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21st Century Engineering Learning and Teaching: Malaysia Perspective and Direction

Syed Ahmad Helmi Syed Hassan (Associate Professor)

Syed Ahmad Helmi is an Associate Professor at the Faculty of Engineering, Universiti Teknologi Malaysia (UTM). He received his Bachelor of Science in Mechanical Engineering from the University of Alabama, USA, Master of Engineering in Advanced Manufacturing Technology (AMT), and PhD in Engineering Education from UTM. He is currently a fellow at the Centre for Engineering Education, and Head of the University's Research Group in Engineering Education (RGEE). Prior to joining UTM, he worked as a maintenance engineer at INTEL, as research officer at the Standard and Industrial Research Institute of Malaysia (SIRIM), and as mechanical and industrial engineer at Sime-Darby, Malaysia. His research focuses on Mechanical Engineering, Industrial Engineering and Engineering Education. His recent works include augmented and virtual reality, academic change management, complex engineering problems, manufacturing systems and optimization, supply chain, and systems dynamic modelling. He is one of the University's Coordinators for Future Ready Educators (FREE). Over the years, he has conducted several workshops on Outcomes-Based Education (OBE) particularly in Student Centred Learning (SCL) throughout Malaysian Higher Institutions, and International Institutions such as in Indonesia, Korea, India, China, Turkey, Morocco, Qatar, South Africa, Pakistan, and Afghanistan. Throughout his career he received several awards such as Global Engineering Education Award 2021, teaching excellent awards, excellent service awards, best paper awards, and gold medals in innovative practices in higher education. He has published several books and more than 130 papers in journals and conference proceedings.

Khairiyah Mohd-Yusof

Professor Dr. Khairiyah Mohd-Yusof is the President of the Society of Engineering Education Malaysia, the founding Director of the Centre for Engineering Education, Universiti Teknologi Malaysia. She is practitioner, trainer, mentor and researcher in scholarly engineering education practices.

CHIN CHIA CHIA YUAN (ENGINEERING EDUCATORS FOR IR 4.0)

graduate research assistant at centre for engineering education

Fatin Aliah Phang

Nor Farahwahidah Abdul Rahman

Narina A. Samah (Assoc. Prof.)

Zaki Yamani Zakaria (Dr)

Nurzal Effiyana binti Ghazali

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Syed Ahmad Helmi*, Khairiyah Mohd-Yusof, Chin Chia Yuan, Fatin Aliah Phang, Nor Farahwahidah Abdul Rahman, Narina A. Samah, Zaki Yamani Zakaria, and Nurzal Effiyana Ghazali

Center for Engineering Education,
Universiti Teknologi Malaysia
**helmi@utm.my*

Abstract

Engineering education in Malaysia has been recognized by the Washington Accord (WA) since 2009. The International Engineering Alliance continuously updates the requirements for the Program Learning Outcomes according to the needs of the current and future global graduating engineers that member countries of the WA must fulfill. Recent requirements emphasize lifelong learning, complex problem solving, engineering activities, and computing and digital tools capabilities geared towards developing engineering graduates ready for 21st century challenges. When brought upon engineering educators, these increasing requirements posed a dilemma because most are not trained to educate students beyond what they have experienced in their previous formal learning processes, which may be irrelevant for today's learners. In a survey conducted by the UK Royal Academy of Engineering, engineering knowledge and skills are the topmost needed challenges to meet the needs of the 4th Industrial Revolution. Thus, to transform engineering education in Malaysia, the gap between the needs of the current and future engineering requirements, with the current engineering education practices, must be determined. Hence, this study aims to identify the gaps in Malaysian engineering education towards preparing 21st century ready educators, study the transition of engineering educators in their attempt to implement innovative education, and finally develop a framework for transforming engineering education through the infusion of innovative teaching and learning to support the development of the future-ready educators. The study uses a mixed-method research design to identify the gaps through document analysis, interviews, questionnaire surveys, and focus group discussions (FGD) among engineering education providers and industry players. The data will be analyzed and triangulated to chart the gaps in engineering education toward preparing 21st century educators. Later, this result will be used to develop the directions, actions, and transformation framework. The findings from this study will be used to formulate Malaysian national policy for transforming future-ready engineering educators who can excel and be on the leading edge of knowledge, innovation, and humanistic values to develop quality engineers in the 21st century. In this work-in-progress paper, only the initial part of the research, which is part of the document analysis, under the training construct, is reported.

