we compare the average rates of items B and C, item C (8.33 out of 10) as a hands-on learning environment has higher rates than item B (7.56 out of 10) as a traditional learning environment.

Table 5. Average significance rate of each question belongs to year three

Module	Measured Course Material		Average Rate	Module	Measured Course Material		Average Rate
Module A (average rate; 8.01 out of 10) **Course Content**	**A.1**	Architectural materials	8.36	**Module C** (average rate; 8.33 out of 10) **Hands-on Learning Environment**	**C.1**	Brick wall mock-up	9.00
			8.00				8.92
	A.2	Methods of building construction	8.31		**C.2**	Cargo container design	7.83
			8.32				7.43
	A.3	Building types	8.33		**C.3**	Scaled model of term project	8.53
			8.14				8.27
	A.4	Design parameters	7.92		**C.4**	Design guide/hand outs	8.03
			7.70				7.91
	A.5	Manufacturing features	7.43		**C.5**	Teamwork	8.47
			7.57				8.86
Module B (average rate; 7.86 out of 10) **Traditional Learning Environment**	**B.1**	Lecture	7.61	**Module D** (average rate; 7.63 out of 10) **Measurement**	**D.1**	Paper based exam	7.42
			7.61				7.40
	B.2	Reading (lecture notes)	8.39		**D.2**	Quiz	7.00
			8.22				5.94
	B.3	Documentary movie	7.49		**D.3**	Lab assignment	7.97
			6.81				7.91
	B.4	Material test	8.03		**D.4**	Rubric for cargo container	8.29
			7.54				7.80
	B.5	Visit of construction site	8.56		**D.5**	Rubric for term project	8.20
			8.30				8.40

☐ Pre-survey results ▨ Post-survey results

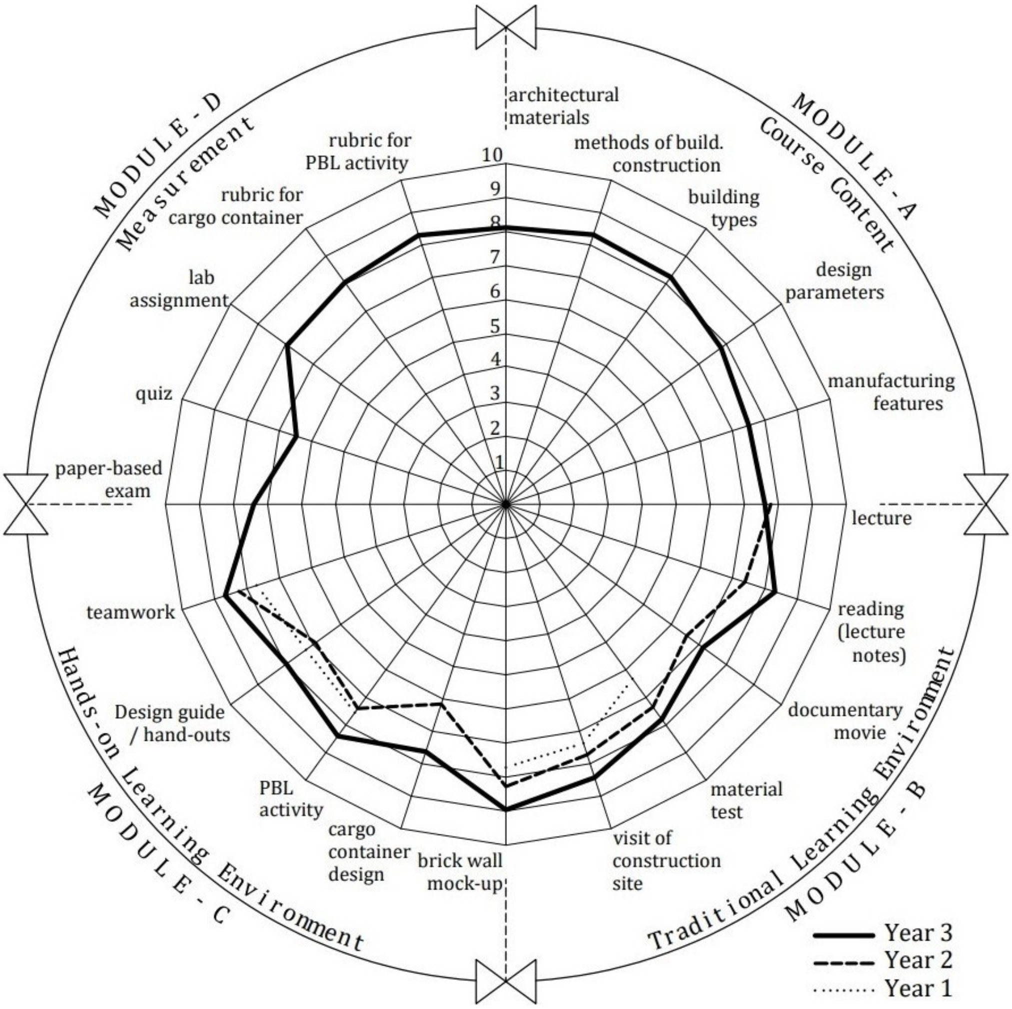


Figure 5. Assessment tool as indirect method; survey results on quadrant (average rate of significance of each question on radar chart)

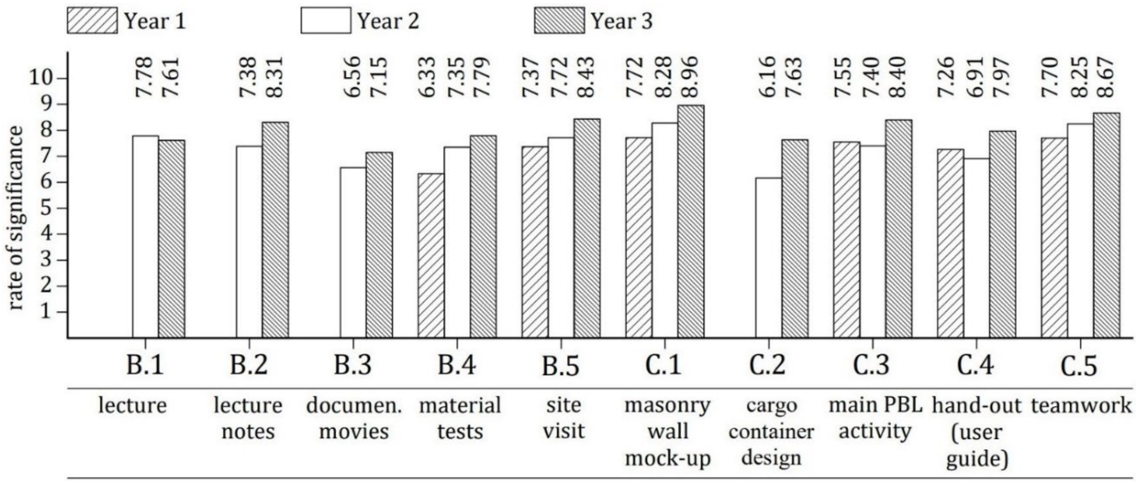


Figure 6. Average rate of significance of each question depicts the results of survey

Besides the traditional lecture learning environment, PBL is an alternative to support teaching fundamentals of architectural materials and methods of building construction. The hands-on learning experience is crucial for students to improve their design skills, resulting in longer retention of desired knowledge. Based on the survey results, the PBL activity demonstrated, on average, a 12% improved retention of materials compared to the traditional lecture settings. Therefore, combining the educational methods, the traditional lecture learning environment, and PBL is recommended based on the survey results and overall student performance. Giving students basic knowledge on the subject enables them to proceed with their studies more consciously in a PBL environment.

Conclusion

Continued improvement of architectural engineering education, which is a necessity of program accreditation, is provided partially by applying advanced curriculum development methods and educational theories on a particular course. In addition, the taxonomy of learning objectives assures the overall goal of improving student performance and expectations. This paper shows how an existing learning environment can be altered by using a well-conceived goal connected with a series of objectives and assessments tailored to the course being examined. The task is accomplished by applying clearly defined application methodology which includes student-centered course design components; learning objectives, instruction types and assessment tools. These components are transferred inside the course blueprint and course assessment matrix in order to illustrate graphically as the course improvement plan. Course learning outcomes meet partially program outcomes which is one of the main target of this study. Success of learning environment is measured by surveys each year and helps to create constant improvement on course curriculum. Survey results show that positive impact of active learning over the traditional lecture learning environment. Based on the survey results, the PBL activity demonstrated, on average, a 12% improved retention of materials compared to the traditional lecture settings. Further development of this method is being shared and implemented in other courses in the architectural engineering program based on these findings. The curriculum for the mentioned course in the case study results from a transition effort from the existing learning environment to desired learning environment. Classification of learning outcomes and implementing diverse teaching and assessment methods resulted in such a definition of the course improvement plan. Method definition in this paper is recommended to educators looking to implement similar changes in their courses.

Discussion on the study is mostly on its link with program accreditation and measurable benefits. It is thought that case study partially meets program accreditation. But this can be measured or a comparative analysis can be performed which provides a deeper analysis as a further study. Moreover, a more critical examination of any limitations of the study and the potential scalability of the course improvement plan would be beneficial. Beside these topics which have directly related with this paper, there are other ways we can look at the study from different perspectives. Having these experience on a particular course in architectural engineering brings further questions in detail as diverse point of view, such as;

- How does rethinking organizational culture with teamwork at active learning conclude in similar courses in architectural engineering education?
- What are the benchmarks between homework and real-life problems in active learning by using educational technologies?
- How open-ended / out-of-the-box study can be performed effectively by students in engineering education?
- How architectural engineering graduates can better meet the expectations of the building industry using PBL?

These research questions may help better understand the benchmarks of active learning with different aspects of architectural engineering education. On the other hand, performing the proposed course improvement plan in other related courses may provide a comparative analysis of applied educational theories. Discussion in this paper shows that further research can bring diverse aspects of active learning implementation to architectural engineering education.

Conflict of interest

The authors declare that they have no conflicts of interest.

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Engineering Education in Industry 5.0: Competency Development and Learning Environment Strategies - A Systematic Review

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Abstract

To identify the competencies that can be developed in engineering students to address the challenges of Industry 5.0 and to demonstrate how learning environments can prepare to foster these competencies. Due to the lack of clarity in existing literature, this research aims to identify the competencies and how engineering education may be preparing to confront the evolution of Industry 5.0. A systematic literature review was conducted using the Proknow-C methodology, covering publications from 2000 to 2023 in the Scopus and Web of Science databases. After filtering, the selected articles were analyzed and compared to fulfill the study's objective. This research identified a bibliographic portfolio of relevant works on the topic of Engineering Education in Industry 5.0, extracting key competencies that can be developed in students. It also identified some characteristics of learning environments for this context. With each industrial revolution, new competencies need to be developed in engineering students. To keep pace with these transformations, engineering learning environments must be prepared to cultivate human capital. This research identified a bibliographic portfolio that enabled the identification of key competencies that can be developed in engineering students within the context of Industry 5.0, contributing to educational institutions in incorporating these references into the training of these professionals.

Keywords: Industry 5.0, Engineering Education, Competencies, Systematic Literature Review.

Introduction

Technology is changing the way companies and society relate and learn. According to Rodríguez-Abitia and Bribiesca-Correia (2021), the fourth industrial revolution has intensified digital transformation. As a result, the newest members of today's society—the new generations—are born and raised in digital environments. Like any ordinary citizen, they also use technology for various purposes, whether at work or in social interactions. In this context, the authors emphasize the need for a new type of education to meet the new way of learning in Society and Industry 5.0.

For Broo et al. (2022), engineering course curricula are not adequately preparing students for the realities of the market. Social, environmental, economic, artificial intelligence, ethics, trust, human-machine interaction, and their social implications are not yet integrated into the teaching. Therefore, education in ethical and value-oriented engineering technology in Industry 5.0 is an urgent and sensitive topic (Longo et al., 2020).

According to Magaldi and Neto (2018), the transformation process occurs through people, with education being one of its most relevant vectors. For the movement to materialize in practice, individuals need to understand the dynamics of the changes and be educated according to this new reality.

In this context, the research question arises: How can engineering education environments prepare for the context of Industry 5.0? The objectives of this research are: (i) to select a significant bibliographic portfolio of literature on engineering education in Industry 5.0; (ii) to conduct a bibliometric analysis of the portfolio; (iii) to analyse the content of articles to identify the competencies and how educational environments should be prepared for Industry 5.0.

Engineering Education

The definition of engineering is provided by the U.S. accreditation body, the Accreditation Board for Engineering and Technology (Abet, 2021): Engineering is the profession in which knowledge of the mathematical and natural sciences acquired through study, experience, and practice is applied with judgment to develop ways to economically use the materials and forces of nature for the benefit of humanity.

According to Bourne et al. (2019), engineering education is traditionally a cornerstone of content-centered, practical, and design-oriented teaching, with

Vieira E. L. (2024), Engineering Education in Industry 5.0: Competency Development and Learning Environment Strategies - A Systematic Review, *ASEAN Journal of Engineering Education*, 8(2), 10-18.

a particular focus on the development of analytical thinking skills (Bourne et al., 2019). Various tools and methodologies, such as active learning (Lima et al., 2017), project-based learning (Mills and Treagust, 2003), flipped classroom (Bishop and Verleger, 2013), etc., are available to educators to enhance effectiveness in engineering education.

Hernandez-de-Menendez et al. (2020) state that Industry 4.0 and Industry 5.0 will require professionals with new profiles. They will need to be more qualified in managing complex production systems, and they will also need to be more creative, strategic, and coordinated.

Industry 5.0 and Society 5.0

In 2017, the concept of Society 5.0 was introduced by Japan, defining it as a human-centered society that balances economic advancement with solving social problems through a system that highly integrates cyberspace and physical space (Cabinet Office, 2022).

In 2021, the European Commission formalized the concept of the fifth industrial revolution (I 5.0: Industry 5.0 or Society 5.0) after extensive discussions with research and technology organizations. The process began with the official publication of a document titled "Industry 5.0: Towards a sustainable, human-centered, and resilient European industry" (Breque and Nul, 2021; Mazur and Walczyna, 2022). This document followed earlier attempts to introduce the fifth industrial revolution since 2017. The introduction of the Industry 5.0 concept resulted from the assessment that Industry 4.0 focused more on digitization and AI-based technologies and less on the original principles of social justice and sustainable development (DS) (Xu et al., 2021).

According to Doyle (2021), I 5.0 focuses on the following fundamental elements: the human being, sustainability, and the ability of a system to maintain essential functions and processes under stress, resisting and then recovering or adapting to changes (resilient system). I 5.0 will create relationships between systems of different classes and technological configurations associated with I 4.0 that are interconnected for mutual benefit and among qualified operators (symbiotic relationship between technology and humans). This aims to create workplaces and environments where humans are at the center of work and capable of generating high-value, high-quality, and customized products. While I 4.0 is characterized by the implementation of cutting-edge technologies leading to better and higher performance, I 5.0 seeks to establish highly cooperative relationships of a synergistic nature between enhanced production systems with new technologies and social systems, aiming for more personalized and massive production of parts, products, solutions, and services (Bednar and Welch, 2019). I 5.0 should be considered in the training of current engineers, as, like I 4.0, I 5.0 represents technological changes and challenges in businesses and society in general.

According to Xun et al. (2021), I 5.0 is not only about comprehensive cooperation between cybernetic machines and humans but also involves aspects of sustainability and social considerations. The I 5.0 paradigm promotes the recognition that companies have the power to achieve broader social objectives beyond the benefits of labor and economic growth. They can be resilient and prosperous providers, allowing production systems to respect the planet's limits and placing workers at the center of production.

The current understanding of Industry 5.0 brings a human touch back to industry. It also involves the incorporation of Artificial Intelligence into human operations to enhance human capacity. The core of Industry 5.0 is the harmony between machines, humans, values, tasks, and ultimately, knowledge and skills that result in personalized/individualized products and services (Leng et al., 2022).

Methodology

The method used for selecting the theoretical framework and constructing the knowledge necessary for the research was the Proknow-C (Knowledge Development Process – Constructivist), proposed by Ensslin et al. (2010). This method consists of a series of steps and procedures, resulting in a bibliographic portfolio with articles relevant to the research topic (Afonso et al., 2011). The method is divided into two main phases, with the first focusing on the selection of the raw article database, and the second on the article filtering process. The first phase can be observed in Figure 1.

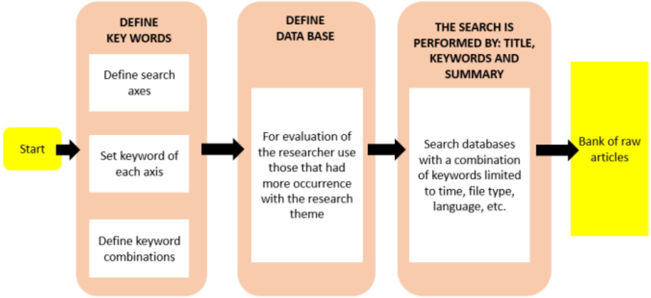

Figure 1. First phase of the Proknow-C method. Source: Ensslin et al. (2010).

Two research axes were defined, labeled "engineering education" and "Industry 5.0." For the "Industry 5.0" axis, two keywords were chosen: "Industry 5.0" and "Society 5.0." The same keyword was used for the "engineering education" axis. The search was conducted on two databases: Web of Science and Scopus, using the proposed keyword combinations and searching the fields of title, abstract, and keywords. The searches were conducted on works published between 2000 and 2023, focusing on journal articles and conference papers.

In the second phase, the process of filtering the raw article database begins, as illustrated in Figure 2.

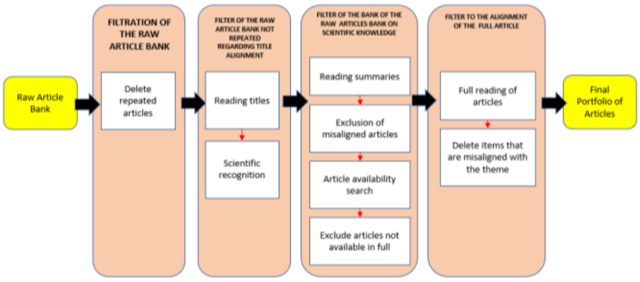

Figure 2. Second phase of the Proknow-C method. Source: Ensslin et al. (2010).

The filtering of the raw article database begins with the exclusion of duplicate articles. The second step involves reading the titles of the articles. Subsequently, the scientific recognition of the articles is verified. This starts with checking the number of citations each article has on Google Scholar. Afterward, the abstracts of the articles are read to make a selection based on the alignment with the research theme, deciding whether to keep or discard them. Following this, the selected articles are read in full. Those that align with the research theme become part of the bibliographic portfolio (ENSSLIN et al., 2010).

Results

The process yielded a gross total of 2,753 articles, with 93 found in the Scopus database and 2,660 in the Web of Science database. Of these, 239 duplicates were excluded. Next, the titles of the remaining 2,514 articles were read to assess their alignment with the research theme, resulting in 83 articles. The following step involved identifying the scientific recognition of the articles, resulting in 66 most-cited articles, accounting for 79.5% of the citations. Afterward, abstracts were read, resulting in 47 articles. Articles with unconfirmed scientific recognition totaled 17, which underwent a new filter for selection. Figure 3 illustrates the filtering process of the Proknow-C methodology.

After filtering out articles with lower scientific recognition, 3 more articles were added to the 47 for which abstracts were read, making a total of 50 articles for checking the availability of the full document. After this verification, 35 articles remained for a thorough reading to confirm alignment with the research theme. After the complete reading, 19 articles remained, representing the bibliographic portfolio on engineering education in Industry 5.0, as shown in Table 1.

A bibliometric analysis of the articles in the bibliographic portfolio was conducted to extract information about the research. One of the analyses performed was the total number of publications per year, as depicted in Figure 3.

Research on engineering education in Industry 5.0 began in 2020, reaching its peak in 2022 with 10 published articles. In 2023, only one research article appeared in the bibliographic portfolio, indicating that it is a recent and rapidly expanding research area with ample opportunities for new discoveries.

Another analysis conducted was the total number of publications by country of origin. The results are presented in Figure 4.

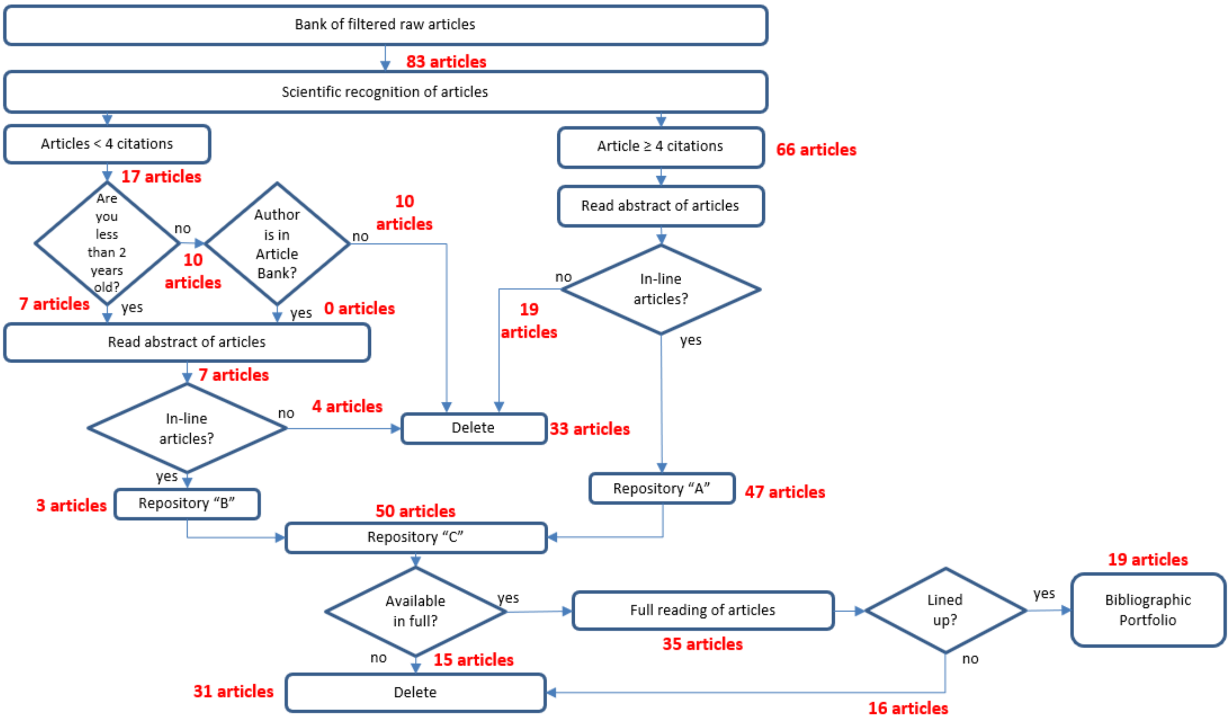

Figure 3. Filtering process leading to the bibliographic portfolio. Source: Author (2023).

Table 1. Bibliographic portfolio. Source: Author (2023).

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Ali, M. Vocational students' perception and readiness in facing globalization, industry revolution 4.0 and society 5.0. In: Journal of Physics: Conference Series. IOP Publishing, 2021. p. 012050.
Alvarez-Aros, Erick L.; Bernal-Torres, Cesar A. Technological competitiveness and emerging technologies in industry 4.0 and industry 5.0. Anais da Academia Brasileira de Ciências, v. 93, 2021.
Broo, Didem Gürdür; Kaynak, Okyay; SAIT, Sadiq M. Rethinking engineering education at the age of industry 5.0. Journal of Industrial Information Integration, v. 25, p. 100311, 2022.
Doyle-Kent, Mary; Shanahan, Breda Walsh. The development of a novel educational model to successfully upskill technical workers for Industry 5.0: Ireland a case study. IFAC-PapersOnLine, v. 55, n. 39, p. 425-430, 2022.
Ghani, A. Engineering education at the age of Industry 5.0—Higher education at the crossroads. World Trans. Eng. Technol. Educ, v. 20, p. 112-117, 2022.
Gutierrez, Silvia Soledad Moreno; Pérez, Socrates López; Munguía, Monica Garcia. Artificial Intelligence in e-Learning Plausible Scenarios in Latin America and New Graduation Competencies. IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, v. 17, n. 1, p. 31-40, 2022.
Hidayat, Hendra et al. The Empirical Analysis of Industrial Work Challenges in the Industrial Revolution 5.0 Towards a Grade Point Average (GPA) for Electronic Engineering Education Students. International Journal of Online & Biomedical Engineering, v. 17, n. 9, 2021.
Jiménez López, Eusebio et al. Technical Considerations for the Conformation of Specific Competences in Mechatronic Engineers in the Context of Industry 4.0 and 5.0. Processes, v. 10, n. 8, p. 1445, 2022.
Kolade, Oluwaseun; Owoseni, Adebowale. Employment 5.0: The work of the future and the future of work. Technology in Society, p. 102086, 2022.
Lantada, A. Diaz. Engineering education 5.0: Continuously evolving engineering education. International Journal of Engineering Education, v. 36, n. 6, p. 1814-1832, 2020.
Maddikunta, Praveen Kumar Reddy et al. Industry 5.0: A survey on enabling technologies and potential applications. Journal of Industrial Information Integration, v. 26, p. 100257, 2022.
Mazur, Barbara; Walczyna, Anna. Sustainable Development Competences of Engineering Students in Light of the Industry 5.0 Concept. Sustainability, v. 14, n. 12, p. 7233, 2022.
Mingaleva, Zhanna ;Vukovic, Nataliia. Development of engineering students competencies based on cognitive technologies in conditions of industry 4.0. International Journal of Cognitive Research in Science, Engineering and Education, v. 8, n. S, p. 93-101, 2020.
Olvera, Marcelo Mejía; Velázquez, Ana Lidia Franzoni; Castellanos, Alejandro Terán. Assessment of Competencies Required for Society 5.0 for Engineering Graduates. IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, v. 16, n. 4, p. 346-351, 2021.
Pacher, Corina; Woschank, Manuel; Zunk, Bernd M. The role of competence profiles in industry 5.0-related vocational education and training: exemplary development of a competence profile for industrial logistics engineering education. Applied Sciences, v. 13, n. 5, p. 3280, 2023.
Rodríguez-Abitia, Guillermo et al. Competencies of Information Technology Professionals in Society 5.0. IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, v. 17, n. 4, p. 343-350, 2022.
Sandoval, José Roberto Santamaría; Sánchez, Esteban Chanto. Society 5.0 Competences in Telecommunications Engineering Graduates, UNED, Costa Rica. IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, v. 17, n. 4, p. 371-378, 2022.
Siegfried, Rouvrais et al. Preparing 5.0 Engineering Students for an Unpredictable Post-COVID World. In: 2020 IFEES World Engineering Education Forum-Global Engineering Deans Council (WEEF-GEDC). IEEE, 2020. p. 1-5.

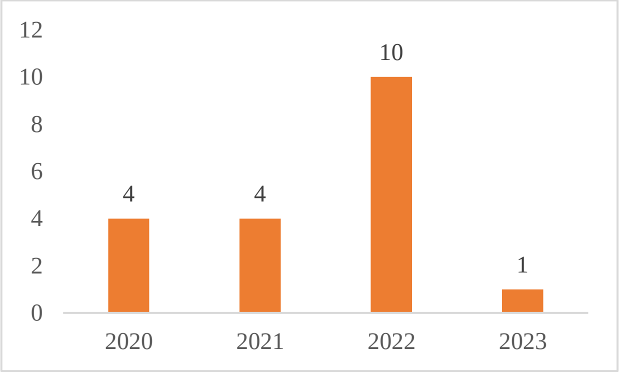

Figure 3. Total publications per year. Source: Author (2023).