Introduction

In the 21st century, new technologies, digitization, and automation profoundly impact the demand for workers across the world. New types of work are emerging, expectations of workers' skills are changing, and some jobs are disappearing. In this environment, policymakers need to identify gaps in engineering value to fill the gaps through upskilling or new hires. The engineering-related market shortages can disrupt economic growth, reduce output, and undermine productivity. If shortages persist in the long run, countries can become less competitive because industries lack the talent to innovate [1], [2]. Moreover, to be competitive, a developed country like Malaysia will also need engineers who can invent and produce the technology, rather than being limited to sales, installation, configuration, and maintenance of imported technological products. Identifying engineering-related expertise shortages as they arise and developing strategies to fill them is essential to maintaining productivity and competitiveness [3]. Many countries worldwide experience labor shortages, and Malaysia is no exception, much to the detriment of the nation's effort to be the innovators and creators of technology, not merely users [4].

Malaysian Higher Education Readiness

The Report on Critical Occupation 2018/2019 highlights the need to train more engineers in the advanced engineering industries, citing the country's efforts to progress towards the Industrial Revolution 4.0 (4IR) [5]. The report mentioned that Malaysia has a relatively young workforce in this sector, with 42.6% of full-time employees between 25 and 34 years of age. Top reasons for hiring difficulties include lack of technical knowledge and skills among engineers, lack of competency, and a small supply pool of talent. For entry-level engineers, the report found that employers have trouble finding engineers with problem-solving and critical thinking skills who can work independently and communicate well. These skills should already be developed among graduating engineers since they feature prominently as program learning outcomes required by the Engineering Accreditation Council. Given that these are the skill gaps of entry-level engineers, the companies must undertake short-term measures for human capital development initiatives. Thus, engineering program owners in Malaysian universities should be concerned about these deficiencies

These weaknesses clearly show a need to effectively train educators to infuse these transferable professional skills in their classes. The Report recommends that the Malaysian Government create engineering talents to prevent a negative impact on Malaysia's growth prospects. Its suggestions include bridging shortages by strengthening tertiary level curricula, providing training for specific engineering skill sets, and temporarily allowing foreigners to fill the gaps. The report also suggested offering higher salaries to retain the current engineering workforce, providing better benefits and incentives for engineers, and training current engineers to fill the gaps.

It is important to note that all these recommendations point to a critical need to improve engineering education for the nation's sake. Increasing the salary of those in engineering-related areas will not do much if the curriculum, which includes the delivery, and institutional ecosystem, do not support the development and implementation of high-quality academic programs. The development and implementation steps are mainly dependent on the quality of educators. Even with their high academic qualifications, the majority of the educators are not trained in teaching the required skills and rapidly changing knowledge and technologies, much less in instilling positive values and understanding 21st century learners [6]. Therefore, there is an urgent need to develop and support engineering educators not only in the 4IR technologies knowledge and skills but also in other 21st century professional skills and values [7]. This is consistent with the Ministry of Higher Education Policy regarding "Framing Malaysian Higher Education 4.0: Values-Infused Future Proof Talents" [8]. Thus, effective and sustainable transformation starts with training and instilling positive values among educators while ensuring an institutional ecosystem to promote quality engineering education for excellence in the 21st century.

Educators are the frontlines and critical resources for higher education institutions (HEI) towards delivering quality education to their nations. Today's educators are needed to be more responsible in better preparing graduates for the 21st century, which requires them to solve problems using technology and apply higher-order thinking skills (HOTS) to solve complex problems. Therefore, educator readiness is a significant factor in meeting 21st-century challenges. Planning talents toward developing neoteric educators is the fourth focus of MyHE4.0 [8], [9], [10]. However, the question is, are Malaysian educators ready to respond to 21st-century challenges? Can Malaysian universities manage the convergence, fluidity, power shifts, contingency, and ethical issues that came with the 21st-century challenges? Investment in emerging technologies and human connectivity, building digital resilience, and institutional capabilities in digital governance and accountability are vital strategies for survival. However, is the Malaysian higher education community doing enough to adapt to this transformation? Moreover, there is increased resistance to change in adapting and shifting the mindset of educators towards adopting technology-based education as it can limit the engagement or involvement of an educator with the students [11].

The COVID-19 pandemic pushed educators to conduct emergency remote teaching, with hands-on laboratory and skills-based workshops disrupted. The inability among educators to shift to online learning and create meaningful learning in their courses, along with the lack of available remote or online laboratories and simulated technology-based skills training, exposed the stark gap between engineering education requirements in the 21st century and what HEIs currently have. Therefore, well-designed and planned pathways to transformation must be adequately studied to bridge the gap in engineering education to transform educators effectively in a sustainable manner.