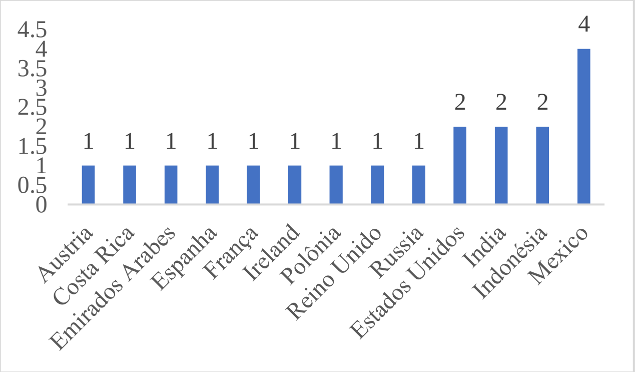

Figure 4. Total publications by country of origin. Source: Author (2023).

The country with the most publications was Mexico, totalling 4 articles, followed by Indonesia, India, and the United States, each with two articles. Other countries contributed with one article each.

Additionally, an analysis of publications by journal was conducted, as shown in Figure 5.

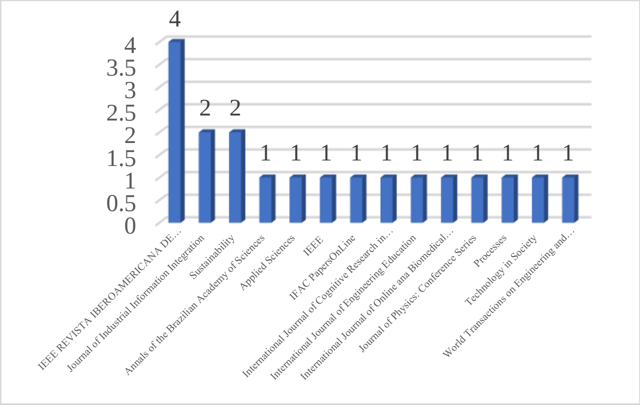

Figure 5. Total publications by journal. Source: Author (2023).

The journal with the most publications in the bibliographic portfolio was the IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, totaling 4 articles. The Journal of Industrial Information Integration and Sustainability each had two publications, while the remaining journals contributed one article each.

An analysis of the most frequently used keywords in the articles of the bibliographic portfolio was conducted, resulting in a word cloud, as shown in Figure 6.

Figure 6. Word cloud of the most used keywords in the articles. Source: Author (2023).

The main keywords identified were "Industry 5.0," "Engineering education," "Industry 4.0," and "Society 5.0," among several others, forming the word cloud of the articles in the bibliographic portfolio.

A content analysis of the articles in the bibliographic portfolio was conducted to identify relevant competencies for Industry 5.0. Additionally, the exploration of how educational environments can prepare for Industry 5.0 was performed, as presented in Table 2.

Table 2. Competencies for I 5.0 and how educational environments can prepare. Source: Author (2023).

Author(s)	Competencies for I 5.0	Educational environments for I 5.0
Ahmad (2022)	Ethics, humanism, teamwork, autonomy.	The use of MOOCs (Massive Open Online Courses) combined with cutting-edge technology and learning systems to simulate high-level learning dynamics with greater precision. Leveraging IoT, cloud computing, AI, machine learning, blockchain, digital twins, gamification, and the metaverse. Customization in teaching through adaptive learning tailored to the student's profile, creating a collaborative study environment.
Ali (2021)	Teamwork, communication, mastery of technologies.	Being prepared for the transition from Industry 4.0 to Industry 5.0 by creating environments that apply technologies, always valuing human capital.
Alvarez-Aros and Bernal-Torres (2021)	Soft skills, problem-solving, decision-making, sustainability, intelligent innovation, and the use of technologies.	Facilitate interaction with Industry 4.0 technologies, using AI, integrated sensors, extreme and intelligent automation, hyper-connected digital networks. STEM-oriented education (science, technology, engineering, and mathematics).
Broo et al. (2022)	Lifelong learning, resilience, sustainability, systemic thinking, project thinking, and future thinking, ethical and social aspects in the use of technological systems, digital and data fluency, statistics, data	Fostering transdisciplinarity, having teaching modules on sustainability, continuous learning environments, and utilizing technological systems. Practical courses on

	visualization, data literacy, ethics, mutual learning, and communication.	data fluency and management, human-agent/machine/robot/computer interaction.
Doyle-Kent and Shanahan (2022)	Problem-solving, collaborative learning, trust, ethics, curiosity.	Stimulate discussions, laboratory simulations, field trips, team projects, hands-on learning.
Ghani (2022)	Mastery of technologies, sustainability, ethical behavior.	Work with problem-based activities, using teaching and learning dynamics to solidify content in classes.
Gutierrez et al. (2022)	Investigative ability, attitude, passion for research, initiative for innovation, critical thinking, self-control, self-motivation, ability to work under pressure, teamwork, knowledge sharing, honesty, humility, respect, ethics.	Incorporate social, technological, economic, environmental, and political aspects into the students' training process.
Hidayat et al. (2021)	Work readiness, knowledge of technologies, teamwork, ethics, communication, problem-solving.	Emphasize the development of soft skills in students, preparing them for the world of work through practical activities.
Jiménez López, et al. (2022)	Problem-solving, human resource management, ethics, attitude, facing challenges.	Use active learning methodologies, employing constructivist education (student-centered), creating engineers capable of facing the challenges of the new industrial revolutions, conducting training according to the industrial needs of each region.
Kolade and Owoseni (2022)	Social intelligence, communication, resilience, knowledge worker, flexibility, autonomy, commitment, creativity, critical thinking, lifelong learning, ethics, culture. Understanding the differences between human and machine capabilities.	Take advantage of online and massive courses (MOOCs) and virtual academies, develop students' autonomy to take on roles that transcend boundaries and contribute to the tacit transfer of knowledge within companies.
Maddikunta et al. (2022)	Create synergy between autonomous machines and humans, occupational safety, flexibility, autonomy, bring the human to the center of the process.	Take advantage of interactive learning experiences using technologies, seeking blended and real-time teaching, using smart education.
Mazur and Walczyna (2022)	Decision-making, use of technologies, ethics, sustainability.	Prepare students for decision-making, technology development, social and environmental areas, ensuring sustainable development.
Mingaleva and Vukovic (2020)	Assessment of importance, identification of factors, learning from mistakes, seeking solutions, decision-making, thinking outside the box, learning ability, quick thinking.	Develop cognitive skills in students so that they learn to make important judgments during decision-making, and especially, learn from mistakes and correct them quickly.
Olvera et al. (2021)	Problem-solving, mastery of technologies, leadership, consideration of social aspects, sustainability, safety and well-being, ethics.	Prepare students with digital skills to produce engineering solutions for problems, leading the construction of a better society by addressing social, economic, and environmental aspects.
Pacher et al. (2023)	Language proficiency, mathematical problem-solving, scientific and technical knowledge, mastery of technologies, continuous learning, entrepreneurship, cultural awareness, time management, emotional intelligence, initiative, negotiation skills.	Prepare students for social realities, interpersonal relationships, negotiation skills, explore the scientific side of students by conducting research and fostering entrepreneurship.
Rodríguez-Abitia et al. (2022)	Oral and written communication, analysis and synthesis of information, problem-solving, solution modeling, autonomous learning, teamwork, decision-making, effective use of ICT tools and new technologies, social responsibility and ethics, analysis of the impact of developed solutions.	Develop competency-based curricula for Industry 5.0, placing the student at the center of the teaching process, nurturing a citizen and professional with a social, economic, and environmental perspective to meet the challenges in the job market.
Sandoval and Sánchez (2022)	Decision-making, teamwork, use of technologies, ability to formulate and manage projects, organization and time planning, appreciation of quality in the career, understanding of safety standards for human life protection, ethics for the benefit of society.	Use forums and case studies to promote situations that assist society, including in final course projects, focusing on aspects of society and Industry 5.0.

Siegfried et al. (2020)	Interpersonal relationships, communication using technologies, adaptability to changes, empathy, judgment and decision-making ability, taking responsibility, ethics, autonomous learning, contributing to professional knowledge and practice.	Develop competencies in their students for Industry 5.0, exploring digital platforms for autonomous learning, working on concepts where students will take responsibility for their actions, striving for continuous improvement, and engaging in practical activities that simulate real situations.

A framework with the main competencies mentioned in the articles from the bibliographic portfolio was designed to understand how to prepare engineering students for Industry 5.0, as presented in Figure 7.

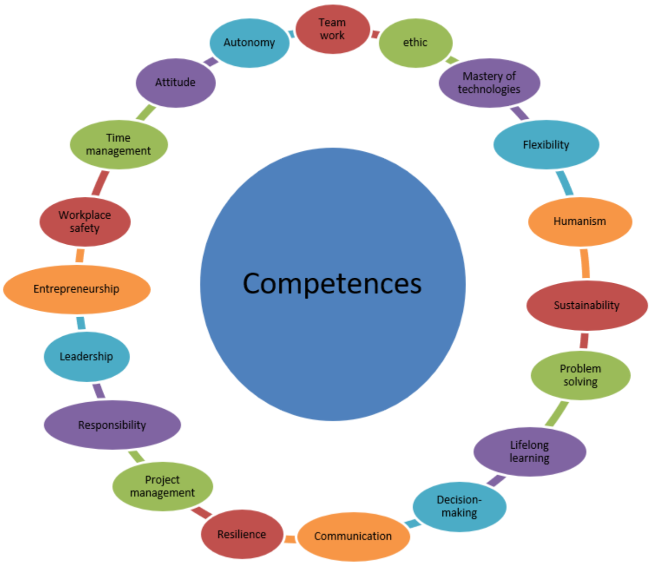

Figure 7. Framework with the main competencies for Industry 5.0. Source: Author (2023).

It was possible to observe that in the process of developing these competencies, many human aspects must be developed to deal with the transition to Industry 5.0, such as ethics, communication, leadership, responsibility, decision-making, attitude, autonomy, time management, lifelong learning, and mastery of new technologies. These competencies align with what was mentioned by Gopalakrishna et al. (2021): Industry 5.0 will be based on decision-making, human creativity, innovations, and critical thinking, which will generate more personalized products, articles, and services with higher added value, while robotic systems will perform repetitive, high-risk, and labor-intensive tasks.

Educational environments must be prepared to operate in engineering education in Industry 5.0. Some characteristics of preparing these environments were extracted, as presented in Figure 8.

These environments must be prepared with their physical, technological, and personnel structure to deal with the development of competencies and the training of engineers for Industry 5.0. Well-qualified human resources will now be more important than ever, and universities will play a key role in shaping the future workforce. Today's and tomorrow's students need to have knowledge and skills useful for facing a highly technological and interconnected environment (Coskun et al., 2019). It was possible to identify that training should develop students in personal, social, environmental, and economic aspects to deal with the human and technological capital of companies. Additionally, using technological resources in education, encouraging autonomy in learning, and valuing interpersonal relationships.

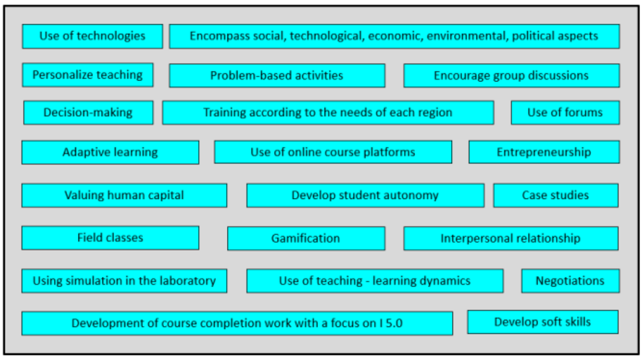
Use of technologies
Encompass social, technological, economic, environmental, political aspects
Personalize teaching
Problem-based activities
Encourage group discussions
Decision-making
Training according to the needs of each region
Use of forums
Adaptive learning
Use of online course platforms
Entrepreneurship
Valuing human capital
Develop student autonomy
Case studies
Field classes
Gamification
Interpersonal relationship
Using simulation in the laboratory
Use of teaching - learning dynamics
Negotiations
Development of course completion work with a focus on I 5.0
Develop soft skills

Figure 8. Framework for the preparation of educational environments for Industry 5.0. Source: Author (2023).

The transition to Industry 5.0 brings with it a series of significant challenges for higher education environments in engineering. Educational institutions will need to update and revise course curricula to include new technologies and concepts that are relevant to this context. Another challenge is the integration between industry and academia, to foster strong collaboration and ensure alignment with the needs of the job market, providing students with access to relevant internship opportunities and practical projects.

Conclusion

This research conducted a systematic literature review on engineering education in the context of Industry 5.0, selecting a bibliographic portfolio on the subject by searching the Scopus and Web of Science databases using the Proknow-C methodology. The portfolio comprised 19 articles. A bibliometric analysis was then performed to identify the years and countries of publication, major journals, and a word cloud with the main keywords used in the articles. Subsequently, a content analysis of the articles was conducted to identify key competencies and how engineering education environments can prepare for Industry 5.0. With these findings, it will be possible to prepare engineering students to face the challenges posed by this transformation process, guiding the actions of educational institutions in shaping their students.

As a suggestion for future work, these competencies can be tested along with actions for engineering education environments to verify their effectiveness in training engineers and their applicability in industrial settings.

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Teaching practices among engineering lecturers with and without professional engineer certification: The case of Universiti Teknologi Malaysia (UTM)

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Abstract

This paper describes the teaching practices among engineering lecturers with professional engineer certification at Universiti Teknologi Malaysia (UTM). Employing a case study design, this study optimised both quantitative and qualitative data. Questionnaires were distributed to 20 lecturers from various engineering faculties who agreed to be the research participants. From the 20 lecturers, five lecturers with professional qualifications (Professional Engineer, Chartered Engineer) participated in the interviews. Questionnaires were also distributed to the students of these lecturers to compare the teaching approaches of the lecturers with and without the professional engineer certification. The analysis of the quantitative data was conducted using SPSS software, while the qualitative data was analysed using NVivo software. Results were obtained from Spearman's test and t-test, as well as from the thematic analysis. From the presented results, the finding could be OBE (outcome-based education) is the most preferred NALI approach for the professional engineer (PEng) lecturer implemented in their teaching and learning processes.

Keywords: Teaching and learning practices, Engineering lecturers, NALI model, Professional certification, Accreditation.

Introduction

In recent years, higher education institutions, especially in Malaysia, have carried out many seminars and trainings for lecturers to focus on effective pedagogical approaches required in teaching and learning in the classroom. This effort is in line with the learning outcomes that are highlighted in universities nowadays (Hamdan et al., 2014). Not to mention, technology and digital transformation, especially in the 21st century era, are focusing more on physical, digital, and biological systems that disrupt lifestyles, businesses, and industries with regards to skills, talents, and jobs (Helmi et al., 2019). Thus, relevant teaching and learning approaches are important to improve students learning in order to conceptualise phenomena and ideas in order to become skilled scientists, mathematicians, historians, physicians, or other experts. 'Good teaching' has always been the focus of most universities in order to produce high-quality student learning (Biggs, 2003; Hamdan et al., 2014).

As for it is, back in 2009, Malaysia was chosen to become a full member of the Washington Accord; a universal agreement among bodies handling engineering degree programme accreditation. The Washington Accord recognises signatory bodies and makes it compulsory to meet the engineering instructional requirements before entering engineering practice in real life. The Engineering Accreditation Council (EAC) in Malaysia, a group that was delegated by the Board of Engineers Malaysia (BEM), the Institution of Engineers Malaysia (IEM), Public Services Department (JPA) and the Malaysian Qualifications Agency (MQA), among the bodies that offered professional engineer certification in engineering curriculum. It is a very challenging situation for academicians who must master 'killer

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subjects' in engineering and have many skills, not to mention critical thinking skills. At the same time, it has a good-quality curriculum that can meet the requirements (Ditcher, 2001; Puzi et al., 2017). Particularly at Universiti Teknologi Malaysia (UTM), the New Academia Learning Innovation model (NALI) has been implemented for many years (Alias & Aris, 2016).

In tandem with this development, this study examined the teaching practices in relation to the NALI model among engineering lecturers with professional engineer certification at Universiti Teknologi Malaysia (UTM). This study employed both quantitative and qualitative data that were collected among lecturers in various faculties of engineering at UTM. The analysis of the quantitative data was conducted using SPSS software, while the qualitative data was analysed using NVivo software. Findings that were obtained from the two types of analysis, the discussions based on the findings, and recommendations for future work are also explained in this paper.

Literature Review

The review of literature is confined within the scope of accreditation and its requirements for professional engineer certification, the NALI model, as well as the current teaching and learning technology.

(i) 21st Century Education

For this year and beyond, technological, and digital advancements have dramatically improved, indicating the beginning of Industry 4.0. Physical, digital, and biological industries were thoroughly utilized for their benefits and high ends in this era. Our lives, enterprises, and industries have evolved to accommodate this occurrence. This 21st-century world has a significant impact on the development of human skills and talent, as well as the employment required in the global era (Helmi et al., 2019). To adapt to this change, it is necessary to enhance education so that future generations can prepare for future requirements.

(ii) Accreditation and New Academia Learning Innovation (NALI)

The International Engineering Alliance (IEA) is the primary organization for six multilateral agreements that establish and administer internationally benchmarked standards for engineering education and entry-level engineering practice among their members. Their vision is to improve the global quality, productivity, and mobility of engineers by being a respected independent authority on best practices in engineering education and professional competence standards, assessment, and monitoring. The Washington Accord (WA) was thus constituted. WA is a self-governing, autonomous agreement between national organizations (signatories) that provides external accreditation to tertiary educational programmes whose graduates are qualified for entry into professional engineering practice. Malaysia joined Japan, Singapore, Chinese Taipei, and Korea as a full member of the Washington Accord in 2009 (International Engineering Alliance, accessed December 20, 2022).

Under the Registration of Engineers Act of 1967 (revised 2015), the BEM registers graduates and professional engineers. Meanwhile, BEM represents EAC in Malaysia for engineering degree accreditation. IEM, MQA, and JPA all represent the EAC. The purpose of accreditation is to ensure that graduates of accredited engineering programmes satisfy the minimal academic requirements for registration with the BEM as a graduate engineer. In addition, the purpose of accreditation is to ensure that institutions of higher education (IHLs) practice continuous quality improvement (CQI). Accreditation may also function as a benchmarking tool for engineering programmes offered by Malaysian IHLs. 30% of the lecturers/instructors must have a professional/industrial/specialist certification or at least TWO (2) years of relevant industrial work experience. If this is not met, the institution should have a staff industrial attachment scheme in place). It is challenging for academicians to implement engineering and critical thinking skills as well as mastery of a high-quality curriculum that can satisfy the requirements (Board of Engineers Malaysia; Puzi et al., 2017, Engineering Technology Programme Accreditation Standard 2020).

In addition to meeting accreditation requirements, universities must prioritize teaching and student recruitment. Effective instruction and interactive learning are more engaging and can motivate students to achieve a high level of comprehension during the lecture. Systematic strategies in teaching and digitalizing the teaching could thereby help reduce the limitations of conventional teaching methods. The New Academia Learning Innovation (NALI) was introduced on this basis. In 2010, academic performance audit panels advised UTM to prioritize effective and high-quality instruction alongside research disciplines. This is consistent with the National Higher Education Strategic Plan Phase 2 (2011-2015), which requires lecturers to implement at least one teaching technique by 2015. Included are Harvard Business School (HBS) case research, problem-based learning, scenario-based learning, peer instruction, service learning, and job creation (pedagogy and andragogy). Ujang et al. (2013) identify the UTM Open Courseware (OCW), UTM-MIT BLOSSOMS, Student-to-Student Edutainment, Video of Exemplary Professionals, OBE analysis systems, and SCL UTM space as digital teaching resources. Nonetheless, in 2016, these techniques were refined and grouped into 15 approaches: outcome-based education (OBE), case study teaching, problem-based learning (PBL), scenario-based learning (SBL), peer instruction, service learning, job creation, high-impact educational practices (HIEPs), and conceptualize, design, implement, and operate (CDIO) for pedagogy and andragogy. In addition, learning materials (digital resources) include UTM Open Courseware (OCW), UTM MOOC, UTM-MIT BLOSSOMS, Video of Exemplary Professionals, Student-to-Student Edutainment, and UTM e-Learning (Alias & Aris, 2016; Lazim et al., 2023).

(iii) Teaching and Learning Technology

Traditional teaching and learning techniques do not emphasize learning, critical reasoning, or interaction. The teacher itself is the only resource for reference and gathering information, beside the books in the library. Students rarely involved with learning on their own. This will result in passive learning and hinder the student's ability to engage in active study. Currently, technology is ubiquitous. The new generation is growing up in a technological environment and inhabiting it. Computers and other mobile technologies have altered how information is gathered in educational institutions. The technological skills we possess provide us with profound insights into the course material. It increases the effectiveness of the instructional lesson period in the classroom (Roy, 2019; Harnish et al., 2018).

In such a scenario, educational technology becomes increasingly prevalent. Educational technology is the process of analyzing, designing, developing, implementing, and evaluating the instructional environment and learning materials for the purpose of enhancing teaching and learning. The purpose of such works is to improve education or the learning process, and the application of technological tools in teaching and learning will help students become interested, engaged, and motivated by providing multiple resources, quick access to information, real-time teaching, and paperless tests and assignments (Kurt, 2015; Castagna, 2021; Hasa, 2020).

Research Questions

Based on the literature review, this study focused on the outcomes of implementation of NALI techniques among the engineering lecturers with professional engineer certification. Three research questions were formulated as the following:

Research Question 1: What is the relationship between lecturers with professional engineer certification and teaching and learning based on NALI model?

Research Question 2: What is the teaching and learning approaches applied by lecturers with professional engineer certification?

Research Question 3: Is there any difference between lecturers with and without professional engineer certification in teaching and learning approaches?

Research Methodology

Research Design and Sampling

In this study, the researchers employed a case study design to explore the implementation of NALI techniques among the lecturers from the engineering faculties at UTM. A case study design was chosen for this study as it allowed the researchers to specifically examine the teaching and learning experiences that were in line with the NALI model with a purposive sample involving UTM engineering lecturers and with extensive data collection and analysis. Thus, this became the bounded unit that was central to the study (Bassey, 1999).

Initially, the researcher distributed an online questionnaire to the lecturers with and without professional engineer certification. Professional engineer certification refers to the awards given to the lecturer both by Board of Engineers Malaysia (BEM) and Chartered Engineer (CEng), Incorporated Engineer (IEng), and Engineering Technician (EngTech) by Engineering Council, UK (Khulief, 2002). However, for our cases, we focus on graduated engineer by BEM, Chartered Engineer, and Professional Engineer by EC UK. Next, lecturers with professional engineer certification were invited to further collaborate with the researchers, and upon granting their agreement and consent, they participated in the interview session. In addition, their students were also invited as participants in the study and eventually took part in the survey study conducted at the end of the study.

Prior to the interviews, a brief introduction related to the study background and purpose was explained, and the consent forms were distributed to the lecturers with professional engineer certification. A total of 20 lecturers with professional certification answered the questionnaires. In addition, online and face-to-face interviews were conducted with five lecturers who volunteered to be the interviewees. Each session lasted from 15 to 25 minutes. The interviews were audio recorded and later transcribed. With the permission of these lecturers, a survey was conducted among their respective students. A total of 134 students who took part in the survey answered the questionnaires that were distributed to them.

The designed questionnaires were distributed to the lecturers of the Faculty of Civil Engineering (FCE), the Faculty of Electrical Engineering (FEE), the Faculty of Mechanical Engineering (FME), the Faculty of Chemical and Energy Engineering (FCEE), and the Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Malaysia. However, the interviews were conducted among the lecturers at UTM Johor Bharu. The interview questions were developed both in Bahasa Malaysia and English in order to elicit congruent findings for lecturers. Qualitative and quantitative data collections were conducted between September and November 2022.

This study was not without limitations. Firstly, during the study, the country was in the process of recovering from COVID-19. During the pandemic, the periods of Movement Control Order (MCO) affected campus activities, which included academic activities, recreational activities, and others. Inevitably, the researchers found it challenging to reach out to the lecturers and students, which resulted in a low response rate. Secondly, this study was also affected by the semester breaks during which engineering lecturers were engaged in other activities like research fieldwork or industrial attachment. Due to these engagements, it was indeed a challenge to conduct interview sessions with the lecturers who initially agreed to be interviewed. Thus, the number of research respondents was not optimised. Thirdly, it was difficult to achieve the objectives of the study because lecturers are bound to their own tracks to be focused in their careers. For example, some lecturers have chosen a research track, and others are more interested in a teaching track. Thus, prior to the arraignments of the interviews, the researchers had to screen out the lecturers' career pathways, that is, whether they were focusing on the research track or the teaching track. In addition, it was found that most of the engineering lecturers approached were more bonded to the research track as compared to the teaching track. Therefore, in terms of teaching approaches, most lecturers were using the same teaching techniques. Thus, this limited the number of interviewees. Fourthly, the researchers also found that not many lecturers agreed to volunteer to be the interviewees. This could be due to COVID-19 safety and other unforeseen circumstances experienced by the lecturers. Such an occurrence delayed the data collection process. Despite all these challenges, the researchers successfully engaged with the chosen participants in order to obtain both quantitative and qualitative data.

Procedures of Data Collection

The research instrument used in this study was a set of questionnaires that were developed by Hamdan et al. (2014). On the other hand, the interview questions were developed by the researchers based on the conceptual framework of the NALI model. The questions are as below:

i. Which of the NALI techniques do you favour most implementing in your class? Why?
ii. What are the challenges and difficulties that you (the lecturer) face during the class session?
iii. Which of the challenges or difficulties do you find the most? For instance, time-consuming, energy-draining, or other reasons?
iv. How do you decide on any NALi technique that you will use in your class?
v. How do you identify _____ (based on their response) as a challenge?
vi. How do you overcome those challenges?
vii. What kind of support do you need to overcome the challenges?
viii. What kind of support do you get from your faculty in overcoming the challenges?

Findings

This section provides the findings derived from the three research questions. The results are presented based on the sequence of the research questions.

i) The relationship between lecturers with professional engineer certification and teaching and learning based on NALI model

The questionnaires were filled out by 37 engineering lecturers. 20 of the lecturers possess professional certification, while the remaining 17 do not. Five of the twenty certified lecturers consented to be interviewed by the researchers. The interview sessions took place both online and in-person. Spearman's rank correlation was utilised to determine the relationship between these two variables. The first variable in this study was the presence or absence of professional engineer certification among lecturers, while the second variable was teaching and learning based on the NALI model. Due to the fact that this study examined the relationship between two variables, the researchers were required to synchronise the number of participants for this test. Therefore, the total for each variable in this test is fixed at 17 respondents from both categories. The Spearman correlation results are tabulated in **Table 1**.