Need to Transform

Engineering educators may think they perform well to prepare graduates to serve the world upon graduation. Unfortunately, reports revealed that engineering graduates lack the quality and perseverance to compete and contribute to the industry for a nation's growth [12], [13]. In this situation, engineering educators must be aware of the urgent need to equip 21st century graduates. Although other factors are certainly in play, having better-trained educators create spillovers throughout the economy. The knowledge and skills of educators available in the education market become a crucial determinant to attract students locally and internationally. Developing educators eventually help produce 21st century graduates and workforce locally for economic growth. This will significantly upgrade the standard of living of Malaysians and improve the national economy.

The 21st century industry requires a highly skilled workforce who are innovators and problem-solvers, who have the knowledge and skills in modern engineering. Hence, transforming engineering education is crucial to producing 21st century graduates. But to do so, transforming and developing engineering educators, and changing the ways they educate is a vital step. Therefore, this research is dedicated to the transformation to accommodate 21st Century via two essential elements: engineering education (focused on knowledge) and innovative learning infusion (focused on application), which will be synergized to deliver high-quality results for the education system output and graduate readiness. From these, the gap and way forward of knowledge, skill, and application framework are identified and integrated to produce a national policy that will help shape the preparedness of engineering educators in Malaysia.

Research Objective

In 2009, engineering education in Malaysia was recognized as a full member of the Washington Accord (WA). Recent requirements of the Washington Accord, in line with the 21-century engineering challenges, emphasize lifelong learning, complex problem solving and engineering activities, and computing and digital tools capabilities. When brought upon engineering educators, these increasing requirements posed a dilemma because most of them are not trained to educate students beyond what they have experienced in their learning process. In a survey conducted by the UK Royal Academy of Engineering in 2016, on respondents across 29 countries from 5 continents, engineering knowledge and skills are the topmost needed challenges to meet the needs of the 21st-century challenges [14]. Thus, to transform engineering education in Malaysia, the gap between the conditions and the current status must be determined.

Hence, this project aims to:

1) Identify the gaps in Malaysian engineering education toward preparing 21st Century educators.
2) Study the transition of engineering educators in their attempt to implement innovative education.
3) Develop a framework for transforming engineering education through the infusion of innovative teaching and learning to support the development of the 21st Century Engineers.

Methodology

To achieve the aims of the project, a mixed-method research design is used. Both quantitative data and qualitative data will be collected through various sources and then triangulated. Firstly, the gaps are identified through document analysis, interviews, questionnaire surveys, and focus group discussions (FGD) among engineering education providers and industry players. The data are analyzed and triangulated to chart the gaps in engineering towards preparing 21st century engineers, particularly in educators' training, values, and institutional eco-system. Later, interviews and FGD are carried out with various stakeholders on the practical measures to transform engineering educators to design and implement innovative teaching and learning. Observations, discussions, and surveys will be carried out during educators' training and their implementation of the new method of teaching and learning to study the transformation. Benchmarking visits will be carried out to discover the best practices. The qualitative data will be analyzed using thematic analysis to identify the gaps and the measures. Later, Delphi method will be employed to finalize the standards. All the data will be examined and triangulated to develop a framework containing the directions, actions, and transformation.

This work-in-progress paper reports the research result of the first objective based on document analysis using thematic analysis that focused on training. A total of 154 research articles, reports, policy papers, and books related to engineering education from the year 2010 to the year 2021 were collected; a total of 117 documents were filtered. Table 1 shows the number of papers compiled and the final number of records that fulfilled the requirements of this research, which are:

a. No earlier than the year 2010
b. Related to engineering education in Malaysia
c. Related to the global trend of engineering education worldwide
d. Related to institutional ecosystem, training, and value of engineering education

Table 1: Document selected for analysis

Document type	Database / website	Number of collected	Number of selected for analysis
Books	National Academy of Engineering, Royal Academy of Engineering	14	9
Reports	National Academy of Engineering, Royal Academy of Engineering	35	28
Policy papers	Board of Engineers Malaysia, Engineering Accreditation Council	15	11
Research articles	Google Scholar, Scopus, ERIC, IEEE Explore, JSTOR	90	69
Total		154	117

The documents were studied and analyzed by experts in engineering education. Each paper was coded based on the main findings of the report. After the coding, the codes and documents were further reviewed and verified by a different expert to secure reliability. In this process, the definitions were developed. Later, the relationships between the sub-themes were identified to become the basis for identifying gaps in engineering education in Malaysia for preparing 21st century educators. Figure 2 shows the overall operational research flow of this project. This paper discussed the interim result of the project that focused on only one construct of the document analysis.

Interim Result

Document analysis was conducted based on three main constructs: training, ecosystem, and values. These are the main categories of transformation identified by the Ministry of Higher Education of Malaysia. However, only document analysis of the training construct will be discussed in this paper.

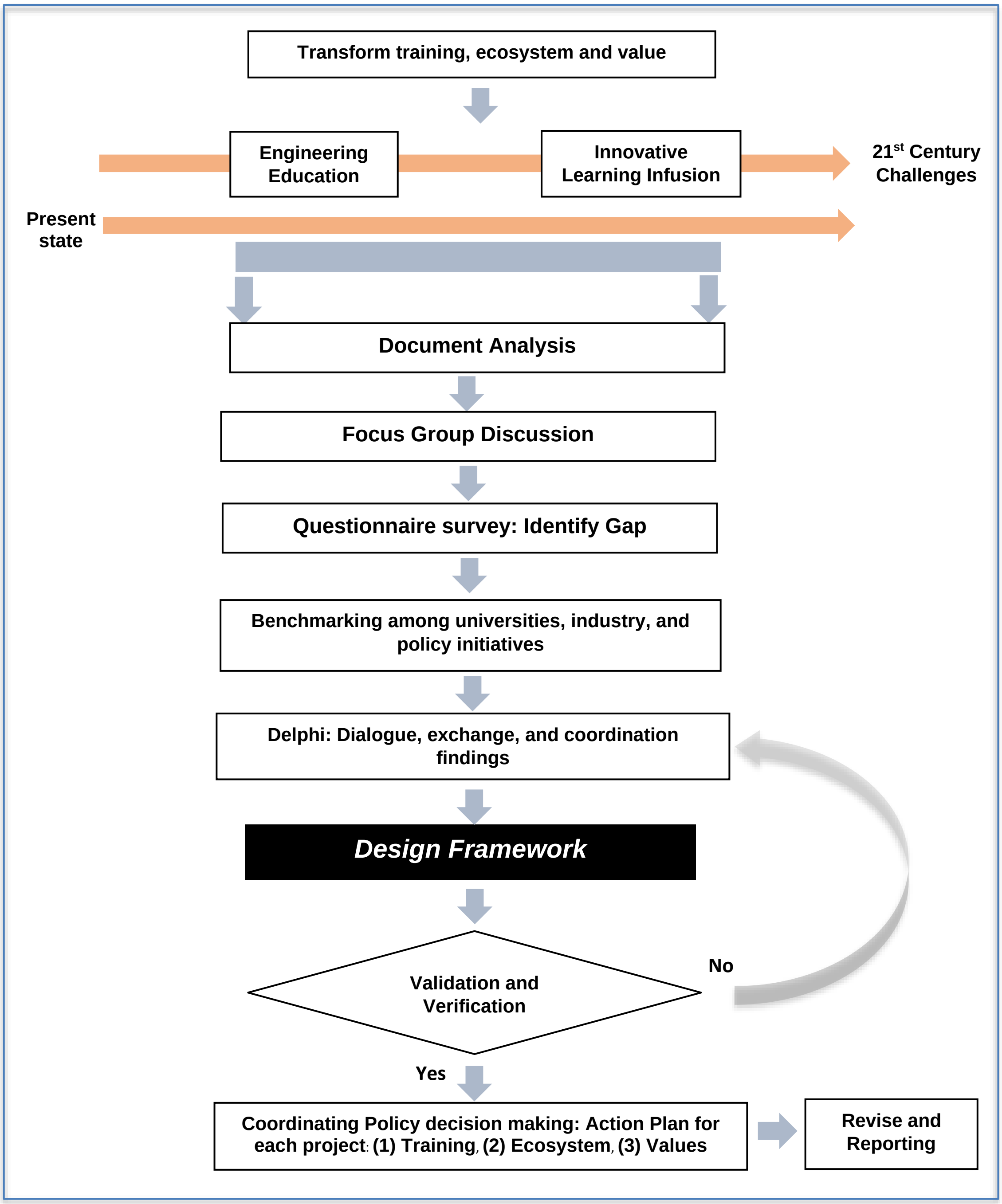


Figure 2: Research Operational Flow

Results from this document analysis are used to guide the researchers to develop the interview protocol for the next stage of the study. To establish document analysis, ten researchers from education and engineering performed the data analysis independently. All researchers are familiar with the general notion of training for engineering educators. The actual analysis process included six stages: article classification, codebook development, set rules for coding, training coders, coding, and analysis. The article classification starts with the general scopes as below:

- Teaching and learning for engineering education mentioned in general.