From the table, it can be seen that there was a positive correlation between two variables, r (17) = .365 and .262, $p < 0.01$, except for D vs di where, r (17) = - .003, $p > 0.05$ (negative correlation). This indicates that lecturers with professional engineer certification used at least one NALI teaching approach in the classroom, excluding digital mode, so it is possible that they are only using the most common and familiar platform, and not all of them. Since the implementation of NALI began in 2010, their influence on classroom teaching practices has likely been a result of their seniority within the UTM. In 2016, the approaches were expanded from twelve to fifteen projects (Ujang et al., 2013; Alias et al., 2016). Therefore, senior lecturers must have a greater understanding of NALI techniques than novice lecturers. It was also assumed that senior lecturers were less enthusiastic about educational technology than their novice colleagues. Therefore, this may explain why they did not implement digital teaching methods in their classrooms.

Table 1. Spearman's correlation for lecturers with IR vs. without IR

Correlations

			B	bi	C	ci	D	di
Spearman's rho	B	Correlation Coefficient	1.000	.365**	-.111	-.222**	.125	.077
		Sig. (2-tailed)	.	.000	.114	.001	.212	.439
		N	221	221	204	204	102	102
	bi	Correlation Coefficient	.365**	1.000	-.149*	-.066	.041	.049
		Sig. (2-tailed)	.000	.	.034	.346	.682	.621
		N	221	221	204	204	102	102
	C	Correlation Coefficient	-.111	-.149*	1.000	.262**	-.166	-.159
		Sig. (2-tailed)	.114	.034	.	.000	.096	.110
		N	204	204	204	204	102	102
	ci	Correlation Coefficient	-.222**	-.066	.262**	1.000	-.095	.114
		Sig. (2-tailed)	.001	.346	.000	.	.344	.254
		N	204	204	204	204	102	102
	D	Correlation Coefficient	.125	.041	-.166	-.095	1.000	-.003
		Sig. (2-tailed)	.212	.682	.096	.344	.	.973
		N	102	102	102	102	102	102
	di	Correlation Coefficient	.077	.049	-.159	.114	-.003	1.000
		Sig. (2-tailed)	.439	.621	.110	.254	.973	.
		N	102	102	102	102	102	102

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Legend: Larger capital alphabets- lecturers with professional engineer certification; small capital alphabets- lecturers without professional engineer certification

ii) The teaching and learning approaches applied by lecturers with professional engineer certification

Five lecturers with professional engineer certification from various faculties at Universiti Teknologi Malaysia, Johor were interviewed using a semi-structured format in order to understand more about their teaching strategies and challenges while interacting with students during class. The evaluations were conducted both in-person and via a web-based meeting platform. Three female and two male lecturers volunteered for the interviews. The duration of each interview session ranges between 15 and 25 minutes.

After identifying codes, sub-themes, and themes from the transcribed data, the results of the interview were interpreted. After the overall classification has been completed, homogeneous categories are determined based on the interview questions and their relationship to the codes. The codes are then transformed into sub-themes and themes that correspond with the research questions. The themes, sub-themes, and excerpts from the lecturer's interview are displayed in **Table 2**.

Six themes were derived from the thematic analysis, as explained below:

a) Knowledge: It needs to be highlighted in the research. Since 2010 (Ujang et al., 2013), the knowledge of NALI techniques has been implemented in the teaching and learning process at UTM. In addition, it is essential to consider the factors that may influence the implementation of various techniques at different engineering schools.

b) Awareness: Before deciding on the techniques, lecturers must have a greater understanding of how to implement the technique in the classroom and why they must do so in order to make the class interactive and students appreciate learning.

c) Challenges: During implementation, there were many challenges for lecturers in the classroom. This includes both internal and external challenges, as well as tangible and intangible obstacles. All these challenges may affect the effectiveness of NALI implementation in the classroom.

d) Assessments: How do you evaluate the efficacy of your classroom instruction? What criteria will be considered in order to enhance your classroom instructional strategies? Students must adhere to certain criteria, which will determine the ability to attract them to the lecturers' classes.

e) Suggestions: Certain lecturers may be able to obtain excellent student feedback. Others may not even be able to attract student attention in class. Therefore, it is essential to emphasise the suggestions that other lecturers must follow or refer to in order to create a healthy classroom environment.

f) Expectations: It is noted that for the NALI technique to be successfully implemented in the classroom, it must originate from both parties. It is more effective if both parties assist one another on the voyage. It can be the initiative of a university, faculty, or department to ensure that students have exceptional class knowledge and master the skills necessary for lifelong application.

Regarding the first sub-theme, knowledge of NALI techniques, the interviewees mentioned approximately 12 active-learning strategies. It is shown in **Table 2**. Outcome-based education (OBE) is the second subtheme. In the interview, outcomes-based education was mentioned approximately 17 times. The following sub-theme is cooperative methods. This strategy was mentioned seven times during the interview. Blended learning, scenario-based learning, and problem-based learning comprise the fourth subtheme. This sub-theme was mentioned approximately thirteen times during the interview. The final sub-theme for the theme of knowledge is collaborative technique. This sub-theme was mentioned approximately three times during the interview.

Table 2. The information on themes, sub-themes and excerpts of interview from lecturer

Themes	Sub-themes	Excerpts of interview
Knowledge	NALI technique • Active learning • Outcome based education • Cooperative learning • Blended learning/scenario-based learning/problem-based learning • Collaborative technique Factors • Syllabus • Subject given • Familiar with scenario/problem • Student participation/activeness/confident	Respondent 1: *‘Yup..it is **active learning**…’* *‘It is like mixed-based..we want to achieve **active learning**..’* *‘We used **active learning**…’* *‘It is to decide whether or not we want to use **active learning** or passive learning, it is?..’* *‘So, there is a chapter that must use **active learning**..most of the time we use **active learning**. 3 to 4 chapters used **active learning**…’* *‘If **active learning**…Is it **active learning**? Are you referring to **active learning**?...’* Respondent 4: *‘It is like **active learning**…’* *‘So, I used blended **active learning**…’* The second sub-theme: Respondent 1: *‘We want to achieve **outcome-based education**…’* *‘**Outcome-based**…?’* *‘It is **outcomes-based education**…’* Respondent 2: *‘It is more on **outcome-based education**…’* *‘If before this is based on **OBE**, so our subject must follow an **OBE**..erm which is why I think most of my subject that was given to me is must use **OBE**, **outcome-based education**..correct or not? Other subjects that I did not teach also use **outcome based learning**, scenario based learning, problem based learning so forth..so for my situation, I was given the subject that required to use **OBE**...’* *‘We must follow **OBE** approach because it has been approved…’* *‘If the subject is based on **OBE**, I must follow **OBE**..To be honest, all the subjects that given to me are based on **outcome based education**...’* *‘This is not based on **OBE** only right?...’* Respondent 3” *‘So, basically one of NALI technique that everyone in UTM even myself, we use **outcome-based learning education**…’* *‘Yup..so for **outcome-based** is pretty much the requirement for the whole UTM..**outcome-based education**…’* The third sub-theme is cooperative technique: Respondent 3: *‘so at the meantime because for the last 2 years it all online acquittance than to do so **cooperative learning**…’* *‘so what I did is to do informal **cooperative learning**…’* *‘when it comes to informal **cooperative learning**…’* *‘for example **cooperative learning**…’* *‘so interest to informal **cooperative learning**…’* *‘because errr you should the paper for example of **cooperative learning**…’* *‘but then there are elements in the **cooperative learning**…’* The fourth sub-themes: Respondent 1: *‘Outcome, case study based learning, **problem based learning**?is it?...’* Respondent 2: *‘outcome based learning, **scenario based learning, problem based learning** so forth…’* Respondent 3: *‘so instead of using **problem-based** because **problem-based** are complicated…’* Respondent 4: *‘NALI technique means the one with **blended-learning**?...’* *‘so, I did **blended learning**…’* *‘**blended learning** means they have lecture-based as well…’*

Themes	Sub-themes	Excerpts of interview
		*'so what I did is **blended learning**..**blended active learning**…'* *'If **problem-based learning**..**problem-based learning** is normally I will use for certain topic that involve with real life application…'* *'so I apply the concept **problem-based** I want to relate with real life application...'* *'I give **scenario** so that they will familiar with the problem..'* The fifth sub-theme: Respondent 5: *'we use **collaborative technique**…'* *'I did **collaborative technique**..**collaborative technique** is required them to be in group of 10 for example…'* The sixth subtheme is the reason why lecturers choose aforementioned NALI techniques in the class: Respondent 1: *'I looked at the **syllabus**…'* *'like traffic engineering subject has 4 chapters…'* *'mostly for chapters….'* Respondent 2: *'but lecturers in our faculties we have the **subject that was given** to us to teach by default…'* *'So **it is given**..when the **subject is given**…'* Respondent 4: *'based on **subject itself**…'* *'I give scenario so that **they familiar with the problem**..'* *'students will response to that forum…'* Respondent 5: *'so..they are **active to participate**…'*
Awareness	• Course • Situation • Subject curriculum • Faculty or university approaches • Initiatives and experience • Subject • Lifelong learning	Respondent 1: *'in **subject** traffic engineering itself…'* Respondent 2: *'due to my **situation**…'* Respondent 3: *'so that one is **faculty or university approaches**…'* *'another one the **course**…'* Respondent 4: *'this is from my **initiative and through experience**…'* Respondent 5: *'because I think **engineering electrical** is a bit difficult…'* *'you will have **life-long learning** skill…'*
Challenges	• Student engagement • Industrial awareness practice • Lecturers awareness • Students' knowledge • Class size • Student involvement • Student late • Ad hoc group	Respondent 1: *'Challenges are to get **engagement with students**…'* *'to retain **engagement with students**…'* *'during pandemic, students just turn on the computer but **lack of engagement** with others in the online class…'* ***'Time consuming**…'* Respondent 2: *'so we want to **relate to industry** is very challenging…'* *'the content of the subject itself **not much to industry**…'* *'so that student can imagine or **link with industry** or real world application…'* *'Ok..aa I think the **environment**..the classroom..the chair the table..the **environment**..in general the **environment**..means what I refer to the **environment** is that class room equipment..even equipment like projector or frontier projector, the chair or many others are actually influence teaching and learning (T & L) session..that is for physical class..for online class, it is worsen as no **class environment** at all.. **environment element** is not there..so for me the most challenging is*
Challenges	• Time consuming • Class environment • People factor • Time constrains • Student answers	

Themes	Sub-themes	Excerpts of interview
		*always **environment**... it is difficult to have everything in 1 short however, I must attract the student not because of **environment** but the subject itself…'* Respondent 3: *'so, first thing for NALI approaches I think the way **they (refer to lecturer) understand** it…'* *'**we need to understand**..so, we need to fulfil the requirement…'* *'challenge number 2 is that **students might not understand** the implementation…'* *'so the idea of getting NALI is to be understood **not only us educator and also the students**…'* *'I think very **difficult to get the student** to get the idea…'* *'**People factor**..it is **people factor**…'* Respondent 4: *'each forum if the student is **so many in the class**…'* *'so, when the **students is too much**, there will be 1 group in passive learning…'* *'so the **class size is small**, may be we can notice from early, otherwise, it is difficult to decide the approach…'* *'**time constrain**…'* Respondent 5: *'if we **get pro-active student**, that is not a problem…'* *'if the student just coming to the class in **the sake of attendance** not for learning, then it is the problem…'* *'sometimes the class is too early in the morning, students are **coming late** because of the bus…'* *'if we have to form the group, they have to **find their own group** because of student availability in the morning…'* *'challenges is when student gives **wrong equation in the test**…'*
Assessments	• Students response • Student evaluation (ePPP) • Student participation • Exam grade	Respondent 2: *'lack of **response**…'* *'we can see from their **response**…'* *'difficult to get their **response**…'* Respondent 3: *'student **response** is definitely…'* *'**feedback** from our ePPP…'* *'we get our **feedback** from the students…'* Respondent 4: *'from exam, from test, from **grade**, only then we know the students…'* Respondent 5: *'from their **response**…'*
Suggestions	• Form small group discussion • Request good facility • Educators awareness • Provide 2 lecturers - class size • Share template question	Respondent 1: *'to overcome it I sometimes do **break up room**..we form **small group**..that **small group** they can choose their own who will be…'* Respondent 2: *'I want to **request good facility**…'* Respondent 3: *'so as part of residency, we are encourage **to share idea and get lecturers to join** activities all…'* Respondent 4: *'if the class size is bigger, perhaps we can have **2 lecturers** in the class at same time…'* Respondent 5: *'sometimes I give them **template question**…'*
Expectations	• Workshop • Industrial engagement • Initiative to introduce to the students • Free teaching • Familiar with the approaches/capstone for final year	Respondent 1: *'I think **workshop**..**workshop** on how to get engage with the student in the class..perhaps, the approach 10 years back is not relevant to current generation (digital generation)…'* *'Support from faculty, **workshop announcement** from time to time…'* Respondent 2: *'to provide this student with industrial application. Suggested good industry..we need to **engage with this industry**…'*
Expectations	• Workshop announcement	

Themes	Sub-themes	Excerpts of interview
	• Implementing industrial consultation • Introduce education approaches • Workshop • Structured curriculum	*'get **involve with the industry**…'* *'involve through research and **consultation with industry**…'* *'for example, if the **industry can comment on certain subject** to improve that for me if they provide several talk or speech to the student..that will be good...'* *'thats how we try **to engage this student with industry**…'* *'certain subject probably we got **direct involvement with industry**…'* *'if students see the **involvement with industry in teaching**, they might probably more interest to dig more knowledge in the class..'* Respondent 3: *'the first few weeks to inform the things to students..**introduce our education** methods…'* *'the faculty the university need to **introduce education approaches**…'* Respondent 4: *'Support like I said before, **free teaching**..a few teaching..perhaps other lecturers can help…'* *'I think more or less from time to time, we have a **workshop**, or **meeting for review**..so, through this **workshop** lecturer can polish teaching style…'* Respondent 5: *'but they **capstone**..**capstone** for 4th year..working under pressure is something must in life learning especially engineering…'* *'I mean **structured curriculum**…'* *'A **structured curriculum**..**structured curriculum** means course information is fully organized…'*

The following sub-theme explains why instructors choose the aforementioned NALI techniques in class. There are four explanations why these teaching and learning (T&L) techniques were utilised. This includes the syllabus (1 occurrence), the topic (4 occurrences), familiarity with a scenario or problem (1 occurrence), and student participation, activity, or confidence (2 occurrences).

The theme of awareness has seven sub-themes. All these subthemes were mentioned multiple times during the interview. For instance, lecturers choose to implement NALI techniques based on the course (2 times), situation (1 time), subject curriculum (3 times), faculty or university approaches (1 time), initiatives and experience (1 time), subject instruction (1 time), and lifelong learning (1 time). This is evident from **Table 2**'s interview responses.

In spite of all NALI implementations during class time, lecturers still encountered some challenges in the classroom. This can be confirmed through interviews with professors. Their sub-themes relate to student participation (3 times), industrial awareness practise (3 times), lecturers' awareness (2 times), students' knowledge (3 times), class size (3 times), student participation (2 times), student tardiness (1 time) and ad hoc group formation (1 time). However, the most difficult circumstances are when time is consumed (1 instance), the classroom environment (8 instances), the people factor (2 instances), the time constraint (1 instance), and student responses (1 instance).

The next topic is assessment. How do instructors determine the efficacy of their classroom instruction? Four sub-themes are present in the interview. There are five instances of student responses, one of student evaluations, one of student participation, and one of exam grades. It is from the interview listed below:

Typically, instructors surmount their difficulties by implementing some suggestions. It is whether to form small group discussions (mentioned three times), request excellent facilities (mentioned once), raise educators' awareness (mentioned once), provide more instructors (mentioned once), and provide template questions (mentioned once).

The final theme of the class's implementation of NALI techniques is expectation. There are approximately ten sub-themes within the interview. It is supported by the university and its faculty and staff. They were workshops (5 times), industrial engagement (3 times), introducing an initiative to the students (1 time), free teaching (1 time), familiarity with the approaches/capstone for the final year (2 times), workshop announcement (1 time), implementing industrial consultation (3 times), introducing education approaches (1 time), university workshops (3 times), and structured curriculum (3 times).

This demonstrates that lecturers favour outcome-based education (OBE) in their teaching practises over other approaches. Blended learning is followed by scenario-based learning, problem-based learning, and active learning. Due to the fact that a particular topic necessitates the use of such a technique. Additionally, the subject curriculum prevents them from employing the technique. The majority of lecturers face challenges when attempting to engage students effectively, due to limited industrial awareness practise during class sessions, students' knowledge of NALI requirements, and class sizes that are too large for a single lecturer. Other obstacles include the classroom environment, which impacts the teaching situation. It is evident from the class responses of the students. During the past two years of a pandemic, they have been required to conduct their classes via an online platform, which exacerbates the situation. They are expected to initiate small-group discussions regarding the lecturer's issue in the classroom. During teaching and learning sessions, it is essential for senior and novice lecturers to have a productive discussion about potential solutions. In addition, it is anticipated that there will be seminars for lecturers to familiarise themselves with NALI techniques prior to teaching.

iii) The difference between lecturers with and without professional engineer certification in teaching and learning approaches

A total of 134 questionnaires from students from various faculties were obtained. The results of the t-test for students in this study are displayed in **Table 3**. It is an analysis comparing the teaching practice of lecturers with and without professional certification, based on the perception of their students.

The table indicates that there is a statistically significant difference between lecturers with and without professional engineer certificate ($p < 0.01$). A smaller p value (0.01) represents a more significant impact (Zhu, 2016). It demonstrates that the teaching practices of lecturers with professional certification are different from those of lecturers without professional certification. As teaching experience is one of the prerequisites for joining the engineering faculties, lecturers with professional certification typically have a solid background in the field. It is stipulated in the Engineering Accreditation Council (EAC) agreement in Malaysia (Puzi et al., 2017). Therefore, lecturers with professional certification are required to familiarise themselves with and implement the suggested approaches for teaching.

Conclusion

This study provides a data analysis and thematic evaluation of the implementation of New Academia Learning Innovation (NALI) techniques in engineering faculties at Universiti Teknologi Malaysia (UTM) among lecturers with and without professional engineer certification. In accordance with the objective of this study, 171 studies covering four faculties namely the Faculty of Civil Engineering (FCE), the Faculty of Electrical Engineering (FEE), the Faculty of Mechanical Engineering (FME), and the Faculty of Chemical and Energy Engineering (FCEE)) were included in the data analysis and approximately five studies in the thematic analysis. Spearman's test of correlation reveals a positive correlation between professional engineer certification and NALI practise. A quarter of the twenty lecturers with professional certification participated in the interview. Five themes and fifty-seven subthemes were derived from the interview. This indicates that lecturers with professional engineer certification utilised at least one NALI technique in the classroom. This is confirmed by the t-test, which indicates that there is a substantial difference in teaching practice between lecturers with and without engineer certification.

Limitation: study carried out during the pandemic, where the experiences are based on the online teaching that may rise the difficulties in engineering teaching implementation. New study to observed the physical teaching must be carried out.

Table 3. T-test analysis among students in two groups

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper
B	Equal variances assumed	4.326	.038	-5.437	1740	.000	-.305	.056	-.415	-.195
	Equal variances not assumed			-5.399	752.744	.000	-.305	.057	-.416	-.194
C	Equal variances assumed	25.702	.000	-7.679	1606	.000	-.283	.037	-.355	-.210
	Equal variances not assumed			-8.367	829.526	.000	-.283	.034	-.349	-.216
D	Equal variances assumed	8.677	.003	-3.200	802	.001	-.243	.076	-.391	-.094
	Equal variances not assumed			-3.436	401.186	.001	-.243	.071	-.381	-.104

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Embracing Biodiversity: A Perspective on Transforming Engineering Education for Sustainable Innovation

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Abstract

In a rapidly changing world marked by escalating environmental challenges, the imperative to integrate biodiversity knowledge into engineering education has never been more pressing. This perspective paper aims to explore the transformative potential of integrating biodiversity principles and practices into engineering curricula. Drawing upon interdisciplinary insights from environmental science, ecology, and engineering education, this paper advocates for a paradigm shift in engineering pedagogy to foster sustainable innovation. Through a lens of collaboration, creativity, and ethical stewardship, this paper explores how embracing biodiversity can empower engineers to address complex 21st-century challenges while nurturing a deeper connection between human ingenuity and the natural world. By illuminating the pathways to integrating biodiversity into engineering education, this paper aims to inspire educators, researchers, and practitioners to embark on a journey toward a more sustainable future.

Keywords: biodiversity, sustainability, innovation, transformative, ethical stewardship.

Introduction

Currently, the globe is at a critical juncture, dealing with unparalleled environmental difficulties arising from climate change, habitat degradation, pollution, and the extinction of species (Zhang et al., 2022). The intertwining of engineering and biodiversity holds profound implications for the future of our planet (Folke et al., 2021; McCormack et al., 2016). As stewards of innovation and agents of change, engineers are uniquely positioned to confront the multifaceted environmental challenges of the 21st century. Yet, traditional engineering education often overlooks the intricate web of life upon which our existence depends. Incorporating biodiversity into engineering education offers a significant chance to prepare upcoming engineers with the essential information, skills, and mindset needed to address the challenges of the 21st century, while also promoting a stronger bond with the natural world.

Traditional engineering curricula have predominantly focused on technical skills and knowledge, emphasizing areas such as mathematics, physics, and discipline-specific engineering principles (Chung, 2011). These programs are structured to produce engineers capable of designing and implementing solutions to technical problems, often with a primary focus on efficiency, cost-effectiveness, and functionality (Paz-Penagos & Pérez-Tristancho, 2022). While these skills are essential, the conventional approach often neglects the broader ecological context in which engineering solutions are applied. In recent years, however, there has been a growing recognition of the need to incorporate sustainability and environmental considerations into engineering education (Wilson, 2019). Despite this shift, the integration of biodiversity specifically remains limited. Initiatives such as the CDIO (Conceive-Design-Implement-Operate) framework have started to incorporate sustainability concepts (Isa et al., 2019), but they often do not explicitly address biodiversity.

One notable effort is the incorporation of sustainable engineering principles, which include aspects of biodiversity, in some curricula. For instance, courses on ecological engineering and green infrastructure are becoming more common, aiming to teach students how to design systems that support natural processes and enhance biodiversity (Dover, 2015; Herzog, 2016). Despite these advancements, the inclusion of comprehensive biodiversity education across all engineering disciplines is still sporadic and lacks a standardized approach. Nevertheless, several universities and institutions have begun to pioneer the integration of biodiversity into engineering education. For example, the University of British Columbia offers a program in Environmental Engineering that includes courses on ecosystem health and biodiversity conservation (Brunetti et al., 2003; Lee-Wardell et al., 2019; The University of British Columbia, 2024).

Ibrahim, M.S.N., Miard, P., Abdullah, N.A., Julius, A. (2024), Embracing Biodiversity: A Perspective on Transforming Engineering Education for Sustainable Innovation, *ASEAN Journal of Engineering Education*, 8(1), 30-40.

Similarly, the Technical University of Denmark has developed courses that emphasize the importance of biodiversity in sustainable development projects (Technical University of Denmark, 2024).

In addition to these specific programs, emerging trends show a broader shift towards interdisciplinary approaches, combining engineering with ecology, biology, and environmental science. This holistic approach is reflected in projects like urban green spaces, where engineers work alongside ecologists to create habitats that support local wildlife while providing social and environmental benefits to urban populations (Ignatieva et al., 2011). By integrating biodiversity principles into engineering curricula, these programs are paving the way for a new generation of engineers who are not only technically proficient but also ecologically aware. This trend underscores the importance of continuing to evolve engineering education to meet the environmental challenges of the 21st century.

In this perspective paper, we advocate for a fundamental reimagining of engineering education—one that places biodiversity at its core. By embracing biodiversity as a guiding principle, we assert that engineering education can transcend its conventional boundaries, catalysing a paradigm shift toward sustainable innovation and ecological stewardship.

Overview of the Graduate Attributes and Professional Competencies

Based on the classifications provided by the International Engineering Alliance (IEA) in Table 1, engineering activities in educational programs encompass a variety of intricate, broadly defined, and clearly specified tasks. Table 2 also highlights that the Washington Accord, Sydney Accord, and Dublin Accord emphasize the knowledge and attitude profile among engineers through programs that provide a systematic, theory-based understanding of natural sciences relevant to the discipline, and awareness of relevant social sciences through WK1, SK1, and DK1.

Nevertheless, the classification largely prioritises the utilisation of natural resources without adequately considering biodiversity. Natural resources, referring to substances obtained from the environment for human utilisation, are separate from biodiversity, which comprises the diversity of life forms and ecosystems. The differentiation is crucial because biodiversity plays a fundamental role in providing necessary ecosystem services and promoting ecological resilience, which are becoming increasingly important for sustainable engineering solutions. The structure of the IEA may unintentionally neglect the significance of biodiversity in engineering education and professional skills, which could restrict the ability of graduates to effectively tackle urgent global environmental issues. By incorporating biodiversity directly into engineering curricula and competency frameworks, educational programmes can more effectively prepare future engineers to create comprehensive, sustainable solutions that harmonise technical advancement with environmental conservation.

Table 1. Range of engineering activities.

Attribute	Complex Activities	Broadly defined Activities	Well-defined Activities
Preamble	Complex activities mean (engineering) activities or projects that have some or all of the following characteristics:	Broadly defined activities mean (engineering) activities or projects that have some or all of the following characteristics:	Well-defined activities mean (engineering) activities or projects that have some or all of the following characteristics:
Range of resources	EA1: Involve the use of diverse resources including people, data and information, natural, financial and physical resources and appropriate technologies including analytical and/or design software	TA1: Involve a variety of resources including people, data and information, natural, financial and physical resources and appropriate technologies including analytical and/or design software	NA1: Involve a limited range of resources for example people, data and information, natural, financial and physical resources and/or appropriate technologies
Level of interactions	EA2: Require optimal resolution of interactions between wide-ranging and/or conflicting technical, non-technical, and engineering issues	TA2: Require the best possible resolution of occasional interactions between technical, non-technical, and engineering issues, of which few are conflicting	NA2: Require the best possible resolution of interactions between limited technical, non-technical, and engineering issues
Innovation	EA3: Involve creative use of engineering principles, innovative solutions for a conscious purpose, and research-based knowledge	TA3: Involve the use of new materials, techniques or processes in non-standard ways	NA3: Involve the use of existing materials techniques, or processes in modified or new ways
Consequences to society and the environment	EA4: Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	TA4: Have reasonably predictable consequences that are most important locally, but may extend more widely	NA4: Have predictable consequences with relatively limited and localized impact.