- Use of specific model/framework/theory for engineering education (sample range from educators and students).
- Teaching and learning with a specific purpose for 21st century challenges.
- 21st-century strategies for education in general.
- Network and resources relationship between industry, institution, society, etc.
- Teaching and learning management.
- Curriculum – cross-curriculum.
- Training (e.g., professional development)

All documents at the beginning of the analysis underwent general screening, following broad focus areas for full text and relevant titles to training. Once the study was completed, the remaining papers were distributed among researchers for initial tagging. Before the initial tagging, researchers were trained on handling the documents. These include how far the information must be extracted to avoid over, under, or missing interpretation between researchers. Papers that do not belong to training were excluded in the following process. The analysis started with developing an appropriate analytical framework to guide all researchers. The researchers from engineering backgrounds were usually not familiar with document analysis. However, they are the experts in their fields. Therefore, the analytical framework was based on Fairclough's critical discourse analysis [15]. Referring to this, the analysis looks for texts, discursive practices, and social practices to seek clarity of the language of documents and their language practices.

To become familiar with the analytical framework, the analysis procedure must be established first. This happened during the second phase, which is codebook development. In the beginning, researchers went through the entire text to identify the context which are the issues that gave rise to a need for the policy/research (i.e., purpose, construction, value). This was followed by texting that needs to be subjected to detailed data analysis, and consequences of training to people, process, and governance.

The process started with identifying the eight scopes of interest during full-text reviews. In this part, the coders created analytical aspects that constitute the study's document analysis to develop an abstract definition for training, the inclusion, and exclusion criteria. After describing the analysis context of training, a pilot analysis was executed among coders to ensure that the process was well thought out, consistent, and with desirable interpretations. This is because, in the end, the coders must first understand the identification of significant ideas operating in each document. Searching for the information that represents training was described as annotation and guided by the following questions:

1) What aspects (that you are looking for) are evident in the policy about training?
2) Does the policy refer to these aspects directly or indirectly?
3) What is stated explicitly in the policy about training?
4) What is not stated in the policy about training but relevant?
5) How does this align with the scope of discussion about training?

The first annotations were done in two cycles that allow other coders on the same document can make validation. All the annotation was then read and further analyzed by the researchers to ensure the suitability of contents with the research contexts. This is because the process of grouping requires the researchers to understand the warrant behind the annotation and how this piece of information was qualified to be grouped later. In defining the ideas about training, the annotations were analyzed to form several strategic areas that were operationally attributed to activity (refer to Table 2). During this content-level annotation, the targeted aspect of the training was tagged with color-coded to allow the researchers to develop a codebook. The development of the codebook refers to the conceptual framework to bring the content-level into the text-level analysis. The initial results from the content-level grouped the information into training that leads to renowned teaching and learning, development program, and engineering learning mechanisms and systems. Here, the analysis was finally conceptualized into several definitions as below:

1) Training exemplifies the efficiency of connecting institutional structure and culture with teaching expertise and changing norms of graduates' outcomes.
2) Training does not focus on the subject specialist but on pedagogical specialists that complement the subject matter delivery.
3) Training is associated with success and failure as a teaching academician among engineering educators.
4) Training here can be identified as a reform-based conceptualization for engineering educators.

The use of the definition is later expanded into the development of sampling frames. Sampling frames listed all the unit analyses from which documents will be drawn. The sampling frame is crucial to ensure that the papers used further for text analysis represent the cultural discipline for training.

The sampling frame was generated with the different codes focused on the context of the study, especially issues, claims, and arguments on the training of educators for engineering education. The views can vary from different perspectives such as framework, reform-based learning, outcome-based training, etc. Furthermore, the context of available initiatives for training is listed with the codes in the second category as well to describe in detail the new requirements, other researchers' models, theories, principles, and guidelines to train engineering educators. The inclusion and exclusion processes were conducted to filter the documents relevant to the research objective based on the codes. All documents that fulfilled the code of requirements by training were included for further analysis.