Familiarity	EA5: Can extend beyond previous experiences by applying principles-based approaches.	TA5: Require a knowledge of normal operating procedures and processes	NA5: Require a knowledge of practical procedures and practices for widely applied operations and processes

Source: International Engineering Alliance. (2021)

Table 2. Knowledge and attitude profile

A Washington Accord program provides:	A Sydney Accord program provides:	A Dublin Accord program provides:
WK1: A systematic, theory-based understanding of the **natural sciences** applicable to the discipline and awareness of relevant social sciences	SK1: A systematic, theory-based understanding of the **natural sciences** applicable to the sub-discipline and awareness of relevant social sciences	DK1: A descriptive, formula-based understanding of the **natural sciences** applicable in a sub-discipline and awareness of directly relevant social sciences
WK2: Conceptually based mathematics, numerical analysis, data analysis, statistics and formal aspects of computer and information science to support detailed analysis and modelling applicable to the discipline	SK2: Conceptually based mathematics, numerical analysis, data analysis, statistics and formal aspects of computer and information science to support detailed consideration and use of models applicable to the sub-discipline	DK2: Procedural mathematics, numerical analysis, statistics applicable in a subdiscipline
WK3: A systematic, theory-based formulation of engineering fundamentals required in the engineering discipline	SK3: A systematic, theory-based formulation of engineering fundamentals required in an accepted sub-discipline	DK3: A coherent procedural formulation of engineering fundamentals required in an accepted sub-discipline
WK4: Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline.	SK4: Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for an accepted sub-discipline	DK4: Engineering specialist knowledge that provides the body of knowledge for an accepted sub-discipline
WK5: Knowledge, including efficient resource use, environmental impacts, whole-life cost, re-use of resources, net zero carbon, and similar concepts, that supports engineering design and operations in a practice area	SK5: Knowledge, including efficient resource use, environmental impacts, whole-life cost, re-use of resources, net zero carbon, and similar concepts, that supports engineering design and operations using the technologies of a practice area	DK5: Knowledge that supports engineering design and operations based on the techniques and procedures of a practice area
WK6: Knowledge of engineering practice (technology) in the practice areas in the engineering discipline	SK6: Knowledge of engineering technologies applicable in the sub-discipline	DK6: Codified practical engineering knowledge in recognized practice area
WK7: Knowledge of the role of engineering in society and identified issues in engineering practice in the discipline, such as the professional responsibility of an engineer to public safety and sustainable development*	SK7 Knowledge of the role of technology in society and identified issues in applying engineering technology, such as public safety and sustainable development*	DK7: Knowledge of issues and approaches in engineering technician practice, such as public safety and sustainable development*
WK8: Engagement with selected knowledge in the current research literature of the discipline, awareness of the power of critical thinking and creative approaches to evaluate emerging issues	SK8: Engagement with the current technological literature of the discipline and awareness of the power of critical thinking	DK8: Engagement with the current technological literature of the practice area
WK9: Ethics, inclusive behaviour and conduct. Knowledge of professional ethics, responsibilities, and norms of engineering practice. Awareness of the need for diversity by reason of ethnicity, gender, age, physical ability etc. with mutual understanding and respect, and of inclusive attitudes	SK9: Ethics, inclusive behaviour and conduct. Knowledge of professional ethics, responsibilities, and norms of engineering practice. Awareness of the need for diversity by reason of ethnicity, gender, age, physical ability etc. with mutual understanding and respect, and of inclusive attitudes	DK9: Ethics, inclusive behaviour and conduct. Knowledge of professional ethics, responsibilities, and norms of engineering practice. Awareness of the need for diversity by reason of ethnicity, gender, age, physical ability etc. with mutual understanding and respect, and of inclusive attitudes

*Represented by the 17 UN Sustainable Development Goals (UN-SDG)

Source: International Engineering Alliance. (2021)

Embracing Biodiversity: A Catalyst for Transformation

Collaborative Learning Ecosystems

Breaking down disciplinary silos and fostering interdisciplinary collaboration are essential for integrating biodiversity into engineering education (Walcutt & Schatz, 2019), aligning with the principles of the Washington Accord, Sydney Accord, and Dublin Accord. These agreements, established by the International Engineering Alliance (IEA), emphasize the importance of equipping engineering graduates with holistic competencies that encompass natural sciences and sustainable practices (International Engineering Alliance, 2021).

Traditional educational structures often compartmentalize knowledge within disciplinary boundaries, hindering interdisciplinary collaboration (McNair et al., 2011). By cultivating collaborative learning ecosystems, educators can facilitate interactions between students, faculty, and professionals from diverse backgrounds, as advocated by the Sydney Accord and Dublin Accord (International Engineering Alliance., 2021). For instance, collaborative projects integrating engineers, biologists, and ecologists offer students opportunities to gain insights from multiple perspectives and apply interdisciplinary approaches to real-world challenges.

Integrating biodiversity into engineering education requires overcoming challenges such as curriculum design and resource allocation, issues recognized by the Washington Accord. This integration is crucial for addressing complex sustainability challenges posed by Industry 4.0, where digitalization and automation intersect with environmental concerns. Collaborative learning ecosystems provide platforms for engineers to collaborate with biologists, policymakers, and other stakeholders, co-creating innovative solutions that prioritize biodiversity conservation amidst technological advancements (Xiaolu, 2023). While interdisciplinary collaboration is essential, it necessitates navigating power dynamics and recognizing diverse knowledge systems. Effective collaboration, according to Wei et al. (2022), requires fostering a culture of openness and mutual learning, aligning with the IEA's emphasis on ethical stewardship and responsible innovation (IEA, n.d.). Furthermore, incentivizing interdisciplinary research within academia is vital, challenging existing reward structures that favour disciplinary excellence over collaborative efforts.

According to the International Engineering Alliance (IEA) classifications in Table 1, engineering activities in educational programmes should include a range of complex, widely defined, and explicitly characterised tasks. For example, courses like "Ecological Engineering in Urban Systems," which were created collaboratively by engineering and biodiversity specialists at University X, and "Biodiversity Conservation and Engineering Solutions," which are taught by interdisciplinary teams at University Y, demonstrate how biodiversity principles are incorporated into engineering curricula. These principles include studying insects for ecosystem health, using forensic analysis in conservation efforts, evaluating species richness, and understanding ecosystem dynamics and habitat management. These courses prioritise a structured, theory-driven comprehension of natural sciences that are applicable to engineering fields. They also promote an understanding of social sciences through WK1, SK1, and DK1, in accordance with the Washington Accord, Sydney Accord, and Dublin Accord. By incorporating the expertise of both engineering and biodiversity specialists in the development and implementation of courses, educational institutions enhance students' learning experiences and equip them to tackle current global challenges using inventive and environmentally friendly engineering solutions that consider the intricacies of biodiversity.

Cultivating Creativity through Biomimicry

Nature serves as a profound source of inspiration for innovation (Pathak, 2019), exemplified by biomimicry—an approach advocated by the Washington Accord and Sydney Accord. Biomimicry involves emulating nature's solutions to engineering challenges, promoting creativity and problem-solving skills among students (Bidwell & Smirnoff, 2022; International Engineering Alliance., 2021). By encouraging students to draw inspiration from the natural world, educators can unlock a treasure trove of sustainable design solutions.

Biomimicry taps into nature's vast reservoir of evolutionary solutions honed over millions of years of adaptation. By studying biological systems, students can gain insights into innovative design strategies that have already been tested and refined by nature (Vázquez-Villegas et al., 2024). This approach not only provides practical solutions to engineering challenges but also fosters a deeper appreciation for the complexity and resilience of natural ecosystems. While biomimicry offers valuable inspiration for engineering design, it's essential to recognize the limitations of directly translating biological principles into human-made technologies. Biological systems operate within specific ecological contexts and constraints, which may not always align with human needs or technological feasibility. Moreover, the ethical implications of mimicking nature should be carefully considered, particularly regarding issues of biodiversity conservation, animal welfare, and cultural appropriation.

Biomimicry inherently bridges the gap between biology and engineering, promoting cross-disciplinary learning and collaboration. By engaging with concepts from biology, ecology, and materials science, students develop a holistic understanding of how natural systems function and evolve. This interdisciplinary approach encourages students to think outside traditional disciplinary boundaries and draw upon diverse sources of knowledge to solve complex problems. While cross-disciplinary learning is valuable, it may also pose challenges related to curriculum integration and faculty expertise. Engineering programs often have rigid course requirements and limited flexibility for incorporating interdisciplinary content (Hitt et al., 2020). Moreover, faculty members may lack training or experience in biomimicry, making it challenging to teach effectively. Addressing these challenges requires institutional support for curriculum development, faculty training, and interdisciplinary collaboration. Educators play a crucial role in guiding students to critically evaluate the ecological and social consequences of biomimetic technologies, aligning with the IEA's commitment to ethical stewardship in engineering education (International Engineering Alliance., 2021).

Biomimicry fosters creativity and innovation by challenging students to think critically and creatively about engineering problems (Bidwell & Smirnoff, 2022). By encouraging students to observe, analyse, and emulate natural systems, educators can cultivate a mindset of curiosity, experimentation, and iterative design. Biomimetic solutions often require unconventional thinking and lateral problem-solving, providing students with valuable skills for addressing real-world challenges (Ersanlı & Ersanlı, 2023). While biomimicry can enhance students' problem-solving skills, it's important to balance creativity with practicality and feasibility. Not all biological solutions are suitable or scalable for human-made technologies, and students must learn to evaluate the viability and sustainability of biomimetic designs. Moreover, biomimicry should be complemented by a strong foundation in engineering principles and design methodologies to ensure that students develop robust and effective solutions.

According to Dicks (2023), biomimicry raises ethical questions about the appropriation of nature's designs and the potential impact on ecosystems and biodiversity. Educators must emphasize the importance of ethical stewardship and responsible innovation in biomimetic design. This includes considering the ecological and social consequences of biomimetic technologies, as well as engaging stakeholders in ethical discussions and decision-making processes. While biomimicry holds promise for sustainable innovation, it is essential to critically evaluate its ethical implications and potential unintended consequences. Biomimetic technologies must be developed and deployed in ways that prioritize environmental integrity, social equity, and cultural sensitivity (Fletcher et al., 2024). Educators play a crucial role in fostering ethical awareness and guiding students to consider the broader implications of their design choices.

In conclusion, biomimicry offers a powerful framework for cultivating creativity and problem-solving skills among engineering students. However, it's essential to approach biomimicry with a critical lens, considering its limitations, ethical implications, and the need for interdisciplinary collaboration. By integrating biomimicry into engineering education thoughtfully and responsibly, educators can inspire the next generation of innovators to harness the wisdom of nature in building a more sustainable and resilient future.

Ethical Stewardship and Social Responsibility

At the heart of biodiversity conservation lies a commitment to ethical stewardship and social responsibility. Engineering education must instil in students a deep sense of ethical awareness and a reverence for the interconnectedness of all life forms. By integrating ethical considerations into engineering curricula, educators can empower students to become responsible custodians of the planet.

Ethical stewardship involves recognizing the moral implications of engineering decisions and taking responsibility for their social and environmental consequences (Kelly, 2008; Tarnai-Lokhorst, 2019). Engineering students must develop a strong ethical foundation that guides their professional conduct and decision-making processes. This includes understanding the ethical principles of beneficence, non-maleficence, justice, and respect for autonomy, as well as considering the long-term impacts of their actions on ecosystems, communities, and future generations. While ethical awareness is essential, it can be challenging to instil in students, particularly within the context of traditional engineering education. Engineering curricula often prioritize technical skills and knowledge over ethical considerations, leading students to overlook or undervalue the ethical dimensions of their work. Moreover, ethical dilemmas in engineering are often complex and context-dependent, requiring students to navigate conflicting values and priorities (Gunckel & Tolbert, 2018; Lönngren et al., 2017). Addressing these challenges requires integrating ethics education into engineering curricula in a meaningful and engaging way, rather than treating it as an optional or peripheral component.

Ethical stewardship entails recognizing the intrinsic value of biodiversity and respecting the rights of non-human beings (Bieling et al., 2020). Engineering students should develop a deep appreciation for the beauty, diversity, and complexity of the natural world, as well as an understanding of humanity's interconnectedness with other species. This ecological perspective encourages students to consider the impacts of their actions on ecosystems and biodiversity, and to prioritize conservation and sustainability in their engineering practices. While promoting reverence for nature is commendable, it can sometimes perpetuate anthropocentric attitudes that prioritize human interests over the intrinsic value of non-human beings and ecosystems. Engineering education must challenge students to critically examine their anthropocentric biases and develop a more inclusive and ecocentric worldview that recognizes the inherent worth of all life forms. Moreover, fostering reverence for nature should not justify paternalistic or conservationist approaches that prioritize preserving nature for human use and enjoyment, rather than respecting nature's autonomy and integrity.

Social responsibility extends beyond environmental conservation to encompass considerations of equity, justice, and human well-being (Ibrahim et al., 2021, 2023; Žižek et al., 2021). Engineering students must recognize their role as agents of social change and advocate for solutions that promote social equity, diversity, and inclusion (Rodriguez et al., 2021). This includes addressing environmental injustices, supporting marginalized communities, and engaging stakeholders in decision-making processes to ensure that engineering solutions meet the needs of all members of society. While social responsibility is integral to ethical engineering practice, it can sometimes be overshadowed by a narrow focus on technical expertise and economic efficiency. Engineering education must broaden its scope to include social and cultural dimensions, empowering students to critically examine the societal impacts of their work and advocate for socially just and equitable solutions. Moreover, addressing social responsibility requires confronting systemic inequalities and power structures within engineering institutions and industries, which may be resistant to change.

The ethical stewardship and social responsibility are essential principles that should be integrated into engineering education to promote biodiversity conservation and sustainability. However, realizing these principles requires overcoming challenges related to curriculum design, institutional culture, and societal values. By critically examining these challenges and fostering a culture of ethical awareness and social responsibility, engineering educators can empower students to become responsible custodians of the planet and advocates for a more just and sustainable future.

Catalysing Transformative Innovation

The integration of biodiversity knowledge into engineering education has the potential to catalyse transformative innovation across a range of sectors (Zambrano-Gutiérrez & Puppim de Oliveira, 2022). From sustainable infrastructure development to ecological restoration projects, engineers equipped with a deep understanding of biodiversity can pioneer novel solutions that harmonize human needs with the natural world.

Biodiversity is a source of inspiration for innovative engineering solutions (Broeckhoven & du Plessis, 2022; Topaz, 2016). By understanding and emulating nature's designs and processes, engineers can develop novel technologies and approaches that are more sustainable, resilient, and biodiverse-friendly (Bianciardi & Cascini, 2023). For example, biomimetic design principles can lead to the development of materials that are stronger, lighter, and more energy-efficient, drawing inspiration from structures found in nature such as spider silk or lotus leaves. While biomimicry holds promise for innovation, it is important to recognize that not all biomimetic solutions are feasible or practical in human-made contexts. Nature operates within specific ecological constraints and trade-offs that may not translate directly to engineering applications. Moreover, biomimetic technologies must be rigorously tested for safety, reliability, and scalability before being implemented at scale. Blindly mimicking nature without considering the broader social, economic, and ethical implications can lead to unintended consequences and reinforce anthropocentric biases.

Integrating biodiversity into engineering education can promote sustainable development by fostering a holistic understanding of ecological systems and their interconnectedness with human societies. Engineers equipped with biodiversity knowledge can design infrastructure and technologies that minimize environmental impact, conserve biodiversity, and enhance ecosystem services (White et al., 2021). For example, green infrastructure projects such as green roofs, rain gardens, and permeable pavements can mitigate urban runoff, reduce flooding, and improve water quality while providing habitat for wildlife. While promoting sustainable development is a laudable goal, it requires addressing systemic barriers and incentives that prioritize short-term economic gains over long-term environmental and social sustainability. Engineering education must challenge prevailing paradigms of growth and consumption and promote alternative models of development that prioritize equity, resilience, and well-being. Moreover, sustainable solutions must be context-specific and culturally appropriate, taking into account the diverse needs and aspirations of different communities and stakeholders.

Biodiversity knowledge can inform ecological restoration projects aimed at rehabilitating degraded ecosystems and conserving endangered species (Haq et al., 2023). Engineers can play a crucial role in designing and implementing restoration strategies that enhance habitat connectivity, restore hydrological processes, and reintroduce native species. By restoring ecosystem health and function, these projects can provide multiple benefits, including carbon sequestration, flood mitigation, and recreation opportunities (Di Sacco et al., 2021). While ecological restoration is essential for biodiversity conservation, it must be approached with caution and humility, recognizing the inherent complexity and uncertainty of ecological systems. Restoration projects can have unintended consequences (Taguchi et al., 2020), such as introducing invasive species or disrupting existing ecological processes. Moreover, restoration efforts must engage local communities and indigenous peoples as partners and stewards of the land, respecting their traditional knowledge and rights. Failure to do so can perpetuate colonial legacies of exploitation and marginalization.

Catalysing transformative innovation through the integration of biodiversity knowledge into engineering education holds immense promise for addressing pressing environmental challenges and promoting sustainable development. However, realizing this potential requires addressing critical gaps and challenges related to feasibility, scalability, social equity, and cultural sensitivity. By critically examining these issues and fostering a culture of interdisciplinary collaboration and ethical stewardship, engineering educators can empower students to become agents of positive change in building a more sustainable and biodiverse-friendly future.

Integrating Biodiversity Knowledge Across Engineering Disciplines

Integrating biodiversity knowledge across engineering disciplines can significantly enhance students' ability to address environmental challenges through interdisciplinary approaches. In civil engineering, incorporating sustainable urban planning and ecological engineering principles can help students understand the importance of green infrastructure and urban green spaces. For instance, courses could include projects where students design city parks using native plant species to support local wildlife or restore degraded wetland areas to improve water quality and provide habitats (Fang et al., 2023). Moreover, training in environmental impact assessments (EIAs) with a strong focus on biodiversity would enable students to assess construction projects' potential impacts on local ecosystems and develop effective mitigation strategies.

Chemical engineering can integrate biodiversity knowledge through green chemistry and sustainable bioprocessing, emphasizing processes that minimize environmental harm (Jiménez-González & Constable, 2011). Environmental biotechnology courses could teach students about using biological processes for environmental remediation, such as designing bioreactors to degrade pollutants in industrial wastewater. Moreover, focusing on sustainable resource management would highlight the importance of conserving biodiversity in the sourcing and processing of raw materials, encouraging students to analyze the life cycle of chemical products for biodiversity impacts.

Electrical engineering can contribute by emphasizing renewable energy systems' role in conserving biodiversity by reducing habitat destruction associated with fossil fuel extraction (Nazir et al., 2020). Courses could explore smart grid technologies that mitigate electrical infrastructure's impact on wildlife, such as developing bird-safe designs for power lines and substations (Hastik et al., 2015). Additionally, teaching sensor technology's applications in biodiversity conservation, like monitoring wildlife populations, can prepare students to support environmental protection efforts.

Mechanical engineering can integrate biodiversity knowledge by teaching eco-design principles and lifecycle assessments that consider biodiversity impacts (Fernandes et al., 2020). Sustainable manufacturing methods that reduce emissions, waste, and energy consumption can be incorporated into the curriculum. For example, students could develop manufacturing processes for automotive parts using recycled materials to minimize waste. Furthermore, biomechanics and bioinspired design courses can inspire students to create engineering solutions based on biological systems, such as designing robotic systems that mimic animal movements to navigate complex environments (Manoonpong et al., 2021).

Implementing these changes requires interdisciplinary courses and projects, collaborations with biology departments, field studies, and real-world applications to give students hands-on experience. Guest lectures and workshops by biodiversity and conservation experts can further enhance the curriculum. By integrating biodiversity knowledge into civil, chemical, electrical, and mechanical engineering curricula, educational institutions can prepare engineers capable of creating sustainable solutions that protect and enhance the natural environment.

In the context of engineering education, the graduate attribute profiles for different types of engineering graduates—Engineer, Engineering Technology graduate, and Engineering Technician—highlight distinct competencies related to natural science (in Table 1). Engineer graduates are equipped to apply a comprehensive understanding of mathematics, natural science, computing, and engineering fundamentals, leveraging specialized knowledge to tackle intricate engineering challenges. Their training emphasizes the integration of multidisciplinary principles, including sustainable development considerations, aligning with accreditation standards such as those set by ABET (2021). Conversely, Engineering Technology graduates focus on applying foundational knowledge of mathematics, natural science, and engineering fundamentals to execute defined engineering procedures and employ appropriate analytical tools suited to their field of specialization. This aligns with educational frameworks which include Framework for P-12 Engineering Learning which emphasizing applied skills and practical problem-solving capabilities, as articulated by American Society for Engineering Education (2020). Engineering Technician graduates, on the other hand, demonstrate proficiency in applying mathematical and scientific principles alongside engineering fundamentals to execute specific technical procedures and practices. Their training underscores the application of codified methods within their specialized field, reflecting a strong emphasis on practical execution and technical expertise (National Science Board, 2019). However, in the context of problem analysis, it is evident that engineering technologists and technicians may lack the depth of natural science elements compared to engineering graduates.

Therefore, this suggests that engineering graduates have a more extensive and profound theoretical knowledge in natural science, which allows them to effectively analyse and create intricate problems. Their education equips them to tackle complex engineering difficulties that demand a sophisticated level of conceptualization and the integration of several scientific principles. Conversely, engineering technologists and technicians prioritize the hands-on implementation of established methods and protocols. Although they excel in implementing and optimizing solutions in their field, they may lack the necessary skills to innovate or create new approaches that require extensive scientific knowledge. This distinction emphasizes the specific responsibilities that each type of engineering professional has in the industry, emphasizing the significance of having a diverse workforce that utilizes the individual strengths of engineers, technologists, and technicians to create comprehensive and efficient engineering solutions.

Based on the classifications provided by the International Engineering Alliance (IEA) in Table 3, engineering activities within educational programs involve a variety of intricate, broadly outlined, and clearly defined jobs. Nevertheless, the classification mainly prioritizes the utilization of natural resources while neglecting to adequately account for biodiversity. Natural resources refer to elements obtained from the environment for human utilization, whereas biodiversity comprises the diversity of life forms and ecosystems. The differentiation is crucial because biodiversity plays a crucial role in providing critical ecosystem services and bolstering ecological resilience, both of which are becoming increasingly important for sustainable engineering solutions. The structure of the IEA may unintentionally disregard the significance of biodiversity in engineering education and professional skills, which could potentially restrict the ability of graduates to effectively tackle urgent global environmental issues. Integrating biodiversity into engineering curriculum and competence frameworks can enhance educational programs by equipping future engineers with the skills to create sustainable solutions that combine technology innovation with environmental stewardship.

Conclusion and recommendations

To summarize, this perspective paper emphasizes the immediate necessity for a fundamental change in engineering education that incorporates biodiversity concepts. While sustainability elements are already implemented in engineering education, biodiversity education remains insufficiently addressed. Specifically, this change involves revising curricula to include biodiversity as a core component and integrating it into existing courses. The teaching methods illustrated in Figure 1, such as problem-based learning, field-based learning, project-based learning, and case studies, represent innovative approaches for integrating biodiversity into engineering education.

Table 3. Graduate attribute profile related to natural science.

Differentiating characteristics	Engineer graduate	Engineering technology graduate	Engineering technician graduate
Engineering Knowledge	Apply knowledge of mathematics, **natural science**, computing and engineering fundamentals, and an engineering specialization as specified in WK1 to WK4 respectively to develop solutions to complex engineering problems.	Apply knowledge of mathematics, **natural science**, computing and engineering fundamentals and an engineering specialization as specified in SK1 to SK4 respectively to defined and applied engineering procedures processes, systems or methodologies.	Apply knowledge of mathematics, **natural science**, engineering fundamentals and an engineering specialization as specified in DK1 to DK4 respectively to wide practical procedures and practices.
Problem analysis	Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, **natural sciences** and engineering sciences with holistic considerations for sustainable development*	Identify, formulate, research literature and analyze broadly defined engineering problems reaching substantiated conclusions using analytical tools appropriate to the discipline or area of specialisation	Identify and analyze well-defined engineering problems reaching substantiated conclusions using codified methods of analysis specific to their field of activity.

Source: International Engineering Alliance. (2021)

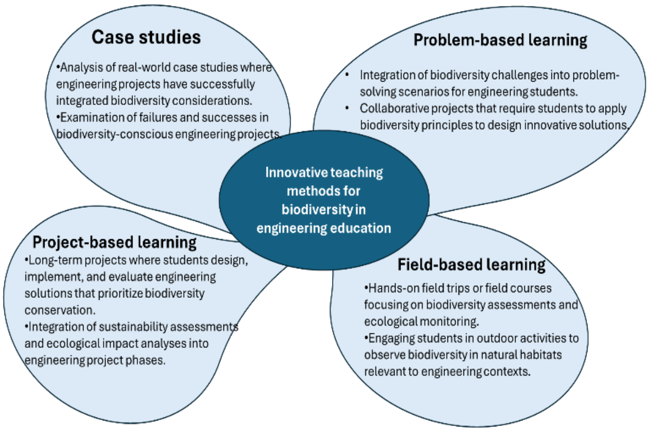

Figure 1. Innovative teaching methods for biodiversity in engineering education

We have seen that including biodiversity into engineering education can empower future engineers to address the unprecedented environmental challenges that our world is presently confronting. By embracing biodiversity, engineers will be able to take the lead in making innovative advancements. They will design transformative inventions that meet human needs while also showing respect and harmony with the natural environment. The significance of collaborative learning environments in breaking down disciplinary barriers and fostering interdisciplinary collaboration has been a central focus of our discussion. Engineers may effectively tackle intricate problems by establishing collaborative environments that bring together engineering students with peers from environmental sciences (e.g. entomology, conservation biology, ecology, wildlife, herpetofauna, etc.) and other disciplines. This allows engineers to benefit from other perspectives and collectively develop groundbreaking solutions.

Furthermore, biomimicry is acknowledged as a powerful framework for cultivating creativity and problem-solving skills in engineering students. In order to successfully include biomimicry into engineering education, it is necessary to incorporate dedicated courses that focus on the principles of biomimicry, project-based learning modules that entail practical applications in real-world scenarios and establish collaborations with industries and organizations that actively engage in biomimicry practices. Engineers can develop sustainable technology by replicating natural processes and deriving inspiration from the designs seen in nature. This technique enhances both resilience and biodiversity conservation.

Engineering education should include ethical stewardship and social responsibility as fundamental principles. Through the incorporation of ethics courses that specifically address sustainability and social fairness, educators can cultivate conscientious engineers who prioritize these principles in their professional endeavours. Incorporating biodiversity knowledge into engineering education has the capacity to inspire revolutionary innovation for a future that is both environmentally sustainable and conducive to biodiversity. By embracing this shift and encouraging collaboration, ingenuity, and principled guidance, we can prepare the next generation of engineers to serve as agents for constructive change in safeguarding the future of our planet. This requires not only recognizing the significance of biodiversity but also actively reorganizing educational structures to properly support and implement these modifications.

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A Comparative Study of Approaches in the Engineering Education System in Malaysia, Singapore, and Finland

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Abstract

This review compares engineering education in Malaysia, Singapore, and Finland, exploring their unique approaches. The purpose of this paper is to discuss, examine, and compare how the learning structure, teaching methods, and challenges in the engineering education system in three selected countries. In Malaysia, the curriculum involves pre-university education and internships, tailored to meet industry requirements. This paper also examines holistic education initiatives of two high-performing education systems—Finland and Singapore. Finland and Singapore are two nations enjoying enviable rankings in international testing benchmarks for academic subjects at all levels. Singapore emphasizes STEM education and a student-centred curriculum. Meanwhile, Finland distinguishes itself with innovative, student-focused learning, promoting collaboration and problem-solving. Teaching methods in Malaysia involve discussion, inquiry, and emerging tech like Augmented Reality. Singapore focuses on STEM, student-centred learning, and 21st-century skills. Finland prioritizes personalized, problem-based learning and collaborative projects. While each country has its strengths, challenges persist. Malaysia aims for a dynamic curriculum, facing issues like teacher competency. Singapore needs a more tech-driven system and industry-academia collaboration. Finland addresses globalization, teacher attraction, and funding for educational improvements. Overall, the study presents the outcome that can help to understand learning structure, teaching methods, and challenges in the engineering education system in Malaysia, Singapore, and Finland.

Keywords: engineering, methods, education, challenges, learning structures.

Introduction

The importance of engineering education cannot be overemphasized in today's rapidly changing technological world. This extensive review examines and compares the engineering education systems of three different countries: Malaysia, Singapore, and Finland. Finland and Singapore are two nations enjoying enviable rankings in international testing benchmarks for academic subjects at all levels (Lidé, S., & Cheong, S. K., 2010).

Malaysia, a fast-expanding country, has achieved considerable advances in engineering education to suit the needs of its burgeoning industry. Singapore, renowned for its strong educational system and technical competence, provides a distinct combination of academic and practical engineering education (C. Lek & C. Kwan, 2017). Finland, on the other hand, is known for its creative and student-centred approach to education, which offers a distinct viewpoint on engineering education (Anne et al., 2010). Each of these countries, with their own socioeconomic, cultural, and historical backgrounds, takes a particular approach to engineering education. The article will analyse these systems, throwing light on their learning structure, methodologies, and challenges in education.

The comparison is not limited to surface-level examination. We look in depth at each country's curriculum, instructional methodologies, industry-academia collaboration, and the balance of academic knowledge and practical abilities. Furthermore, we look at how each country's particular difficulties and possibilities have influenced its approach to engineering education.

This detailed research is not only a great resource for educators, students, and politicians, but it also initiates a discussion about the future of engineering education. It encourages readers to think about these various systems and evaluate what features can be useful in their own circumstances. There are 3 main sections that will be discussed in this journal as in Figure 1.

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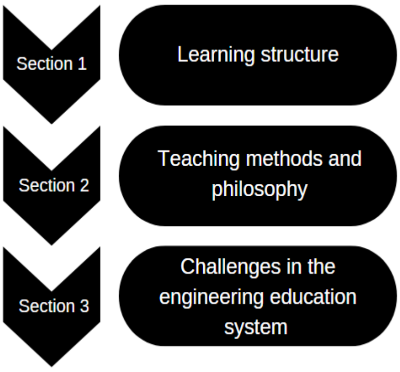

Figure 1. Three main sections

Learning Structure

Malaysia

In Malaysia, engineering programs are offered at both the undergraduate and postgraduate levels. Before entering university, students must complete pre-university programs such as the Malaysian Higher School Certificate (STPM), Matriculation, A-levels, or any other comparable certification. These pre-university programs serve as a foundation for students to acquire the necessary knowledge and skills required for engineering studies. Upon completion of the pre-university program, students must proceed to the undergraduate program. Students can choose to pursue a bachelor's degree in engineering at various universities in Malaysia. These programs typically take four years to complete and cover a wide range of engineering disciplines, such as civil, mechanical, electrical, and chemical engineering. Additionally, some universities also offer specialized engineering programs like aerospace or biomedical engineering. One requirement for the students to graduate is that they must do an internship or industrial training to gain practical experience in their chosen field. The first local university in Malaysia to offer engineering degree programs is Universiti Malaya (Megat Mohd Noor et al., 1999). There are a few attributes that the Board of Engineers Malaysia (BEM) considers necessary in preparing for contemporary engineering practice, which is the ability to apply mathematics, science, and engineering science in solving engineering tasks, the ability to understand environmental, economic, and community impacts on development, and the ability to communicate effectively and ethically in discharging duties (Megat Mohd Noor et al., 2002). After earning a bachelor's degree, students can continue their education with a master's degree in engineering, which typically takes one to two years. A Ph.D. in engineering is an option for those who are interested in research and academia.

Singapore

In Singapore, there are various levels of study forengineering in Singapore. One of which is pre-university education, undergraduate education, internship, and post-graduate education. Before attending university, students in Singapore frequently do an engineering programme. Taking GCE Advanced Level (A-level) examinations or pursuing other similar credentials such as the International Baccalaureate (IB) certificate are common examples. Nanyang Technological University (NTU) is one of Singapore's top institutions for engineering education and research (C. Lek & C. Kwan, 2017). NTU's College of Engineering is made up of six internationally recognised engineering schools, each with its area of expertise. The engineering schools are focused on technology and innovation, and all six are routinely ranked among the best colleges in the world. Internships are frequently included in engineering programmes to expose students to real-world engineering practices. This industry cooperation allows students to apply classroom information in a professional context and learn vital practical skills. All Nanyang engineering undergraduates in their third year of study participate in 24 weeks of attachment in industry, either in Singapore or overseas (Lee, 2005). Postgraduate education is available, including master's and Ph.D. programmes in the engineering profession. Postgraduate studies may entail more specialized research and in-depth study of certain areas. For example, National University of Singapore (NUS) offers Master of Science (M.Sc.) and Master of Engineering (M.Eng.) programs in various engineering disciplines, such as Electrical and Computer Engineering, Chemical Engineering, and Mechanical Engineering.

Finland

In Finland, the history of formal engineering education dates back approximately 150 years, while the profession itself has over 200 years of history. The first Finnish engineers were men of practice, trained by the apprenticeship system, and used the title The Factory Master. Germany's system is the model for Finland's higher education system. There are two recognized categories of education: universities and Ammattikorkeakoulus, which translates to "Vocational College" but is also sometimes called "University of Applied Sciences" (Tulkki, 1999). In Finland, children start their education in a voluntary preschool program, provided up to age six through neighborhood centers called "päiväkoti." Following that, students must attend a nine-year comprehensive school (peruskoulu) for compulsory education from the age of seven to sixteen. Following this, students have the option of applying to a vocational school, senior secondary school (Lukio), or directly entering the workforce.

Students attending senior secondary school often prepare for higher education in ammattikorkeakoulu (AMK), or polytechnic, or a yliopisto, or university. The bilingualism between Finland and Sweden is preserved, and students are required to speak both Finnish and Swedish. Many also study English. All education in Finland is cost-free, including lower school supplies. In higher education, students pay minimal fees, and receive government-guaranteed study loans, housing allowances, and financial grants. Finland's universities grant only the equivalent of Master's and Doctorate engineering degrees. Only the AMKs offer bachelor's degree programs, with typical programs requiring 160 credit units (CU) of study (King, 1999).

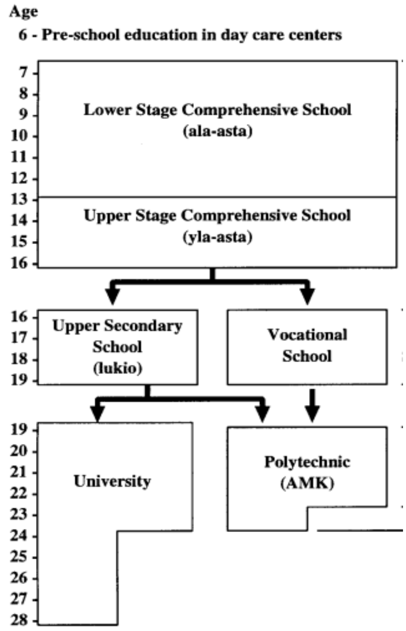

Figure 2. The Finnish Education System (King, 1999)

For four years, the students average 25 hours per week of classroom study with a lecturer. The university master's degree program requires 185 CUs or involves five years of 25 hours per week of classroom work. In the case of an engineer, fundamental studies consist of approximately 17 courses, encompassing three courses each in calculus and physics, four courses in a foreign language, and additional coursework in statistics, economics, and information technology (King, 1999). Practical experience, known as work placement, is a mandatory part of the program and typically spans four to six months of full-time work at a Finnish or international company. This practical work experience is generally undertaken after around two and a half years of study.

Teaching Methods and Philosophy

Malaysia

The teaching and learning methods used by engineering educators in Malaysia are discussion, inquiry, remembering, and imitating (Yunos et al., 2020). In alignment with the Malaysia Education Blueprint 2013-2025, enhancing to achieve the transformative goals outlined in the education blueprint and most modern engineering education combines traditional in-person classes with online learning (Low et al., 2021). A teaching method known as Problem-Based Learning (PBL) started gaining more recognition. The fundamental concept of PBL revolves around the notion that learning occurs through the exploration of solutions to real-world problems, instead of theoretical problems in the classroom (Wangel, 2021).

Table 1. Comparison between Malaysia, Singapore and Finland in learning structure.

Aspect	MALAYSIA	SINGAPORE	FINLAND
Pre-university	Malaysian Higher School Certificate (STPM), Matriculation, A- levels or equivalent.	GCE Advanced Level (A-level) examinations or International Baccalaureate (IB) certificate.	9 years comprehensive school (peruskoulu). Then, vocational school, senior secondary school (Lukio) or entering the workforce.
Duration of bachelor's degree	4 years to complete	usually around four years for a bachelor's degree	programs at Ammattikorkeakoulus (polytechnics) typically require four years
Duration of internship	usually 10 weeks-6 months	24 weeks of industry attachment in the third year of undergraduate study.	typically spans four to six months after around two and a half years of study
Credit hours of engineering course	140-150 credit units	160 credit units to fulfill the graduation requirements	160 credit units (CU) of study

Teaching Methods and Philosophy

Malaysia

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The teaching and learning methods used by engineering educators in Malaysia are discussion, inquiry, remembering, and imitation (Yunos et al., 2020). STEM approach refers to an educational method that combines the knowledge, skills, and values of Science, Technology, Engineering, and Mathematics to address challenges related to everyday life, community, and environment (Shahali et al., 2017). In the context of teaching and learning, STEM knowledge refers to the incorporation of ideas, concepts, principles, theories, and understanding within the STEM field that is integrated into the curriculum of all STEM subjects. The designed and developed curriculum strives to provide students with knowledge, skills, and values through activities facilitated by teachers, whether conducted inside or outside the classroom setting (Bahrum et al., 2017).

Engineering education specifically involves the use of laboratory equipment and apparatus which needs safety protocol and significant financial investment. The recent global pandemic has also impacted the instructional and learning aspects of engineering education as all classes and laboratory sessions are being conducted through online distance learning (ODL) methods (Enzai et al., 2021). Augmented Reality (AR) learning method is introduced. A well-planned AR is expected to improve the learning process, especially for science and engineering subjects as they involve substantial amounts of equipment and apparatus (Enzai et al., 2021).

Singapore

Singapore Teaching Practice (STP) is a foundational component of Singapore engineering courses' teaching techniques and philosophy. It is a paradigm that sets out a clear foundation for good teaching and learning in Singaporean schools (Ministry of Education, 2022). The STP is based on the concept that teaching is a profession that requires an in-depth understanding of how students learn and how teachers may promote this learning successfully (Ministry of Education, 2022). It reflects the collective expertise of Singapore's educators, acquired over years of practice and research.

The emphasis on STEM education is an important part of Singapore's engineering schools' teaching techniques and philosophy. STEM, which stands for Science, Technology, Engineering, and Mathematics, is a multidisciplinary subject in which students learn about all these topics in one course (Teo & Choy, 2021). STEM education's idea is to teach skills and subjects in ways that are relevant to real-world problems (Teo & Choy, 2021). This approach to education is growing into an integrated curriculum designed to prepare students for the problems of the 21st century.

The Singapore Curriculum Philosophy also influences the teaching techniques and philosophy in engineering courses. This ideology reflects the teaching fraternity's essential principles about learning, placing each student at the center of educational decisions (Ministry of Education, 2022). These ideas influence curriculum design and execution, ensuring that it is student-centred and promotes successful learning.

These principles drive the teaching techniques and philosophy of engineering courses in Singapore. The goal is to train students to be creative and inventive problem solvers, researchers, engineers, and designers (Rajandiran, 2020). This strategy guarantees that students are well-prepared to face real-world challenges and make valuable contributions to the profession of engineering. In addition to these, Singapore's Ministry of Education has identified specific 21st-century capabilities that the STEM education strategy addresses (Ministry of Education, 2023). These include critical thinking, creative thinking, communication, cooperation, and informational abilities (Ministry of Education, 2023). STEM education not only prepares kids for their future vocations but also promotes in them a love of learning.

Finally, the methods of instruction and philosophy used in Singapore engineering courses are intended to give students with a thorough, real-world practical, and interesting educational experience. They want to provide students with the skills and information they need to succeed in their future employment and contribute to the growth of engineering. This comprehensive approach to education guarantees that students are not only academically competent but also have the abilities required to negotiate the complexity of the real world. It demonstrates Singapore's commitment to developing a future-ready generation of engineers.

The most widely recognized and promoted teaching philosophy in Singapore vocational education is the student-centred teaching concept. This teaching concept focuses on the development of students' personalities, the cultivation of self-learning ability, and the embodiment of the learning effect. It is found that students take an active role in the learning process rather than being passive recipients of information from teachers (Ding, L. 2023).

Finland

Finnish engineering education is known for its innovative and student-centered approach to teaching and learning. Personalized learning is given top priority in Finnish engineering courses, where students are urged to assume control over their education. With this method, students can work at their own pace and concentrate on their unique strengths and shortcomings (Anne et al., 2010). Finnish university sector adapted the German model and thus the Humboldian understanding is deeply rooted in Finnish universities (Hölttä, S., 2000).

Finnish engineering courses put a strong emphasis on student collaboration, which encourages learning from one another and helps students build their abilities to collaborate. The teaching methods in Finnish universities, particularly in engineering, prioritize student engagement and participation. The focus on developing critical thinking abilities and a love of learning is evidence of a philosophy that encourages students to take an active role in their own education. These programs' strong feeling of community is consistent with the idea that collaborative learning environments improve students' overall educational experiences. A learner-centred approach, for instance, is demonstrated by the University of Eastern Finland Teacher Training School, which emphasizes the significance of striking a balance between various goals, tactics, and instructional resources. This method is part of a larger educational philosophy that acknowledges the differences in the demands and learning preferences of teachers and students.

In general, Finnish engineering education emphasizes practical, student-focused, Problem-Based Learning (PBL) and collaborative learning approaches through its teaching methods and philosophy. As Finnish engineering courses prioritize hands-on learning experiences, institutes are encouraged to incorporate innovative methods like the double-flip approach and gamified mathematics. According to Visitedufinn, these techniques actively involve students in the learning process, facilitating a deeper understanding of complex concepts. The double-flip approach, for example, allows students to engage in problem-solving tasks during class sessions and watch video lectures at home.

Many schools have also embraced the Problem-Based Learning (PBL) successfully. Metropolia University of Applied Sciences initiated a significant curriculum reform, emphasizing the adoption of a new PBL curriculum in engineering education. Meanwhile, Griffith University introduced a PBL unit for first year engineering students, receiving favourable feedback from both students and teachers (Vesikivi, 2015). The goal of the unit was to provide a hands-on, interesting learning environment that would encourage the growth of problem-solving and teamwork skills. Finally, Helsinki Metropolia University developed a cooperative project-based learning course specifically designed for engineers (Lavonen, 2021).

One of the teaching theories that has been used in Finland is the student-teacher relationship (Tormey 2021). Tormey's three-dimensional model of student-teacher relationships in higher education highlights the multidimensional nature of emotions in student-teacher relationships and goes beyond simple measurements of emotional valence. In the field of engineering education, paying attention to emotions is valuable because of their significance especially when engineers engage with ethical aspects in their work or solve emotion-provoking, complex, and wicked problems (Roeser 2012).

Table 2. Comparison between Malaysia, Singapore, and Finland in teaching methods and philosophy

Aspect	MALAYSIA	SINGAPORE	FINLAND
Teaching Methods	• Discussion • Inquiry • Remembering and imitating	• Singapore Teaching Practice (STP) • STEM education	• Problem Based Learning (PBL) • Collaborative learning
Philosophy and Approach	Quality enhancement aligning with the Malaysia Education Blueprint	STEM education, student centered, 21st-century skills	Innovative, student centered, emphasis on PBL
21st-century Skills Emphasized	Introduction of Augmented Reality (AR)	• Critical thinking • Creative thinking	• Critical thinking • Problem solving • Teamwork

Challenges in the Engineering Education System

Malaysia

The role of the future engineer in this technologically advanced society is becoming more challenging due to the globalization of industry and engineering practices. Current societal challenges, such as international competition, global environmental issues, a growing and diverse population, and rapid population expansion. Consequently, engineers will encounter intensified challenges and competition. In response, he future engineering education system should emphasize comprehensive engineering programs to facilitate easy mobility, flexibility, and adaptability to evolving technologies and environments. Hence, a more dynamic curriculum in engineering education is needed. Recognizing the importance of nurturing highly competent engineers for the future, the Malaysian Ministry of Higher Education (MOHE) has pressured universities to graduate engineers who can effectively compete in the job market (Nor et al., 2020).

Past research has identified various challenges with STEM education, such as the limited application of STEM in rural areas. The discrepancy in competency among teachers in STEM, is not balanced between urban and rural areas (Khairani, 2017). Teachers' inadequate understanding of STEM concepts is also one of the challenges (Idris et al., 2023). Insufficient equipment, and a lack of proper equipment in school laboratories (Belalang et al., 2016). Teacher's attitude towards STEM also contributes to the challenges (Thibaut et al., 2018).

Singapore

Singapore's engineering education system faces various issues. One of the most pressing concerns is adjusting to a quickly changing environment, which involves cultivating an entrepreneurial and flexible culture that is also more inquisitive overall (Mun See, 2021). This involves preparing kids for self-directed learning. Another difficulty is the transition to more digital and technology classrooms. This entails developing 21st-century abilities in students and converting instructors from mere recipients of knowledge to co-creators of knowledge (Mun See, 2021).

A fundamental difficulty is a lack of collaboration between industry and academics (Ivanov et al., 2023). The industry needs qualified individuals to be competitive, and academia must keep up with the newest industrial trends and innovations. Engineers are needed to address future issues that Singapore may confront (Lai, 2020). This entails reducing issues to their core causes to create rational, elegant solutions for navigating society through uncertain ground.

Finally, there is a requirement for a clear and successful strategy that incorporates a common vision and commitment to the required restructuring and mentality shifts (Ivanov et al., 2023). These issues necessitate a multifaceted strategy that includes changes in teaching techniques, curriculum design, industry-academic collaboration, and a shift in mentality towards lifelong learning and adaptation.

Finland

Even though Finland's engineering courses boast impeccable methods and educational philosophy, they are not exempt from facing significant challenges. First and foremost, the rapid pace of globalization and technological advancements demands adaptation to prepare engineers for the evolving demands of the global workforce (Korhonen et al., 2007). Apart from that, the need for an active and participatory approach in engineering education is one of the main obstacles. Conventional methods and materials are being questioned as global ICT sector initiatives underline the need for an educational framework that is flexible enough to adapt to changing circumstances while also actively involving students in a dynamic learning environment. (Korhonen et al., 2007).

Another important problem that comes up is how appealing teaching is, especially for those in the technical area. For Finland's engineering education to be of a high calibre overall, teaching positions must continue to be attractive (Korhonen, 2011). It may be more difficult to encourage and inspire the upcoming generation of engineers in the absence of a thriving teaching environment.

Finally, tackling these issues requires sufficient cash and resources to be available. The amount of cash and resources that the education system receives strongly affects its ability to develop and satisfy the changing needs of engineering students. Sufficient funding guarantees that academic institutions can make the required adjustments, purchase modern technology, and offer students an excellent education (Korhonen, 2011).

Table 3. Comparison between Malaysia, Singapore and Finland in challenges in engineering education system.

MALAYSIA	SINGAPORE	FINLAND
• Evolve to adapt with technologically advanced society • A more dynamic curriculum in engineering education is needed • Insufficient equipment and a lack of proper equipment in school laboratories	• Adjusting to a quickly changing environment • Transition to more digital and technology classrooms • A lack of collaboration between industry and academics • A requirement for a clear and successful strategy that incorporates a common vision and commitment to the required restructuring and mentality shifts	• The rapid pace of globalization and technological advancements demands adaptation to prepare engineers for the evolving demands of the global workforce • The need for an active and participatory approach in engineering education • Insufficient cash and resources.

Conclusion

In conclusion, this analysis contrasts the approaches in the engineering education system in Malaysia, Singapore, and Finland, examining their distinct methodologies. This research also looks at holistic education approaches in two high-performing school systems: Finland and Singapore. Malaysia's curriculum includes pre-university education and internships that are customized to industrial requirements. Singapore prioritizes STEM education and a student-centred curriculum. Meanwhile, Finland distinguishes itself via creative, student-centred learning that encourages cooperation and problem-solving. Malaysia's teaching methods include conversation, research, and developing technologies such as Augmented Reality. Singapore prioritizes STEM, student-centred instruction, and 21st-century skills. Finland values personalized, problem-based learning and collaborative projects. One of the main challenges faced by Malaysia is insufficient equipment and a lack of proper equipment in school laboratories. Meanwhile, Singapore also faces difficulty in the transition to more digital and technology classrooms. Finland is also not exempt from facing significant challenges such as the need for an active and participatory approach in engineering education. Overall, the study's findings can be used to better understand the learning structure, teaching techniques, and issues of the engineering education systems in Malaysia, Singapore, and Finland.

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Project-based Experiential Learning in Designing Truss Structure for First Year Chemical Engineering Students

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Abstract

The successful integration of a novel and dynamic project-based learning (PBL) methodology, grounded in experiential learning principles, within the pedagogy of the first-year Chemical Engineering program, yielded transformative outcomes in the teaching and learning of the Statics course. This endeavour involved a project-based experiential learning approach, wherein students actively engaged in the conceiving, designing, constructing, and testing a truss structure. This strategic shift from conventional teaching methods to a student-centred approach aimed to empower the learning experience. Facilitated by project-based experiential learning, students collaborated in groups to conceptualize, build, and evaluate the truss structure, fostering self-directed learning skills and enhancing 21st Century 4C skills. The project was designed based on constructivist learning theory, emphasizing experiential learning and scaffolded activities to support students in achieving the project's outcomes. Throughout the project journey, students consistently demonstrated proficiency in applying free-body diagram concepts, which aligns with the constructivist approach to learning. This evidence was documented in student-prepared vlogs, showcasing their ongoing application of theoretical knowledge to practical challenges. At the project's conclusion, a survey was conducted among 124 students in the first semester of the 2022/2023 academic year to assess project outcomes. The results indicated high levels of agreement among students, with 96% agreeing to collaboration elements, 90.4% to communication, 91.2% to critical thinking, and 90.4% to creativity. Moreover, 88.8% of students agreed that their knowledge in designing basic truss structures improved, 96.8% felt more confident in analysing truss structures, and 81.6% found creating montage videos beneficial. Through our innovative methodologies, we contribute to the advancement of engineering education and ensure that our students are prepared to face the challenges of the future with confidence and creativity.

Keywords: Experiential learning; project-based learning; student-centred learning; statics; truss design

Introduction

Constructivists view learning as a journey of uncovering meaningful information. According to constructivist theory, learning occurs when individuals build new understanding through the interplay between their prior knowledge and new experiences. They believe this approach can alleviate learning difficulties with the support of teachers and knowledgeable peers (Jumaat et al., 2017). One compelling application of Constructivist Theory in the classroom is Project-based Learning (PBL). This learner-centred approach empowers students to conduct research, integrate theory and practice, and apply their knowledge and skills to develop viable solutions to defined problems (Sadikin et al, 2019). One of the key elements to have effective and successful PBL is the students take responsibility for their own learning.

Experiential learning, rooted in constructivist theory, is characterized as 'learning by doing.' In this approach, the learner actively engages in the educational process, achieving understanding through an ongoing cycle of inquiry, reflection, analysis, and synthesis (Mughal and Zafar, 2011). Experiential learning, a core component of constructivist learning theory, emphasizes the importance of students actively engaging with and reflecting on their experiences to construct knowledge. Constructivism asserts that learners build their understanding through hands-on experiences and critical thinking, rather than passively receiving information. PBL aligns with this theory by placing students in real-world scenarios where they must apply their knowledge to solve complex, ill-structured problems. This active engagement fosters deeper comprehension and retention of the material (Staehle et al., 2023).

In the context of this study, the PBL methodology not only embodies the principles of constructivism but

Sarkawi, M.S., Mohamed, M., Shamjuddin, A., Alias, H., Mohamad, Z. (2024), Project-based Experiential Learning in Designing Truss Structure for First Year Chemical Engineering Students, *ASEAN Journal of Engineering Education*, 8(1), 49-55.

also leverages experiential learning. Students are encouraged to integrate theoretical knowledge with practical application and collaborate with peers to design and analyse project. This project requires students to apply engineering concepts, engage in iterative problem-solving, and reflect on their learning process, thereby reinforcing their understanding through direct experience. By incorporating experiential learning into PBL, this approach ensures that students are not merely passive recipients of information but active participants in their educational journey. This dynamic method of instruction equips students with the skills and knowledge necessary for real-world applications, fostering both personal and academic growth (Ghosheh Wahbeh et al., 2021).

One of the key novelties lies in our emphasis on learning through real experiences. Rather than relying solely on theoretical concepts, students actively participate in the entire project lifecycle, from conceiving the idea of designing a simple truss structure to its practical implementation and operation (Fadda and Rios, 2017). We have also fostered a seamless integration between manual and computational approaches, encouraging students to explore diverse methodologies and apply both traditional and cutting-edge tools in their design processes. To ensure comprehensive evaluation, we have developed innovative assessment criteria that go beyond conventional metrics.

Our assessment includes the creation of engaging vlogs and the use of demonstration rubrics, which provide a multi-dimensional perspective on students' learning progress. Furthermore, we offer a well-documented project description and manual, backed by tangible evidence, to showcase the students' progress and accomplishments throughout the project. This novel approach aims to empower students with practical skills, critical thinking abilities, and a deeper understanding of truss design, nurturing their passion for engineering and PBL.

Our project introduces a set of ground-breaking ideas and methodologies that truly set it apart from traditional practices, showcasing its novelty in engineering education. The core innovation lies in the seamless integration of the PBL, real-world experience, and a dual approach combining manual and computational methods. By guiding students through the PBL, we create a comprehensive learning experience that mirrors the professional engineering process.

This approach not only equips students with technical knowledge but also hones their project management, teamwork, and problem-solving skills - essential qualities sought after in the engineering industry (Ricaurte and Viloria, 2020). The emphasis on real-world experience takes learning beyond theoretical concepts. By engaging students in the design of a simple truss structure, they confront genuine engineering challenges, make informed decisions, and witness the practical implications of their solutions.

This experiential learning fosters a deep understanding of engineering principles and motivates students to take ownership of their learning journey. While manual techniques offer hands-on experience and develop students' spatial visualization skills, computational tools enable them to analyse complex data and optimize their truss designs efficiently. This integration empowers students to leverage the best of both worlds, preparing them to adapt to diverse engineering scenarios in their future careers. By emphasizing collaboration, communication, critical thinking, and creativity through the 4C skills framework, we instil in students a holistic understanding of engineering practices, encouraging them to think innovatively and approach problems from multiple angles.

This paper explores the innovative use of PBL and experiential learning principles in a Statics course for first-year chemical engineering students at Universiti Teknologi Malaysia. By engaging students in the design of truss structures, this approach fosters a deeper understanding of engineering concepts and enhances practical problem-solving skills. This initiative serves as the backbone of our teaching and learning practices, allowing students to engage in a holistic learning experience. By integrating the PBL, we foster a new generation of engineers equipped with not only technical expertise but also the practical and soft skills needed to excel in the dynamic and ever-evolving field of engineering.

Methodology

Implementing PBL is complex and challenging for both instructors and students, and this is intentional. The depth of engagement required by PBL often means it is neither simple nor easy. Considerations for implementing PBL include providing significant instructional scaffolding for students who are new to this form of instruction. New learners require support in developing problem-solving skills, self-directed learning abilities, and teamwork and collaboration skills. This project would require the students to apply engineering principles, collaborate with peers, and iteratively refine their designs based on feedback and analysis. Such an experience not only deepens their understanding of statics but also equips them with essential skills for their future careers. Engaging students in PBL prepares them for real-world challenges, fostering a deeper understanding and application of their knowledge, and promoting lifelong learning skills.

Learning Outcomes and Course Mapping

This project focussed on three of the course learning outcomes (CLO). The CLOs are mapped to the respective programme learning outcomes (PLO). The project was designed according to the constructive alignment framework as shown in Table 1.

Project Objectives

This project centres on the truss structure topic, necessitating students to employ their comprehension of trusses to fulfil the project's objectives. The objectives of the project are for students to be able:

1. To draw and design the proposed 2D truss structure using AutoCAD software.
2. To fabricate and demonstrate the 2D truss structure.
3. To analyse the forces of the 2D truss structure.

The project consists of five (5) stages which are: (i) Sketch and design, (ii) AutoCAD drawing, (iii) Calculation, and (iv) Fabrication and finally (v) Demonstration. The flowchart of project activities is illustrated in Figure 1.

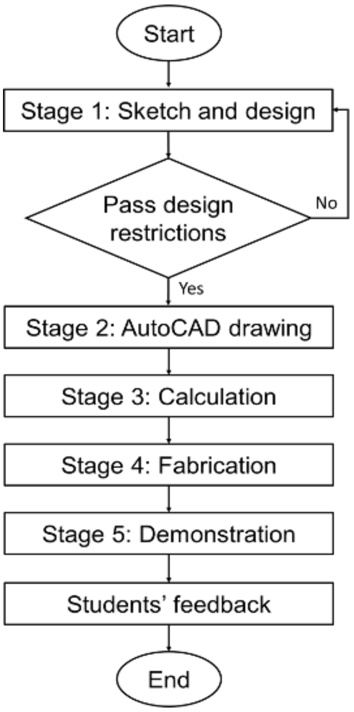

Figure 1. Flowchart of project activities

Design Restrictions

The design parameters for the truss structure encompass specific constraints:

1. The design should encompass a minimum of 5 and a maximum of 15 sticks.
2. Each truss member must not possess a double layer.
3. The alteration of a stick's length to form smaller truss parts is prohibited.
4. Creating a truss frame is disallowed; joining members exclusively occurs at the stick's end.
5. The truss structure's minimum horizontal distance (x-axis) must be 30 cm.
6. Deployment of solely one bolt and one nut per joint is stipulated.
7. Adhesive agents such as glue, paste, cello tape, nails, threads, or strings are strictly prohibited in securing or fastening joints.

The illustration of the five stages is shown in Figure 2. The scaffolding activities were provided throughout the project to support and guide students. Initial project instructions were given to outline the project execution. Sketches and drawings underwent validation based on design restrictions before proceeding to Stage 2. AutoCAD drawing activities were supervised by trained personnel to ensure accuracy and proficiency. Calculations were refined during class activities to reinforce learning. Lastly, the fabrication process was facilitated by technical staff in the workshop, ensuring students had the necessary support and resources to complete the project successfully.

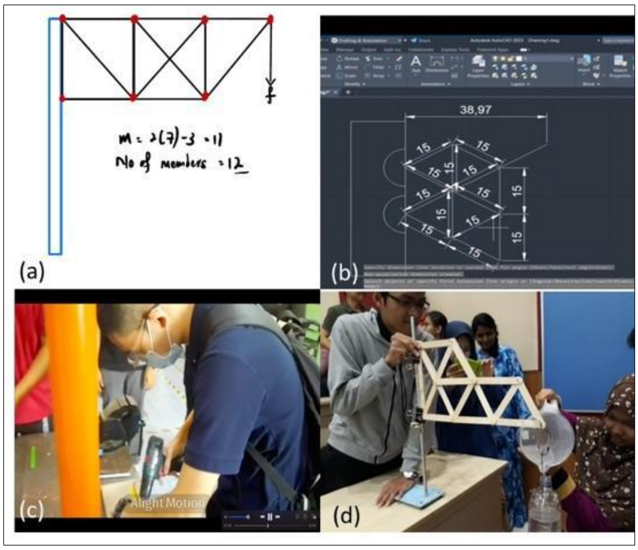

Figure 2. Stages of project activities

Assessment Method

The assessment methodology for the truss structure project is meticulously designed to ensure comprehensive evaluation of both the constructed structure and the group's collaborative efforts. The central criterion is the truss's capacity to sustain a minimum 0.5 kg load without failure, underscoring its functional integrity (Table 2). The rubric was crafted to evaluate two key criteria, making the assessment both comprehensive and engaging. First, it measured students' ability to apply theoretical knowledge to the project, focusing on creativity, structural design, and the loading capability of the trusses. Second, it assessed students' generic skills, particularly their teamwork abilities. This assessment process is documented through the creation of a comprehensive video, capturing all group activities from initial discussions to the final demonstration. Reports and videos must adhere to specified submission guidelines. A peer evaluation system operates at each project stage, underlining the importance of cooperative group dynamics. The culmination involves a live presentation in front of expert panels where the design is showcased, assembled, and tested. The assignment mandates a designated group member to record the demonstration.

Distinguished by their highest load-bearing capacity, each section's top performer will be awarded, with a "Best of the Best" accolade encompassing all sections. The project report entails a detailed account of the group's composition and roles, an introduction to the truss structure, comprehensive free-body diagrams, 2-D AutoCAD drawings, meticulous calculations, and references. The submission should adhere to specified guidelines and be channelled through the respective e-learning section. Incorporating multimedia, the video report mandates the use of original footage or images to construct a 5 to 10-minute montage. While adaptation from external sources is permissible, direct copying is restricted. This video, required in MP4 format within a maximum size of 450 MB, must comprise the list of members' tasks and chronicle the entire project process from discussions to final demonstration. Evaluator assessment hinges on a rubric encompassing Loading, Design, Demonstration, and Creativity criteria for both the structure and the video report. This meticulous evaluation process ensures a comprehensive assessment of students' efforts and their truss structure designs. A survey has been conducted using online Google Form to solicit feedback from students regarding the impact of the project on their learning outcomes.

Table 1. Constructive alignment framework of the project

Course Learning Outcome (CLO)	Stage of project activity	Program Learning Outcome (PLO)	Learning Activity	Assessment
Apply the free-body diagram for analysis of various equilibrium force systems (CLO2).	Stage 1 - 3	Engineering Knowledge: Apply knowledge of mathematics, natural science, computing and engineering fundamentals and chemical engineering to develop solutions to complex engineering problems (PLO1).	Calculate external and internal forces for all truss members.	Project report
Demonstrate truss design project to class audience (CLO4).	Stage 5	The Engineer and Society: Apply reasoning to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems (PLO6).	In-class demonstration and competition	Strength of truss
Work in a team to propose a truss design (CLO5).	Stage 1 - 5	Individual and Teamwork**:** Function effectively as an individual, member or leader in diverse teams and in multi-disciplinary settings (PLO10).	Brainstorming, drawing, calculation, fabrication, and demonstration	Peer rating and observation during demonstration

Table 2. Project assessment rubrics

Area Assessed	Excellent (4)	Good (3)	Fair (2)	Poor (1)
Loading	Truss is able to support loads beyond 1.5 kg	Exceeds minimum loading requirement of 1kg (1-1.5 kg)	Supports minimum loading requirement (1 kg)	Cannot support minimum loading requirement (< 1 kg)
Design	Truss is well designed. All truss members and joints are neatly constructed	Comply with design requirement. Most parts are neatly constructed	Comply with design requirement. Some parts are neatly constructed	Did not comply with design specification (minimum horizontal length 30 cm & number of truss member 10 – 30). Presence of frame.
Demonstration	Every group member contributes to project material & demonstration	Most group member contributes to project material & demonstration	Few group members contribute to project material & demonstration	Only ONE member contributes to project material & demonstration
Creativity	Design is well thought off and very creative	Design has acceptable creativity	Design is presented with minimal creativity	Design has little creativity

Results and Discussion

Project output

In our endeavour to implement the PBL and foster innovative teaching and learning practices, creativity emerged as a cornerstone of our approach. Central to this was the design of the truss structure, which presented students with a specific set of specifications and limitations. While these constraints served as guiding principles, they also ignited the spark of creativity within our students. One of the defining features of our project was the flexibility it afforded students in designing their truss structures. Rather than prescribing rigid templates, we encouraged students to explore their imaginations and apply engineering principles to create unique solutions. This approach not only allowed for diverse truss designs but also gave students a sense of ownership and autonomy in their learning journey. To attract students' interest and empower them toward self-directed learning, we integrated elements that actively engaged their creativity. Our PBL practices included innovative learning activities, assessments, and materials meticulously crafted to foster problem-solving skills and critical thinking. For instance, students were tasked with designing truss structures capable of supporting specific loads, requiring them to apply theoretical knowledge in practical contexts (Figure 3). They had to think creatively, often reimagining traditional engineering concepts to meet project objectives. Furthermore, we incorporated hands-on activities such as truss construction and load testing, promoting active engagement and kinesthetics learning. These activities challenged students to think on their feet, make real-time adjustments, and apply creativity to optimize their designs. In addition to these broader methodologies, our project featured several specific examples that underscored our creative approach. Students were encouraged to develop novel joint configurations, experiment with materials, and explore innovative load distribution techniques. These instances not only enriched their understanding of truss design but also ignited their passion for engineering. our project's creative elements were woven throughout the teaching and learning process, from the initial design phase to the hands-on construction and testing. By offering flexibility, hands-on experiences, and a platform for inventive problem-solving, our PBL practices not only enriched the educational experience but also nurtured a culture of creativity, critical thinking, and self-directed learning among our students.

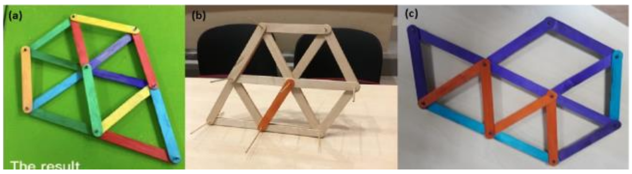

Figure 3. Actual truss designed by students

Students' feedback

A survey was conducted among 124 students enrolled in the Chemical Engineering program, who were taking the Statics course during the first semester of the 2022/2023 academic year, to gather insights into the project's outcomes. One of the survey questions pertained to the project's goal of integrating Education 4.0 / 21st Century 4C's Skills (Collaboration, Communication, Critical Thinking, Creativity) into students' learning experiences. Students were asked to rank their proficiency in these four skills after completing the project, using a scale from 1 to 5, indicating their level of agreement. Please note that 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree. The results (Figure 4a) showed that 96% of students provided a percentage agreement exceeding 80% for the collaboration element, 90.4% for communication, 91.2% for critical thinking, and 90.4% for creativity. The second statement posed to students was, "Please tick the following if you feel the Statics Project has helped to enhance your knowledge in these fields: 1. knowledge in designing basic truss structure, 2. knowledge in analysing truss structure, and 3. knowledge in creating montage videos." The findings (Figure 4b) demonstrated that 88.8% of students indicated an agreement percentage exceeding 80% for the enhancement of knowledge in designing basic truss structure, 96.8% for analysing truss structure, and 81.6% for creating montage videos.

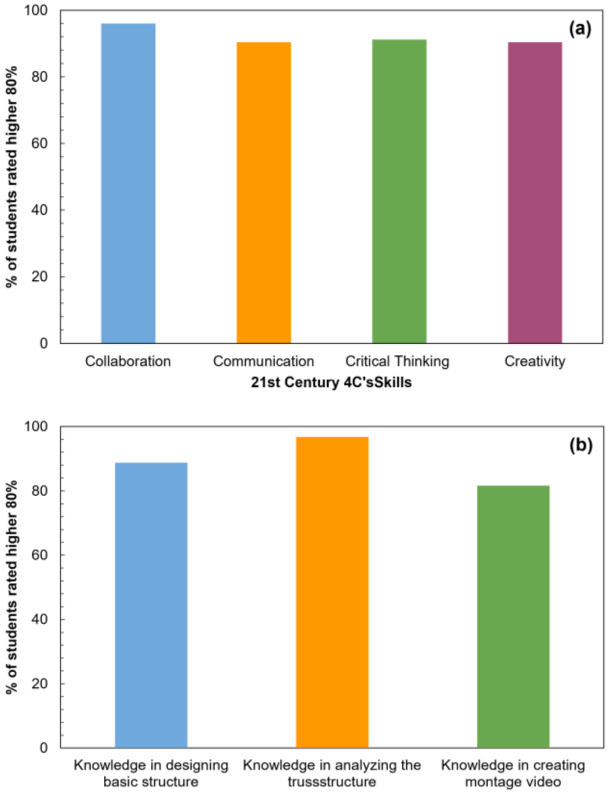

Figure 4. a) Students' experience on 21st Century 4C's Skills; b) Students' knowledge enhancement

Impact on students' learning experiences

Through the implementation of our innovative teaching and learning practices, we have witnessed profound impacts on students' learning experiences, with a focus on engagement and empowerment. One significant outcome has been the promotion of essential 21st-century 4C skills - Collaboration, Communication, Critical Thinking, and Creativity - among students. By working in collaborative teams throughout the project, students learn to effectively communicate ideas, engage in critical discussions, and foster a creative mindset to solve complex engineering challenges. This emphasis on 4C skills equips them with invaluable competencies required in their future careers (Kokotsaki et al, 2016). Our approach has nurtured a positive and strong relationship between students and lecturers. By encouraging open dialogue and close mentorship, we have created a supportive learning environment where students feel comfortable sharing their thoughts and seeking guidance. This personalized interaction has empowered students to take ownership of their learning and seek continuous improvement, fostering a sense of mutual respect and trust between students and faculty. Another remarkable impact has been the boosted confidence that students gain as they progress through the project. By actively engaging in the entire design process and witnessing their ideas materialize, students feel a sense of achievement and accomplishment (Chikkamath et al., 2016). This newfound confidence transcends the project and spills into other aspects of their academic journey and beyond. Lastly, our approach has led to a significant increase in students' engagement with the learning process. As they work on real-world projects with tangible outcomes, students become more invested in their education. The hands-on experience and practical relevance of the project foster a genuine interest in engineering and encourage students to explore beyond the classroom curriculum. Our innovative teaching and learning practices have a profound impact on students, emphasizing engagement and empowerment. By promoting 21st-century 4C skills, nurturing strong relationships, building confidence, and encouraging active involvement in the learning process, we have successfully created a transformative educational experience that prepares students for future challenges and opportunities.

Students' performance on truss knowledge

The PBL methodology grounded in experiential learning principles was implemented in both academic sessions 2022/2023-1 and 2023/2024-1. However, the PBL methodology was not executed during the academic session 2021/2022-1 due to Covid-19 pandemic. The truss structure project took place in the 2022/2023 academic session to enhance students' understanding and application of engineering principles. In the subsequent 2023/2024 session, the decision was made to focus on a different topic, specifically the Pappus-Guldinus theorem, to broaden students' exposure to various engineering concepts. This variation in project topics was intended to provide a diverse learning experience and align with curriculum objectives aimed at comprehensive skill development in engineering education.

Figure 5 illustrates the comparison of Program Learning Outcomes (PLOs) achievements for the academic sessions 2021/2022-1, 2022/2023-1, and 2023/2024-1. There were improvements in the achievement of PLOs 6 and 10 during the 2022/2023-1 and 2023/2024-1 sessions compared to 2021/2022-1. PLOs 1, 6 and 10 achievements were consistent in both academic sessions 2022/2023-1 and 2023/2024-1. The impact of implementing PBL approach, conducted only during the academic years 2022/2023-1 and 2023/2024-1, may have influenced the variations observed in PLO achievement. Notably, the average performance of students on truss structure questions during final examinations in the 2022/2023 session was 81% across all sections, contrasting with 75% in the 2023/2024 session. This disparity indirectly indicates the efficacy of the truss structure project in enhancing students' grasp of the subject matter.

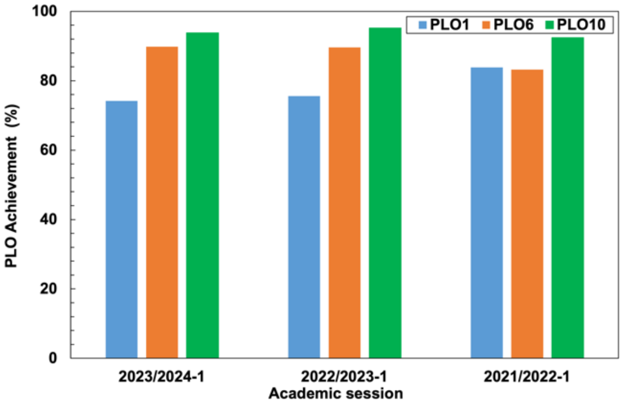

Figure 5. PLOs Achievement comparison

The fluctuations in PLO achievement across the three sessions suggest the influence of various instructional, curriculum, and possibly external factors. Further analysis is needed to understand the specific factors influencing PLO achievement and to determine the effectiveness of interventions such as the truss project. However, the data presented in the bar chart provides valuable insights into trends in PLO achievement across multiple academic sessions and highlights potential areas for further investigation and improvement.

Conclusion

In conclusion, this study underscores the successful implementation of an innovative and dynamic PBL methodology, rooted in experiential learning principles, in the teaching and learning activities of the Statics course for first-year Chemical Engineering students. Through our innovative methodologies, we contribute to the advancement of engineering education and ensure that our students are prepared to face the challenges of the future with confidence and creativity. The outcomes revealed a substantial positive impact on students' acquisition of 21st Century 4C skills, emphasizing collaboration, communication, critical thinking, and creativity. The project's efficacy in enhancing students' knowledge in designing and analysing truss structures, as well as creating montage videos, was evident from the robust survey findings. The transformative effects of this approach are not only confined to the technical realm but also extend to fostering a profound shift in the students' learning attitudes and abilities. This investigation signifies the potential of innovative pedagogical methodologies to enhance both practical engineering skills and holistic cognitive competencies, thereby charting a promising path for future engineering education initiatives.

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Impact of Game-Based Learning on Engineering Education: A Systematic Review

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Abstract

The evolving landscape of Engineering Education (EE) necessitates innovative pedagogical strategies to meet industry needs. Game-Based Learning (GBL) integrates gaming elements into educational contexts, enhancing interactivity and engagement. However, the effectiveness of GBL across various academic levels and disciplines remains underexplored. This systematic literature review aims to comprehensively analyze the use of GBL in EE, focusing on its application across various engineering fields and educational levels, the goals driving its implementation, the design features of GBL tools, and their educational outcomes. Utilizing IEEE Xplore for literature search and Rayyan AI for systematic review management, 22 studies were included after rigorous screening. Results indicate GBL's predominant use at the undergraduate level, especially in fields linked to digital technologies. Key goals for GBL include enhancing motivation, supporting skills development, and improving engagement and practical skills. Design features like interactive gameplay, feedback mechanisms, and 3D environments were identified. GBL significantly improves student engagement, motivation, knowledge acquisition, learning experiences, and practical skills development, typically investigated using mixed-methods research designs. This review highlights GBL's potential in the field of EE, offering insights into its application, design features, and benefits, and guiding future research and implementation strategies.

Keywords: Game-Based Learning, Engineering Education, Educational Outcomes, Interactive Learning, Digital Technology.

Introduction

The rapidly evolving landscape of Engineering Education (EE) demands innovative pedagogical strategies that effectively bridge the gap between current industry requirements and traditional educational outcomes. Industries increasingly require graduates who possess technical proficiency along with skills in collaboration, leadership, and problem-solving (McGunagle & Zizka, 2020). This has highlighted the limitations of conventional educational methods and spurred interest in alternative approaches like GBL when training engineering students.

GBL involves the integration of games to support teaching and learning objectives that infuses the engaging elements of gaming into educational environments, aiming to enrich learning experiences through increased interactivity, competition, and simulation (Gee, 2003; Pivec, 2007). Recognized for its potential to significantly enhance student engagement and facilitate the acquisition of complex competencies (Garcia et al., 2020; Udeozor et al., 2022), GBL represents a promising approach to meet the dynamic demands of contemporary EE.

This review gains importance in the context of the Fourth Industrial Revolution (IR4.0) transitioning into the Fifth Industrial Revolution (IR5.0), characterized by significant technological advancements and a shift toward more personalized, collaborative, and sustainable practices. Additionally, the during and post-COVID-19 era has accelerated the adoption of digital technologies and remote learning modalities, presenting both challenges and opportunities for the integration of GBL into engineering curricula (Rassudov & Korunets, 2020).

Despite its potential, the application of GBL in EE needs thorough examination to comprehend its effectiveness across various academic levels and disciplines. Previous reviews often focus on specific fields like software and computer engineering and do not explore the broader applications across diverse fields such as mechanical, electrical, and civil engineering, nor do they sufficiently consider different

Raja Rosli, R.M.K., Techanamurthy, U., Zakaria, A.F. (2024), Impact of Game-Based Learning on Engineering Education: A Systematic Review, *ASEAN Journal of Engineering Education*, 8(1), 56-63.

academic levels (Alanne, 2015; Garcia et al., 2020; Despeisse, 2018). Besides that, a review by Udeozor et al. (2022) while they do address GBL in EE, however, is limitedly to digital games utilization.

Moreover, with the increasing interest in gaming among young adults, it is critical to evaluate how GBL can be optimized to enhance educational outcomes. For instance, in Malaysia, gaming exhibits a substantial overall penetration rate of 85%, reaching 100% among individuals aged 20 and below (Survey Report: Malaysian Gaming Industry 2023, Engagement Lab). Hence, this review aims to provide an updated, comprehensive analysis of both digital and non-digital GBL utilization, their integration into engineering curricula, and assessing their impact on educational outcomes through the following research questions:

RQ1: *How do different academic levels and engineering fields shape the use of GBL?*

RQ2: *What goals lead to using GBL in EE, and how do these goals affect the choice of games and platforms?*

RQ3: *What are the main design features and standards for developing GBL tools, and how are these tools used in engineering courses?*

RQ4: *What educational outcomes does GBL bring to EE, and how they are typically investigated?*

Methods

. Our literature search was carried out across IEEE Xplore database as previous related reviews indicate the most common and highest studies pertinent to GBL in EE are in the mentioned database (Alanne, 2015; Despeisse, 2018; Garcia et al., 2020; Udeozor et al., 2022). We utilized a combination of Boolean operators, wildcards, and specific search terms related to GBL and EE. The search string: *("game-based learning" OR "digital game-based learning" OR "GBL" OR "DGBL" OR "serious game*" OR "educational game*") AND ("engineering education" OR "STEM education")*, is tailored to IEEE Xplore database to maximize the retrieval of relevant studies.

A literature matrix table was constructed to systematically record and extract relevant information such as objectives, methodologies, and findings from the selected studies. Following this, we primarily utilized thematic analysis to analyze and synthesize the extracted data, complemented by minor quantitative statistical analysis. This approach allowed us to identify common themes, patterns, and relationships across the studies. Through collaborative efforts, all three authors contributed to the qualitative synthesis, ensuring a comprehensive integration of data and deriving meaningful insights.

Our systematic literature review adheres to strict inclusion criteria to ensure the relevance and quality of the studies analyzed, as follows:

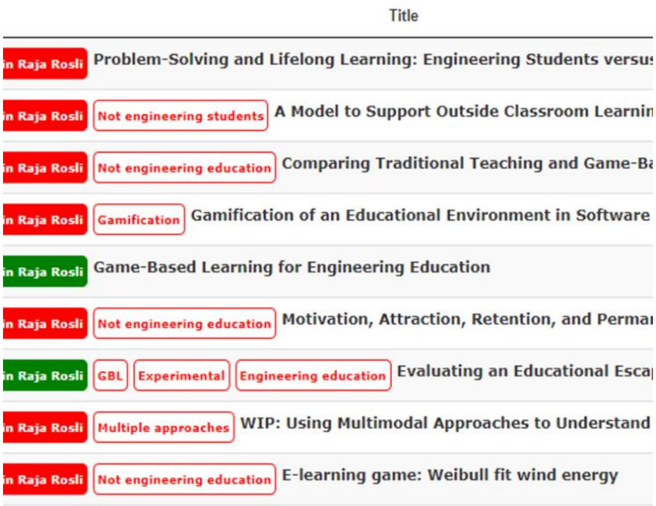
1. **Specific to EE:** Only studies explicitly focusing on engineering disciplines at either the undergraduate or graduate level were included. This encompasses studies on general engineering as well as specific branches such as mechanical, electrical, civil, and chemical engineering.
2. **Use of GBL:** Studies included were those that specifically investigated the implementation and outcomes of GBL. Covered methodologies included simulations, virtual reality, serious games, board games, and both digital and non-digital games designed for educational purposes.
3. **Reported Outcomes:** The review focused on empirical studies that involved conducting original research based on direct or indirect observations or experiences, aimed at generating new data.
4. **Publication Date:** Only studies published from January 2019 to April 2024 were considered to capture the most current insights and trends in the field.
5. **Language:** The search was limited to studies published in English to facilitate thorough review and analysis.
6. **Document Type:** The review was confined to peer-reviewed journal and conference papers to ensure the quality and scholarly rigor of the sources.
7. **Methodological Approach:** The studies included adopted quantitative, qualitative, and mixed-methods research designs.

Rayyan AI Application to Aid Selection Process

The selection process involved a preliminary screening of titles and abstracts followed by a full-text review, utilizing Rayyan AI (https://www.rayyan.ai/) for systematic review management. Rayyan is a collaborative web-based platform designed to facilitate the systematic literature review process. It aids study selection by allowing for references importation, offers tools for manual with suggested deduplication, and enables blind reviews to minimize bias. This feature is especially beneficial in efficiently managing the large volumes of data typically involved in SLRs, ensuring a rigorous and systematic assessment of literature and is also time saving (Ouzzani et al., 2016). Therefore, by employing Rayyan, independent reviews by each author were done, and for any disagreements were resolved in discussion to reach consensus.

Figure 1. Word cloud generated by Rayyan AI

Figure 1 shows a feature of Rayyan AI that showing the most common topics within reviewed articles. Initially, we created a new review in Rayyan and imported references from various databases. The platform's automated and manual deduplication tools ensured a clean dataset. Reviewers, invited via email, used the blind review feature to independently screen articles. Decisions were color-coded for clarity: red for exclusions, green for inclusions, and white for articles marked as 'maybe', as illustrated in Figure 2 below.



Title

- in Raja Rosli | Problem-Solving and Lifelong Learning: Engineering Students versu
- in Raja Rosli | Not engineering students | A Model to Support Outside Classroom Learnin
- in Raja Rosli | Not engineering education | Comparing Traditional Teaching and Game-Ba
- in Raja Rosli | Gamification | Gamification of an Educational Environment in Software
- in Raja Rosli | Game-Based Learning for Engineering Education
- in Raja Rosli | Not engineering education | Motivation, Attraction, Retention, and Perma
- in Raja Rosli | GBL | Experimental | Engineering education | Evaluating an Educational Esca
- in Raja Rosli | Multiple approaches | WIP: Using Multimodal Approaches to Understand
- in Raja Rosli | Not engineering education | E-learning game: Weibull fit wind energy

Figure 2. Rayyan AI interface showing article screening decisions

Reviewers also added specific labels and exclusion reasons to each reference as shown in Figure 3. After the initial screening, we resolved conflicts through consensus discussions. For the full-text review, included references were copied into a new review where full texts were uploaded and mapped for detailed evaluation. Upon completion, Rayyan facilitated the export of included references and provided a log of all review actions, ensuring transparency and reproducibility. Images illustrating the Rayyan AI interface and our process, highlighting the red, green, and white color indications, have been included to enhance clarity.

Exclusion reasons	–
Not engineering education	61
Not empirical	8
Review Paper	7
Not engineering students	6
Not GBL	5
Not Learning Criteria	5
GBL	2
Experimental	2
Multiple approaches	2
Engineering education	2
Gamification	1
might be GBL	1

Figure 3. Exclusion reasons tracked in Rayyan AI

The search initially yielded 388 records. After automatic filtering, removing duplicates and screening titles and abstracts, 36 articles were reviewed in full text. Ultimately, only 22 studies met the rigorous inclusion criteria in this review. The selection process is detailed by adopting PRISMA flow diagram as shown in Figure 4, illustrating the narrowing from initial identification to final inclusion.

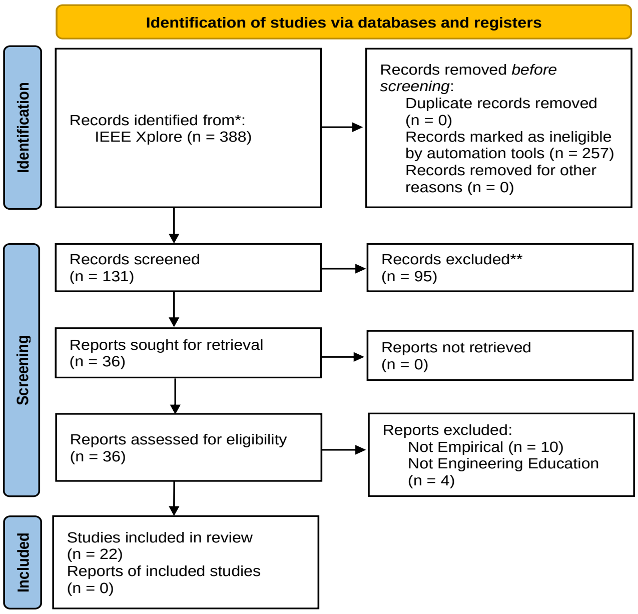


Figure 4. PRISMA 2020 flow diagram illustrating the process of study selection (Page et al. 2020)

Results

A. Influence of Academic Levels and Engineering Fields on the Use of Game-Based Learning

Figure 5 reveals that GBL is predominantly utilized at the undergraduate level across various engineering disciplines. Software Engineering stands out with the highest number of undergraduate studies (6), followed by Electrical and Computer Engineering (3). Studies such as Ivanova, Kozov & Zlatarov (2019) and Oren, Pedersen & Butler-Purry (2021) exemplify the integration of GBL into undergraduate courses, indicating a preference for interactive tools to enhance foundational education. The chart also shows that disciplines closely linked to digital technologies, such as Software and Electrical Engineering, frequently employ GBL. This reflects a trend where GBL is leveraged to align with the interactive and technological nature of these fields. Although fewer in number, some studies investigate GBL at the postgraduate level, as seen in fields like Software Engineering and Civil Engineering. This suggests that GBL is recognized for its value even in advanced educational stages, providing a versatile tool for enhancing learning outcomes. Overall, the distribution of GBL usage across undergraduate and postgraduate levels in various engineering fields highlights its adaptability and appeal in EE, demonstrating its effectiveness in both foundational and advanced educational contexts.

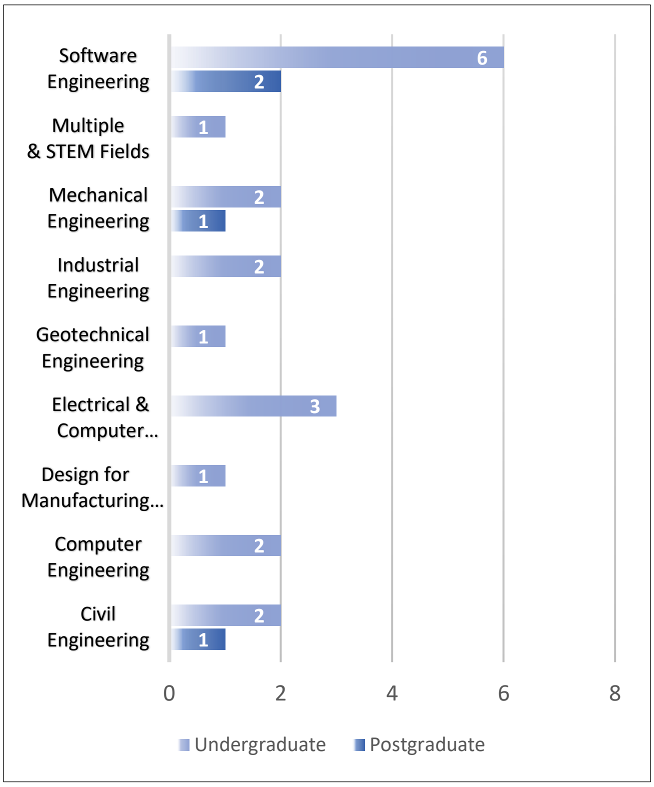


Figure 5. Distribution of Academic Level by Engineering Field

B. Goals for Using Game-Based Learning in Engineering Education and Their Impact on Game and Platform Selection

Table 1 shows the diverse objectives of GBL in EE, which guide the choice of game types and platforms. Key aims include enhancing student motivation and understanding through formats like serious games on platforms like Unity (Ivanova et al., 2019; Velaora & Kakarountas, 2021); supporting skills development with tools such as simulations across both digital and tabletop settings (Cook-Chennault & Villanueva, 2019; Lui et al., 2019); and improving engagement and practical skills via immersive technologies like augmented reality (Gordillo et al., 2020; Ibrahim et al., 2019). Additionally, the use of educational games and tools like LEGO Serious Play assesses and boosts educational outcomes, while innovative approaches such as virtual reality advance the frontier of technology in education (Oren et al., 2021; Sousa, 2020; Cook-Chennault & Villanueva, 2019). This variety of objectives and platforms highlights GBL's adaptive use in EE, tailored to specific learning outcomes and engagement strategies.

Table 1. Summary of GBL in EE: Objectives, Genres, Types, and Platforms

Common Objective	Game Genre	Type	Playable Platform
Enhance Motivation and Understanding	Mixed Games, Serious Game, Tic-Tac-Toe, Strategy Games	Mixed, Digital	Various, Web applications, Unity
Support Learning and Skills Development	Simulation, Hands-On Simulation, Business Simulation, Educational App	Digital, Non-Digital	Web-based browsers, Table-top, Web-based
Improve Engagement and Practical Skills	Escape Room, Serious Games, Augmented Reality	Digital, Non-Digital	Escapp platform, Unity, Mobile App
Explore and Assess Educational Game Impact	Educational Video Game, Board Games, LEGO Serious Play	Digital, Non-Digital	3-D role-playing, Physical board games, Physical LEGO bricks
Innovative Learning Experiences and Tools Utilization	Puzzle Game, Virtual Reality, Simulation, Storytelling	Digital	Computer-based platforms, Mobile devices

C. Key Design Features and Standards for Developing Game-Based Learning Tools and Their Application in Engineering Courses

Table 2 outlines the primary game features, design frameworks, and implementation strategies for GBL tools in EE. Commonly identified design features include interactive gameplay, feedback mechanisms, 3D environments, interdisciplinary learning elements, role-playing, and narrative storytelling, enhancing engagement and personalized learning. For example, Gordillo, López-Fernández & Tovar (2022) highlight the effectiveness of interactive gameplay, while Daskalogrigorakis et al. (2021) emphasize the importance of feedback mechanisms. Key frameworks guiding GBL development are educational game design principles, gamification principles, instructional design principles, learning theories, and serious games frameworks. Studies by Lui, Lee & Fung (2019) and Cuevas-Ortuño & Huegel (2020) illustrate how these frameworks ensure educational effectiveness. Educators employ various strategies to integrate GBL tools, including collaborative learning, online learning, drill and practice, and inquiry-based learning (IBL). For instance, Ivanova, Kozov & Zlatarov (2019) demonstrate the benefits of collaborative learning, while Evangelou, Kapsoulakis & Xenos (2023) discuss the use of GBL tools as supplementary resources. These elements collectively foster dynamic, interactive learning environments that address modern educational demands and prepare students for real-world engineering challenges.

Table 2. Primary Game Features, Design Frameworks, and Implementations of GBL in EE

Category	Common Characteristics/ Strategies	Related Reference
Design Features (Game elements incorporated in the game)	Interactive Gameplay	Gordillo, López-Fernández & Tovar (2022), Jain et al. (2022)
	Feedback Mechanism	Daskalogrigorakis et al. (2021), Oren, Pedersen & Butler-Purry (2021)
	3D Environment	Gill et al. (2023), Cui et al. (2023)
	Interdisciplinary Learning Elements	Evangelou, Stamoulakatou & Xenos (2021), Evangelou, Kapsoulakis & Xenos (2023)
	Role-Playing	Ivanova, Kozov & Zlatarov (2019), Jain et al. (2022)
	Narrative and Storytelling	Cuevas-Ortuño & Huegel (2020), Maisiri & Hattingh (2022)
Design Frameworks (Standards/ frameworks guiding the design and development of the game)	Educational Game Design Principles (e.g., clear learning objectives, in-game assessment)	Lui, Lee & Fung (2019), Cui et al. (2023)
	Gamification Principles (e.g., game mechanics, rewards)	Velaora & Kakarountas (2021), Hare, Tang & Zhu (2023)
	Instructional Design Principles (e.g., ADDIE, Agile)	Cuevas-Ortuño & Huegel (2020), Gill et al. (2023)
	Learning Theories (e.g., Constructivism, Experiential Learning Theory)	Velaora & Kakarountas (2021), López-fernández et al. (2021)
	Serious Games Frameworks (e.g., Input-Output GBL Model)	Ivanova, Kozov & Zlatarov (2019), Evangelou, Kapsoulakis & Xenos (2023)
Implementation Strategies (How educators use the games in their teachings)	Collaborative Learning	Ivanova, Kozov & Zlatarov (2019), Jain et al. (2022)
	Online Learning	Celorrio-Aguilera & Freire (2021), Gordillo, López-Fernández & Tovar (2022)
	Drill and Practice	Ivanova, Kozov & Zlatarov (2019), Daskalogrigorakis et al. (2021),
	Inquiry-Based Learning (IBL), Problem-Based Learning (PBL), Challenge-Based Learning (CBL)	Lui, Lee & Fung (2019), Cuevas-Ortuño & Huegel (2020)
	Supplementary Tool	Cook-Chennault & Villanueva (2019), Evangelou, Kapsoulakis & Xenos (2023)

D. Educational Outcomes of Game-Based Learning in Engineering Education and Methods of Investigation

Table 3 highlights the significant benefits of GBL in EE, documenting improvements across domains such as engagement, motivation, knowledge enhancement, satisfaction, and practical skills development. These benefits are consistently noted across various research designs. Engagement and motivation are frequently enhanced, as shown in mixed-methods studies employing surveys and qualitative feedback (e.g., Ivanova, Kozov & Zlatarov, 2019; Cook-Chennault & Villanueva, 2019). Knowledge and learning outcomes are also markedly improved, with methods ranging from quantitative to mixed, verifying learning gains through pre- and post-tests (e.g., Gordillo et al., 2020; Lui, Lee & Fung, 2019). GBL tools are generally found to improve learning experiences and satisfaction, as seen in both mixed methods and quantitative studies (e.g., Sousa, 2020; Evangelou et al., 2021). Additionally, GBL facilitates the development of practical skills, through mixed methods and qualitative inquiries (e.g., Daskalogrigorakis et al., 2021; Maisiri & Hattingh, 2022). Collectively, these outcomes underline GBL's comprehensive impact in enhancing not just academic performance but also student engagement, perceptions, and practical competencies in EE.

Table 3. Overview of GBL Educational Outcomes in EE: and Methodologies

Educational Outcome	Example of Findings	Research Design
Increased Engagement and Motivation	1. Increased interest in software engineering (Ivanova, Kozov & Zlatarov, 2019) 2. Motivation to learn G-code programming (Daskalogrigorakis et al., 2021) 3. Heightened engagement in	1. Mixed Methods (Primarily Quantitative) Example: Ivanova, Kozov & Zlatarov (2019): Surveys; qualitative feedback. 2. Mixed Method Sequential Exploratory Example: Cook-Chennault & Villanueva (2019):

	agile software development (Lui, Lee & Fung, 2019)	Questionnaire; focus group discussions.
Enhanced Learning Outcomes and Knowledge Acquisition	1. Improved test scores in software modeling (Gordillo et al., 2020) 2. Better understanding of requirements elicitation (Ibrahim et al., 2019) 3. Enhanced knowledge of agile principles (Lui, Lee & Fung, 2019)	1. Mixed Methods (Primarily Quantitative): Example: Lui, Lee & Fung (2019): Pre- and post-tests; surveys; observations. 2. Quasi-Experimental Example: Gordillo et al. (2020): Pre- and post-tests; surveys. 3. Quantitative Example: Ibrahim et al. (2019): Online questionnaires.
Improved Learning Experiences and Satisfaction	1. High engagement and enjoyment in civil engineering (Sousa, 2020) 2. Positive feedback for "My life as a software engineer" (Evangelou et al., 2021) 3. Fun and motivating LEGO Serious Play (López-Fernández et al., 2021)	1. Mixed Methods Example: Sousa (2020): Pre- and post-tests; surveys; observations. 2. Quantitative Example: Evangelou et al. (2021): Pre- and post-tests; SUS questionnaire.
Development of Practical Skills	1. Practical application of truss stability (Cook-Chennault & Villanueva, 2019) 2. Hands-on G-code programming experience (Daskalogrigorakis et al., 2021) 3. Real-world problem-solving in geotechnical engineering (Cui et al., 2023)	1. Mixed Methods Example: Daskalogrigorakis et al. (2021): Surveys; qualitative feedback. 2. Qualitative (Self-Reflective Inquiry) Example: Maisiri & Hattingh (2022): Reflective questions. 3. Quantitative Example: Cui et al. (2023): Pre- and post-tests.

Discussion

The systematic literature review revealed that GBL is predominantly utilized at the undergraduate level across various engineering disciplines, particularly in fields closely linked to digital technologies such as software and electrical engineering. The primary goals for implementing GBL include enhancing motivation and understanding, supporting skills development, and improving engagement and practical skills. Key design features identified include interactive gameplay, feedback mechanisms, 3D environments, interdisciplinary learning elements, role-playing, and narrative storytelling. GBL has shown significant positive impacts on student engagement, motivation, knowledge acquisition, learning experiences, and practical skills development, typically investigated using mixed-methods research designs.

The review found that GBL is more frequently used at the undergraduate level across diverse engineering fields, aligning with Alanne (2015) and Garcia et al. (2020), who noted the extensive use of GBL in software and computer engineering. However, our findings extend this understanding by highlighting GBL's broader applicability in other disciplines such as mechanical, electrical, and civil engineering. This broader application indicates that GBL is effective not only for early education stages but also across a variety of engineering fields, suggesting a universal appeal and adaptability of GBL in foundational engineering education. The quantitative analysis illustrated in Fig. 5 provided additional insights into the distribution of GBL usage across different academic levels and engineering disciplines.

The review identified that enhancing motivation and understanding, supporting skills development, and improving engagement and practical skills are primary goals for using GBL with impact in EE. This aligns with Despeisse (2018), who emphasized the cognitive and affective outcomes of games and simulations. The thematic analysis of objectives showed how different goals influence the choice of game genres and platforms, such as serious games and simulations, used to achieve specific educational outcomes. The integration of these tools helps address diverse learning needs and preferences, optimizing educational outcomes across various engineering disciplines. This comprehensive approach contrasts with studies focused solely on specific skills or fields, indicating the broader educational goals identified in this review. However, Garcia et al. (2020) primarily focused on soft skills development in software engineering, which may not fully capture the broader educational goals identified in our review.

In terms of design features and standards, the review identified interactive gameplay, feedback mechanisms, and 3D environments as key elements, consistent with the design principles discussed by Garcia et al. (2020) and Udeozor et al. (2022). Both studies emphasize the importance of these features in creating engaging and effective educational tools. The thematic analysis showed that interdisciplinary learning elements, role-playing, and narrative storytelling are crucial for developing comprehensive GBL tools that cater to varied educational contexts and enhance the overall learning experience. This comprehensive approach contrasts with Alanne (2015), who focused more on gamification elements like competition and rewards, indicating different design priorities based on educational contexts.

Our findings on the educational outcomes of GBL indicate significant improvements in student engagement, motivation, knowledge acquisition, learning experiences, and practical skills development. This is supported by Udeozor et al. (2022), who reported similar benefits from digital game-based learning. Our review expands on these findings by demonstrating that non-digital GBL tools also contribute to these positive outcomes, suggesting that the benefits of GBL are not limited to digital formats. This comprehensive impact underscores GBL's potential to enhance various aspects of EE, preparing students to meet the challenges of the modern workforce effectively.

Conclusion

This systematic literature review highlights the transformative potential of GBL in EE. GBL enhances student engagement, understanding, and skill development across various engineering disciplines and educational levels. It effectively adapts to diverse learning environments, meeting a wide range of educational needs. The integration of interactive gameplay, feedback mechanisms, and interdisciplinary elements makes GBL a versatile and powerful tool, significantly improving educational outcomes and preparing students for the challenges of modern engineering practice. This review contributes to the field by providing a comprehensive analysis of GBL's effectiveness and offering insights into its application, design features, and educational benefits, thereby guiding future research and implementation strategies in EE.

However, the review is limited by its reliance on a single database, IEEE Xplore, which, while comprehensive in its scope within engineering fields, may omit relevant studies available in other academic databases or journals. This could potentially skew the breadth and depth of analyzed data. Additionally, the restriction to English-language publications from the past few years may exclude valuable broader historical perspectives or relevant studies conducted in other languages.

Future research should aim to include multiple databases to capture a wider range of studies and consider including grey literature to provide additional insights into emerging trends and practical implementations of GBL. Expanding the linguistic scope of the literature search and extending the temporal range could uncover more diverse and comprehensive insights into the use of GBL in EE.

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Revolutionizing Engineering Education: Adapting Curricula to Address Artificial Intelligence Challenges and Opportunities

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Abstract

Undergraduate university education is at an impasse, and the pandemic has merely highlighted its problems. There will be stark consequences if nothing is done to alleviate the issues. Mechanical Engineering is taken as an example, mainly because the authors are familiar with mechanical engineering, though it is suspected that the problems go beyond that. The issue currently faced is outlined, and one possible solution is offered. A new way to look at a course of study for engineering education is proposed. This is based on a different perspective on engineering education and considers that modern technologies have modified every aspect of knowledge retrieval and dissemination, particularly the dissemination of Artificial Intelligence as a tool for research and knowledge archive. The curriculum proposed here answers questions such as: Why should the course of study for becoming engineers begin by first dividing the required knowledge into a fixed and finite set of subjects; why should the courses last a fixed number of weeks with a certain number of hours each? The proposal is explained using the commonly used mechanical engineering curriculum, but it applies to any branch of engineering or any other field.

Keywords: Engineering Curricula, Artificial Intelligence, Education Challenges, Certification.

Introduction

This analysis is about undergraduate education (González and Wagenaar, 2008, Agogino, 2008), and we must be clear that when we talk of students, we only talk of undergraduates (graduate/postgraduate studies are something else, more related to research, publications, and external funding). Because of the authors' background, much of what we will discuss here will be specifically related to mechanical engineering. However, the basic ideas apply to other branches of engineering and other disciplines and areas of study in universities.

Books have been written about wasting time and money going through a university curriculum[3] (see, for example, Caplan, 2018). Sometimes, however, people are under the misplaced impression that the phenomenon occurs in disciplines that can be loosely called "social sciences," but not necessarily in the "hard or exact sciences" (including engineering). The authors fear that current trends of reduction in undergraduate enrollment (Aguilar, 2021), NSC Research Center, 2022) will continue and lead to something drastic that no one wants. Curriculum reform in universities must come from inside; otherwise, it will be imposed by other factors (such as racial diversity Adepoju, 2023), choice of majors Devereaux, 2023, and other possible characteristics). It is important to take action right away to alleviate the situation.

Ideas of the educational process have changed in recent years, most of the modifications coming from theories such as *competence training* and *constructivism*, among others. They all propose new teacher- student interactions to improve the learning process but provide no specific recommendations for a different perspective. Regardless of the pedagogy or the educational model, students always construct their knowledge base and skills individually and adapt to the environment by themselves.

Lately, there have been significant changes in information technology which must also be considered. The internet has redefined communication channels, information storage, and search. Artificial intelligence (AI) revolves around the search for information, and its easy availability leads to the need for a change in the formal educational process. This incorporation of technology opens up many questions regarding engineering education and how it should be modified:

1. The need to divide engineering knowledge into a fixed number of courses.
2. If information (that can be transformed into knowledge) is available almost everywhere, why do students have to receive it at a fixed location from a professor?
3. What should the role of universities be in the new engineering education?

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There are many ways to answer these and related questions. To begin with, the educational system must first define the knowledge and skills a person must have to be an engineer. We are not talking about a university system in any particular country, but worldwide; they are all similar or strive to be.

Furthermore, what did we learn from the pandemic? In addition to a partial change to the work-from- home concept and home delivery of groceries, universities have been profoundly changed, even though most would like to return to the way things were before the pandemic. Video classes have been shown to work somewhat, but they can be further perfected. And if this is so, what is the purpose of traveling long distances to attend brief face-to-face classes?

The Current Situation

The fixed and finite set of subjects and a specified duration for each course have shown many advantages, such as a progressive learning framework, a certain level of quality and consistency in education, an explicit schedule for covering material, and meeting academic deadlines. A structured curriculum ensures students are exposed to theoretical foundations and practical applications, preparing them for real-world engineering challenges and professional practice. Nevertheless, it is facing many limitations, particularly in the context of new technologies like Artificial Intelligence (AI) and the abundance of information on the internet. AI and other emerging technologies are advancing rapidly, often outpacing the traditional curriculum development cycles. This rapid evolution can make it challenging for structured frameworks to keep up-to-date with the latest technological advancements and their implications for engineering practice. Many engineering problems today require interdisciplinary knowledge and skills that may not fit neatly into traditional subject boundaries. For instance, AI applications in engineering often require knowledge from computer science, mathematics, and specific engineering disciplines, necessitating a more integrated approach that traditional frameworks may struggle to accommodate. Engineering education is evolving towards more flexible and adaptive models in response to these challenges.

From a learning point of view, the current engineering curricula present several limitations and drawbacks. It imposes rigid timelines for learning specific topics, leading to superficial understanding or memorization rather than deep learning and conceptual mastery. Students may feel constrained in their ability to delve deeply into subjects that interest them or are critical for their career aspirations. They need help connecting knowledge that represents different engineering aspects with similar fundaments and mathematical models, for example. Engineering is a field where lifelong learning is essential due to rapid technological advancements; thus, the current engineering curricula may not adequately prepare students for continuous learning and adaptation throughout their careers, as they might focus more on completing predefined syllabi rather than developing skills for self-directed learning, or may limit opportunities for students to explore creative solutions and innovate within their coursework. There is a growing movement towards more flexible educational models in engineering, such as modular courses, competency-based learning, project-based learning, and interdisciplinary programs. These approaches aim to provide students with greater autonomy over their learning paths, accommodate diverse learning styles and paces, foster more profound understanding and critical thinking, and better prepare students for the dynamic and complex challenges they will face in their engineering careers. (Chiu, 2024; Chiu et al., 2023; Gunawardena et al., 2024; Tavakoli et al., 2022)

Some characteristics of the current old curriculum

In its basics, educational activities currently follow an evolutionary cycle, as shown in Figure 1. Cycling from deductions based on previous knowledge, using analogies to understand physics-based models with similar mathematics, and reinforcing the knowledge with repetitions. For example, looking at the specific case of the mining industry in Mexico, the *Real Tribunal de Minas* appointed experts, and the *Colegio de Minería* started formal courses for teaching future mining experts. The process for appointing mining experts ended when an academic jury examined each candidate and decided to nominate one or more. Over the years, the procedure for appointing experts has changed, but it is the origin of the current engineering degrees.

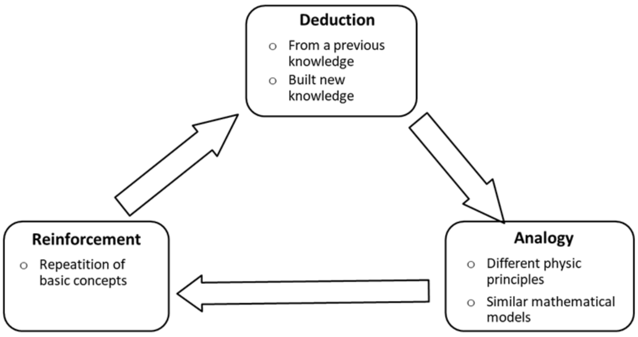

Figure 1. The situation as it is now (Jauregui-Correa, 2022)

A major "revolution" (to give it a name) in engineering education came after the Second World War. The curriculum changed from studying geometry, mensuration, surveying, and topology to calculus and physics-based mechanics. That approach has served us well for the decades since then, but it is time for another revolution. One source (Lattuca et al. 2006) says that "by the 1980s ... new graduates were technically well prepared but lacked the professional skills for success". Technology detonates societal changes, or perhaps it is the opposite; in any case, they are closely related.

Networking with other students is one of the strengths of the current system. The students come to know their peers, who may sometimes help them in some way in the future. On-campus lodgings are a few ways to achieve that since lifelong friendships are often born there. The students also greatly benefit from internships in industry, and in any change, a way must be found to keep that. Another issue is that of specialization. One of the main roles of universities is to create a multicultural space for sharing experiences beyond specialization. Society has a problem in that even the well-educated (like people with Ph.D., for instance) know only a small fraction of today's knowledge. Surely someone like Newton or Galileo knew a larger proportion of scientific knowledge of their times than a Ph.D. does of knowledge today. When the population of the Earth suffers a COVID-19 pandemic, antibacterial gels abound, but few know the difference between a bacterium and a virus. We have already mentioned that, even within universities, it is difficult for experts in one discipline to talk to those in another. An expert in one field is a beginner in the rest of human knowledge. However, it is hard to know what to do with the problem of specialization: by its very nature, it *must* exist if knowledge is to advance, but it is also, in some ways, counter-productive. Like most professors, the authors go to conferences where they meet and talk mostly to others who can understand them and rarely meet or talk to those who do not.

A fresh, new start on the curriculum

Current undergraduate engineering syllabi in universities and polytechnics worldwide are not exactly working: they do not do what they claim to do for the students. It is important to make a stronger link between engineering education and what the graduate actually does later. Rarely does a graduate of such a program after, say, 20 years of working at a job affirm that "I have really used all my education at some point in my career." And if he or she has not used a particular course, then it seems that it can be removed without much argument. Why is it there? However, the issue is not that simple: it seems to us that some mental maturity is associated with spending time sitting in a course and following a train of argument, not to mention other benefits like regularly taking exams or doing the assigned homework. However, much of that can be absorbed without any emphasis on, say, Newton's Laws of Motion; in fact, the student comes to believe that it is Newton's Laws and their application that we are teaching when it is all about being able to think straight about mechanical processes and relate *cause* and *effect*. A more profound question as to whether an equation such as $F = ma$ is a definition of force F, mass m, or acceleration a is worth considering but rarely studied. What is true, however, is that budding engineers learn how to use the equation. More than that, however, they should *feel* it in the sense that any force results in an acceleration, independently of the quantitative relation between them. Statics is, of course, a special case of this dynamics. If tweaking, or making small changes to the curriculum, does not improve the educational system, what will? If we gave each of us a blank sheet of paper to write down the knowledge base that we think a mechanical engineering graduate should have, we can only be sure that they would all be different, and most will differ from what is currently taught. For a fresh approach to education, one has to begin by asking what the students use in their jobs. However, there are also many difficulties with curriculum change. Faculty like to teach what they have learned as students and what they have taught before. Usually, likes and dislikes are formed early in their careers and do not change over their working lifetimes. For various other reasons, faculty currently in the educational system cannot be expected to change it radically, and it is easier for those outside to make suggestions that may, unfortunately, cut to the bone.

What the students really need to know! (Harris and Krousgrill 2008, McCahan et al. 2015)

The first thing to find out is what the students really need to know. It stands to reason that engineers must have enough knowledge and abilities to solve problems in the field. However, what should they be taught to get there? Many students are proud that they do not use all the math they are taught ("I am good with my hands but not good in math," they may say, "that is why I am in engineering"). So should math be eliminated from the curriculum? It is easier to say what is superfluous in the curriculum than what should be in it. Some aspects are, however, obvious. Students need to know how to think rationally, which is really hard to teach. However, that is what we assume we are teaching in traditional courses, even though the take-home message for the student is more like how-to, i.e., how to solve particular problems given to them in assignments or exams. Engineers must develop the ability to solve problems with the available tools within a limited time. Mathematics plays a crucial role in forming this ability. These courses must be treated as a calculator for children: very useful in reality but totally useless if they do not know what the results mean. The internet has tools to derive equations or to solve complicated algebraic formulas, and engineering students continuously use them to do homework assignments but do not necessarily develop the abilities described in Figure 1. When an engineer uses a math tool, for example, to find the derivative of a function, they expect a specific solution. In general, mathematical modeling leads to understanding. However, AI has become very strong today because we have been unable to model complex mechanical systems from the ground up completely. What has happened in the past serves as a basis for predicting the future. In contrast, engineering students have no previous knowledge of what they expect. Therefore, for the student, any answer will be correct, even if they have input a wrong function. This example illustrates the risks that modern computational tools can create if engineering abilities are not developed properly during education. These types of problems currently occur because breaking the curricula into a set of curses does not guarantee that the knowledge evolves from subject to subject.

A concrete proposal for the future

Other techniques have tried to solve learning problems by modifying the teaching process (without questioning the root problem or even identifying it). Examples are the education model based on competencies, and the inclusion of project-oriented learning, among others. None of them have questioned the need to modify the entire curriculum and dissolve the rigid structure of a fixed number of courses with a fixed number of classes and specific hours per week. Plus, there is the issue of accreditation and grading.

The main task is to develop an ability to reason, such that students will be able to analyze, evaluate and synthesize any problem (that could be solved using engineering skills) regardless of the time frame. The proposal compiles different thoughts and ideas discussed in our communities and presented in other forums (Berlanga et al. 2022). The effectiveness of non-synchronous education and the application of assessment tests has proven to be effective in many educational systems; therefore, this proposal is an evolution of teaching engineering experiences that have broken the traditional framework. In the new model, teachers would no longer be needed to instruct students; their role would be to curate the reading material and select the appropriate sources of information. They also have to prepare laboratory exercises to reinforce theoretical knowledge, and the relationship with students must be through coaching and advising them in preparing for exams. The proposed model is based on the idea of self-formation. Instead of breaking engineering knowledge into a fixed number of courses, every student must approve a set of examinations, laboratory procedures, and the development of projects to receive an engineering diploma. The tests must be organized sequentially and can be presented at any time; in this way, each student will determine their own rhythm based on their abilities and needs. The universities will become spaces for sharing knowledge and experience, coaching (if online coaching is not effective enough), and laboratories for hands-on work and research.

The new engineering learning process is based on a new paradigm (González and Wagenaar, 2008, and Mina, 2013). The roles of those involved are different from before; students would have to acquire new knowledge and thinking abilities by themselves. They would have to read textbooks, review videos, and do exercises at their own pace. They would not have to attend classes. They would progress in the program at their own pace. The idea is represented in Figure 2, where the examination structure is shown. Each circle, or node, represents a certification test of a set of common concepts and skills and is a prerequisite for the following nodes. Evaluating subjects has become a complex issue; the first question is grading. What does grading mean? Every country has its particular grading system, which distinguishes each student individually; nevertheless, the grading system cannot determine individual knowledge; thus, students must prove their knowledge and the engineering abilities they acquired during their studies. In the proposed method, there is no grading, every node has to be approved, and the distinction among students is the time they spend approving all the certifications, which are the nodes.

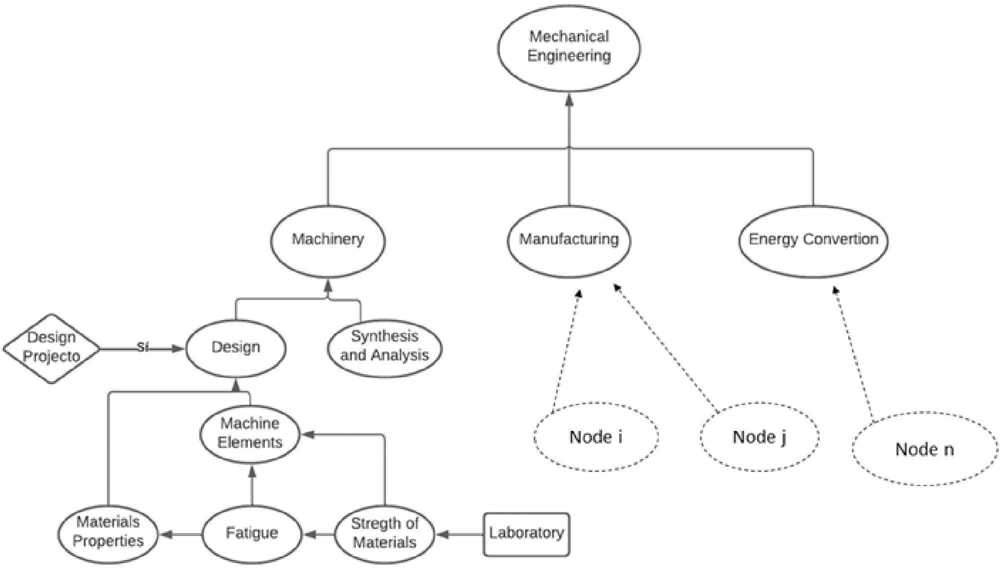

Figure 2. Outline of the alternative proposed curriculum.

The proposed method defines three types of nodes: theoretical, practical, and projects. Theoretical nodes are closely related to developing thinking skills and basic engineering concepts, from physics and mathematics to specific engineering subjects. Practical nodes are designed as laboratory activities with well-defined experiments and specific outcomes; students must fulfill a set of laboratory activities with their corresponding technical reports. Laboratory activities must be designed to develop testing skills, using logbooks, writing technical reports, using specialized instruments, and so forth. Before any practical nodes, students must have approved the theoretical prerequisite nodes. Project nodes are designed as complementary activities, where students combine theoretical and previous practical knowledge to solve real problems.

Additionally, teachers can organize short courses to reinforce individual studies. These classes should not be mandatory; they must be designed to support the learning process and could be taught at any time. The length of the courses must be adapted to the specific needs and requirements of the students. Table 1 is a summary of the roles in this new engineering curriculum.

Table 1. New Roles

Actor	Role
Student	Self-study Prepare for examinations Attend coaching sessions when needed Carry out joint projects and laboratory activities Involvement in extra-curricular activities within the university Network with other students
Professor	Curate certification material Design and update certification exams Coach students in specific subjects Monitor students' evolution Prepare and coordinate projects and laboratory activities Organize short courses Research
Staff	Organize and support cultural activities Administer student enrollment Procure laboratory and project materials Coordinate examinations and certification

Conclusions

The university system is headed for a crossroads, at which point some choices must be made. The pandemic has helped make it painfully clear that business as usual will not work, and some alternative must be found. *When* that happens is anyone's guess. The organizational structure of current universities is not flexible enough to change as needed. This, of course, is not the only line of business in trouble. In the restaurant business, for instance, people have realized that they go to restaurants not just for the food, and the waiters do not want to work for pittance either.

The present paper has proposed a new paradigm to prepare engineering schools for adapting to the technological revolution. The new curriculum model would eliminate the need for classes, courses, and grading and would force the students to acquire theoretical and engineering knowledge by themselves. The new curriculum is organized as knowledge nodes that guide and support students to construct engineering skills and knowledge for professional practice. In them, professors will have new roles. Instead of teaching, they will help students, individually or in groups, develop the necessary skills to fulfill the certification requirements, curate the material being studied, and update exams. They will organize laboratory activities and design specific projects. Networking is crucial for engineers; thus, students will participate fully in project development and laboratory practice, without the need for attending other classes at the same time. The methodology will use newly developed technologies and take advantage of AI, the internet, and the experience of working at home during the pandemic. Although not specific to engineering, we offer practical strategies for assessing (Marzano et al. 1993) and improving student learning, including developing competencies and skil.

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Assessing the Reliability and Validity of a Survey Questionnaire for Online Laboratory Courses in Mechanical Engineering Programs

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Abstract

In Mechanical Engineering academic program, the laboratory courses were conventionally hands-on nature that requires access to specialized equipment for practical learning experience purposes. However, immediate execution of Open and Distance Learning (ODL) during the global pandemic of COVID-19 has shaped new phenomena in teaching and learning including the laboratory courses. Assessment of the potential to continue with the online approach for the laboratory courses for better accessibility, flexibility, safety, and cost-effectiveness is necessary. This study aims to assess the validity and reliability of the designed survey questionnaires in investigating the suitability of conducting Mechanical Engineering laboratory courses in tertiary education via ODL method. The laboratory courses in Mechanical Engineering programs are diverse, each focusing on different areas of the discipline such as Manufacturing Process, Engineering Workshops, Applied Mechanics, Computer Aided Design and Thermofluids. However, the question was designed to suit all the laboratory courses offered by the program. Three domains of online delivery were investigated, the course delivery method, the assessment method, and suitability of the online delivery method. The reliability and validity of the survey questionnaire were assessed through a pilot test with a minimum of thirty respondents by using Principal Component Analysis (PCA) and Cronbach Alpha (CA). The analysis is done by deploying the Statistical Package for the Social Sciences (SPSS) software. The analysis results indicate the survey questionnaires are reliable and valid, the Cronbach Alpha value of 0.928 and Kaiser-Meyer-Olkin (KMO) index of 0.81. Thus, the survey questionnaires can be disseminated at large for the actual data collection purposes.

Keywords: Survey Questionnaire Assessment, Online Laboratory Course, Tertiary Education, Mechanical Engineering Academic Program.

Introduction

The COVID-19 pandemic has impacted the teaching and learning approach at universities globally. The pandemic brings challenges to the universities especially in the practical activities and laboratory exercises (Svatos et al., 2022). Online learning gained prominence during the pandemic, as it provided a crucial alternative to in-person education. Now that the pandemic has subsided, thus the necessity of continuing online learning, particularly for lab courses that traditionally rely on hands-on, in-person instruction should be investigated for the emergency remote teaching situation (Ferrie et. al., 2020).

Furthermore, in the engineering field the transition to online learning presents unique complexities, especially for courses and subject matter that contain technical elements (Asgari et al., 2021). Thus, an innovative Open and Distance Learning (ODL) using a reliable learning management system (LMS) is crucial (Cui et al., 2023). To immediately address this issue Universiti Teknologi MARA, School of Mechanical Engineering has taken the initiative to investigate the teaching and learning readiness of the laboratory courses among the students and the educators. Survey questionnaire approach is used for data collection for this exercise. Survey questionnaire is one of the means of collecting standardized quantitative primary data that are consistent and coherent for analysis (Satya & Roopa, 2017).

A survey questionnaire is a convenient way of gathering data from the target respondents in a period. The data gathering approach can be in the form of face-to-face interview, online survey, telephone interviews, and postal surveys (Ornstein, 2014). Technically, a survey questionnaire is just an ordinary list of questions for common people. But design of the questionnaire will determine the conclusiveness of the findings. Typically, the questionnaire must be well structured that include the language used, the type of the questions posted, the sequence of the questions arranged and many other attributes which have the direct impact to the survey results (Yaddanapudi et al.,

Yusoff, N., Abd Razak, A., Mohd Abbas, N. (2024), Assessing the Reliability and Validity of a Survey Questionnaire for Online Laboratory Courses in Mechanical Engineering Programs, *ASEAN Journal of Engineering Education*, 8(1), 70-75.

2019). Close-ended question allows the respondent to choose the predetermined responses, easier and faster but with limited information. Example of such questions are the one that is constructed using Likert scale (Taghinejad et al., 2023). On the contrary, open-ended questions requires the respondents to answer according to their perception and experience, it is time consuming but resulting to gaining deeper information (Ohji et al., 2021). A mixed of close and open-ended questions are likely to harvest high response rate with more informative data (Semyonov-Tal & Lewin-Epstein, 2021). Study shows that a well curated questionnaires able to generate an effective and accurate data of survey results (Taherdoost, 2016).

Despite of the urgency in getting the valuable insight of the required information, one should not compromise on the appropriate method of gathering the reliable data. Once the survey questionnaire is developed, pilot testing that assessing the reliability and validity of the set questions needs to be done (Yaddanapudi et al., 2019). Pilot test of the survey questionnaire is a critical step in the design of questionnaires before the actual data collection commences (Ornstein, 2014). Reliability is about the consistency of the survey questionnaire in attaining the answers from the respondents, despite of the gender differences in the set target group (Silva et al., 2023). Validity of the questionnaire relates to its accuracy in assessing what it was intended to measure, as indicated by the predetermined questions. (Koy et al., 2023). As matter of protocol, the reliability test needs to be performed before the validity test is done because the survey questionnaire must be consistent thus reliable then only rationale for the validity assessment (Sarmah & Bora Hazarika, 2012).

The study presents an assessment of the survey questionnaires in investigating the suitability of conducting Mechanical Engineering laboratory courses in Mechanical Engineering academic programs via ODL method. The pilot study was commenced to assess the reliability and validity of the survey questionnaire using Cronbach Alpha (CA) and Principal Component Analysis (PCA) test, respectively. Finally, the conclusion is made whether disseminating the survey questionnaire at large to the target respondents is viable or not.

Methods

This study was conducted in three stages. In stage 1 the survey questionnaire was designed according to the purpose of the study. Then in stage 2 the set questionnaires were disseminated to the target population for pilot testing. Stage 3 is where the reliability and validity of the survey questionnaires were analysed using Cronbach Alpha (CA) and Principal Component Analysis (PCA) test, respectively. The CA coefficient analysis is used to determine the internal consistency and homogeneity of items in Likert-type scales (Köse & Çelebioğlu, 2018). The interpretation of the CA coefficient internal consistency and homogeneity is available in Table 2 (Aithal & Aithal, 2020). The PCA is a useful method for the validity test for a newly developed survey questionnaires where factors in each understudy domains have not yet tested (Laura & Stephanie, 2011). The PCA is also recommended to be used when no prior theoretical basis or model exists (Taherdoost et al., 2014). The qualifying indicator for PCA test is Kaiser-Meyer-Olkin (KMO) that measures the sampling adequacy and Bartlett's Test that 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 or above 0.7(Hair J et al., 2014). Whereas, for the 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).

Then, from here the factor extraction and factor loading were done to determine the number factors (in this case the questions set in the questionnaires) that needs to be extracted. It is basically to determine the number of factors that best represent the interrelationships among the set variables (Shrestha, 2021). It is said that the eigen value > 1 is considered significant and the factor loading value of >0.4 indicates the factors represent the purpose of the study (Shrestha, 2021).

All the above analyses were done by deploying the Statistical Package for the Social Sciences (SPSS) software.

Stage 1: Design of the Questionnaire

Discussion was conducted among the lecturers who are teaching the laboratory courses at the School of Mechanical Engineering, UiTM Shah Alam. The intention of the discussion is to get the insights of the relevant information needed for the study. Six engineering laboratory courses that are offered for the Bachelor (Hons) in Mechanical Engineering program were selected for the study. The courses are MEM564 (Manufacturing Processes Laboratory), MEM460 (Engineering Workshop Practice Laboratory), MEC424 (Applied Mechanics Laboratory), MEC435 (Computer Aided Design Laboratory), MEC454 (Thermofluids 1 Laboratory), and MEC554 (Thermofluids 2 Laboratory). For this study, three main domains were investigated: i) effectiveness of the teaching and learning delivery, ii) the assessment method, and iii) suitability for the Open and Distance Learning (ODL).

Table 1 presents the three main domains and the set questions for the investigation. Two types of question structure were adopted for the study, a close-ended and open-ended questions. The former was set with 5-likert scale quantification measurement and the latter was to get the qualitative feedback from respondents such as recommendation for improvement from students. The survey questionnaires were created using online google form. The online platform that are used for disseminating the survey questionnaires are by Emails, WhatsApp, and Telegrams.

Table 1. The Questionnaire Domains and Descriptions

Domains	Descriptions
Online Distance Learning Suitability **1.**ODL suitability for this course [Material delivery (e.g., recorded video)] **2.**ODL suitability for this course [Teaching delivery] **3.**ODL suitability for this course [Learning activities] **4.**ODL suitability for this course [Assessment (e.g., report)] **5.**ODL suitability for this course [Knowledge/skill gained] **6.**ODL suitability for this course [Application of knowledge/ skill in assessment]	This domain reflects the respondents' perception on the suitability of the ODL for their specific needs; in the perspective of teaching and learning delivery as well as the assessment method.
Online Distance Teaching & Learning Delivery **7.**ODL delivery method [Live online lecture/ demonstration] **8.**ODL delivery method [Recorded video lecture/ demonstration] **9.**ODL delivery method [Recorded audio lecture/ demonstration (with slides)] **10.**ODL delivery method [Lecture note/manual]	This domain reflects the respondents' perception on the type of the teaching delivery of ODL.
Online Distance Learning Assessment **11.**ODL assessment [Asynchronous assessment type] **12.**ODL assessment [Synchronous assessment type] **13.**ODL assessment [Submission platform through LMS] **14.**ODL assessment [Submission through WhatsApp/ Telegram]	This domain reflects the respondents' perception on the assessment method during ODL.
Recommendation for Improvement from Students	This domain reflects the respondents' recommendations for improvements in ODL

Two types of question structure were adopted for the study, a close-ended and open-ended questions. The former was set with 5-likert scale quantification measurement and the latter was to get the qualitative feedback from respondents such as recommendation for improvement from students. The survey questionnaires were created using online google form. The online platform that are used for disseminating the survey questionnaires are by Emails, WhatsApp, and Telegrams.

Stage 2: Pilot Test

The pilot study commences with the MEM564 (Manufacturing Processes Laboratory) course. The survey questionnaires were disseminated via online to thirty (30) students that enrolled the course. Previous study suggests that the suffice pilot test sample size can be as minimum as 12 or 30 respondents (Sarmah & Bora Hazarika, 2012). Other study affirms that a minimum of 10 respondents per instrument is recommended (Laura & Stephanie, 2011). The pilot test is a screening process before the actual data collection begins. The advantage of the pilot test is it assists the researcher to detect any weaknesses in the questionnaire in terms of the theme, content, grammar, sentence structure, and the survey questionnaire layout format (van Teijlingen & Hundley, 2002). Close monitoring is done during this stage and any feedback or recommendations from the respondents are taken seriously for the next improvement. At this stage, the survey responses data cleaning is done to ensure that there are no duplications or errors such as incomplete responses in the data set since this data is consider as prime data. Processing the accuracy of the prime data before further analysis is crucial to ensure the outcome of the subsequent analysis is accurate and reliable (Mullat, 2011). The data cleaning activities is prerequisite before the reliability and validity test are performed.

Stage 3: Reliability and Validity Test

After the pilot test, the reliability and validity of the survey results were evaluated using Cronbach's Alpha (CA) and Principal Component Analysis (PCA), respectively. Once the reliability and the validity of the questionnaires are achieved, the survey questionnaire is ready for the distribution to the target populations; the six selected laboratory courses, MEM564 (Manufacturing Processes Laboratory), MEM460 (Engineering Workshop Practice Laboratory), MEC424 (Applied Mechanics Laboratory), MEC435 (Computer Aided Design Laboratory), MEC454 (Thermofluids 1 Laboratory), and MEC554 (Thermofluids 2 Laboratory).

Reliability: Cronbach Alpha (CA)Test

The reliability of the survey results is done to assess the internal consistency of the survey results. Cronbach Alpha (CA) coefficient is a common indicator to measure the internal consistency of the survey results of the intended purpose. Table 2 displays the list of CA value and its interpretation according to the degree of the reliability. Subject matter expert suggests that Cronbach Alpha's value should at least 0.7 to indicate an adequate internal consistency and reliability in each questionnaire (Christmann & Van Aelst, 2006).

Table 2. Interpretation of Cronbach Alpha (CA) (Aithal & Aithal, 2020)

Value of Cronbach's alpha (α)	Degree of Reliability
1 α ≤ 0	A fundamental problem in the design of the questionnaire and the researcher should relook into the format of the questionnaire intended to use for the survey.
2 0 < α < 0.5	Low internal consistency and hence poor inter-relatedness between items. Should be discarded or revised.
0.5 < α < 0.7	0.5 < α < 0.7 Moderate internal consistency and reliability of a given questionnaire. Can be revised.
α = 0.7	Adequate internal consistency and reliability of each questionnaire.
0.7 < α < 0.9	High internal consistency and reliability in each questionnaire. Can be revised.
0.9 < α < 1.0	There are items in the questionnaires may be redundant, and the researcher must consider removing the items from the questionnaire. i.e. repeated questions in multiple ways.
α = 1.0	Perfect internal consistency in each questionnaire.

Validity: Principal Component Analysis (PCA) Test

The reliable components of the survey results were further analysed its validity using Principal Component Analysis (PCA) test. The PCA test is used to measure the principal components of the questionnaires. The PCA test provides empirically robust results and 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, the PCA indicator of 0.6 and above are broadly accepted by many researchers (Aithal & Aithal, 2020).

Results and Discussions

Reliability and Validity of the Questionnaire

A total of thirty (30) students who have registered for the MEM564 (Manufacturing Processes Laboratory) course participated in the pilot test survey. Table 3 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 3. Case Processing Summary for the Pilot Survey Response

Description		Number of Respondents	%
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 4 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 teaching & learning delivery, the assessment method, and its suitability for the online distance learning (ODL) domains (Table 1 refers). Cronbach's Alpha (α), 0.928 indicates high internal consistency and homogeneity of the survey questionnaires.

Table 4. Reliability Statistics

Cronbach's Alpha (α)	Number of Items
0.928	14

Table 5 shows the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test outcomes. The KMO coefficient of 0.81 indicates that the sample size of 30 respondents is appropriate for factor analysis. The Bartlett's sphericity test is significant with chi-square value of 387.688 and degree of freedom 91; (p<0.05). These results indicate that the sampling data is adequate and fit for the PCA test.

Table 5. KMO and Bartlett's Test

Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy		0.810
Bartlett's Test of Sphericity	Approximate; Chi-Square	387.688
	Degree of Freedom	91
	Significance (p value).	0.000

Table 6 highlights the extracted principal components results of the understudied fourteen (14) components. These components are based on the survey questions that are listed in Table 1 which categorised according to the three domains: ODL suitability, ODL Teaching & Learning Delivery and ODL assessment. In this study, principal components eigenvalue of more than 1 were extracted, with an eigenvalue of more than 1. The four dominant components are of the ODL suitability:

1. ODL suitability for this course [Material delivery (e.g., recorded video)]
2. ODL suitability for this course [Teaching delivery]
3. ODL suitability for this course [Learning activities]
4. ODL suitability for this course [Assessment (e.g., report)]

The four extracted components accounting to the total of 83.963% of the total variance. It is suggested that the proportion of the total variance should be at least 50%(Shrestha, 2021). The result shows 83.963% common variance shared by the 14 components can be accounted by the four said factors. This is the reflection of the KMO value of 0.810, which can be considered favourable and indicates that the factor analysis is useful for the variables.

Table 6. The Extracted Principal Components

Components (No)	Eigenvalues		
	Total	Variance %	Cumulative %
1	7.970	56.931	56.931
2	1.364	9.745	66.676
3	1.335	9.538	76.215
4	1.085	7.749	83.963
5	0.657	4.694	88.657
6	0.429	3.062	91.719
7	0.316	2.259	93.979
8	0.285	2.032	96.011
9	0.198	1.416	97.427
10	0.122	0.871	98.298
11	0.111	0.791	99.089
12	0.063	0.452	99.541
13	0.037	0.261	99.802
14	0.028	0.198	100.000

Kaiser-Meyer-Olkin Measure of Sampling Adequacy. 0.810
Bartlett's Test of Sphericity; Sig. (p = 0.000)

The first component accounts for the 56.931% of the total variance with eigenvalue of 7.970, the second component has explained 9.745% variance with eigenvalue 1.364, the third component explained for 9.538% variance with eigenvalue 1.335, and the fourth component explained for 7.749% variance with eigenvalue 1.085.

Table 7. Summary of Factor Loading

No	Components	Factor Loading
1	ODL suitability for this course [Material delivery (e.g. recorded video)]	0.869
2	ODL suitability for this course [Teaching delivery]	0.870
3	ODL suitability for this course [Learning activities]	0.884
4	ODL suitability for this course [Assessment (e.g. report)]	0.849
5	ODL suitability for this course [Knowledge/skill gained]	0.875
6	ODL suitability for this course [Application of knowledge/skill in assessment]	0.864
7	ODL delivery method [Live online lecture/demonstration]	0.885
8	ODL delivery method [Recorded video lecture/demonstration]	0.785
9	ODL delivery method [Recorded audio lecture/demonstration (with slides)]	0.795
10	ODL delivery method [Lecture note/manual]	0.772
11	ODL assessment [Asynchronous assessment type]	0.851
12	ODL assessment [Synchronous assessment type]	0.875
13	ODL assessment [Submission platform through LMS]	0.863
14	ODL assessment [Submission through WhatsApp/Telegram etc.]	0.718

Table 7 presents the summary of the Factor Loading for the underlying components. The average value of 0.840 (> 0.4) indicates all the components in this case the set questions represent the purpose of the study, in investigating the suitability of conducting Mechanical Engineering laboratory courses in tertiary education via ODL method. Hence, none of the questions that need to be extracted for that purpose and the survey questionnaires is good to go for the next level.

Thus, both reliability and validity tests indicate that the survey questionnaires are consistent and valid for distribution for larger data collection group. Also, the pilot sample size of thirty (30) respondents suffices for the preliminary qualifying analysis.

Conclusions

The pilot test provides a decisive view of the survey questionnaires conformity for the intended purpose. The Cronbach's Alpha value of 0.928 exhibits high internal consistency of the survey questionnaires.

Also, the pilot sample of thirty (30) respondents is adequate with the Kaiser-Meyer-Olkin (KMO) index of 0.81 (adequacy with merit). In addition, the Bartlett's sphericity test value of p = 0.000 indicates the sample is statistically significant and viable. It can be concluded that the set questions in the survey questionnaire are correctly understandable and interpretable by the intended respondents. Hence the survey questionnaires are ready for dissemination to the larger group for data collection purposes. Suggestion for future research work in the survey discipline is to explore more analysis function in the SPSS for the reliability and validity test such as test-retest reliability, inter-rate reliability, split-half reliability, and expert validation.

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