Table 2 shows the codes, strategic areas, and scopes for training. Training can be defined as the efficiency of connecting institutional structure and culture with teaching expertise and changing graduates' outcomes. Training does not focus on the subject specialist but instead on the pedagogical specialist that complements the delivery of the subject matter. Training is associated with success and failure among engineering educators as teaching academicians. Therefore, training here can be identified as a reform-based conceptualization for engineering educators. The sub-themes are Teaching and Learning practices, Development Programs, and Engineering Learning Mechanisms and Systems. From the themes and sub-themes developed within the context of eight strategic areas (S1 to S8), their relationships are shown in Figure 3.

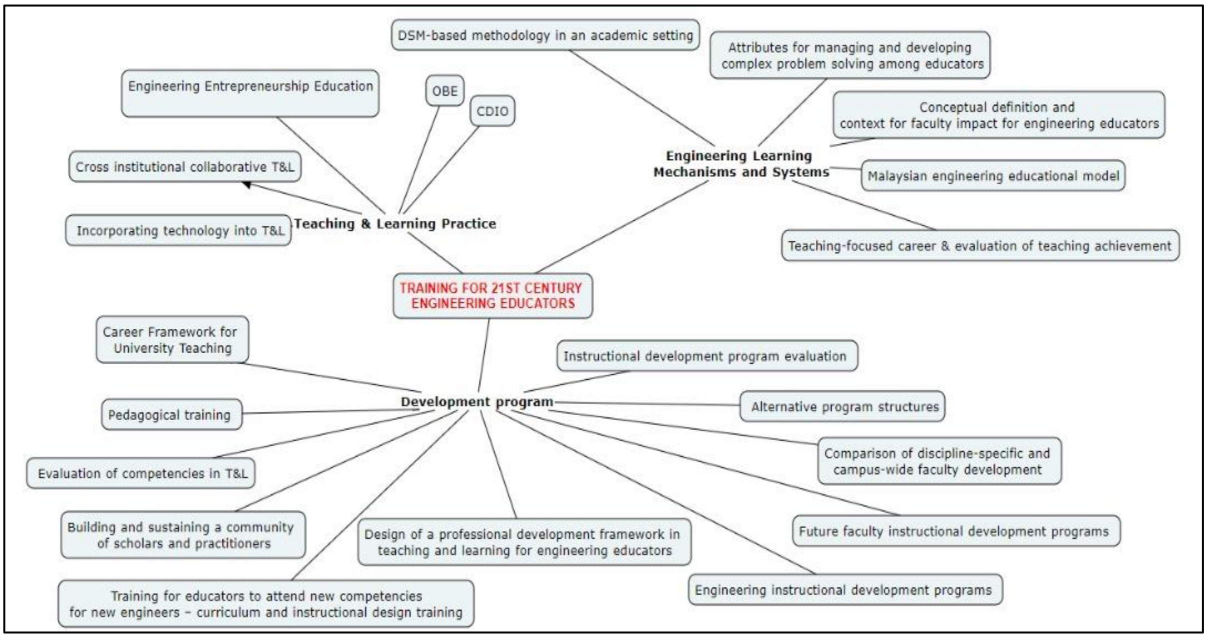
Table 2: Codes, strategic areas, and scopes for training

Strategic Areas	Scope	Codes
S1: Practice Development	Displayed particular professional dispositions which included knowledge, skills, and values that hang together in the practicing or	**Professional development (Teaching and Learning)** **Community of Practice** - educators having communities in implementing T&L

	enactment of a practice in which they play a part to teach engineering educators	
S2: People Development	Facilitating the learning of engineering educators through researching, critically reflecting, and evaluating teaching performance	**Educators' assessment supportive tools** -evaluate practices that affect the ecosystem
S3: Practice of developing practice	Cultivating a culture of care and collaboration with transparent communities of practice principles as condition, practice such as coaching and conducting action research	**Professional development (pedagogy for engineering educators, new curriculum, system support** - Knowledge transfer/communication within faculty/department **Learning organization** -Where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together **Professional development (career framework)** -A framework with a clear career path for engineering educators provides guidelines as a training basis for their career advancement
S4: Systemic leading practice / Systemic educational development	Model of development of knowledge and skills needed for engineering educators	**Curricular/new curricular/curricular mapping** -the process of setting goals, procedures, and objectives to make engineering educators more competitive.
S5: Diversity	We are linking organizational training and outcomes at the two and developing engineering educators for the current job environment. Focusing on fostering positive transformation through culture change.	Training in Workplace design
S6: Educational leadership and administration	role of school/faculty leadership in curriculum setting. It is a process of setting goals, procedures, and objectives to make a company or organization more competitive. Typically, strategic management effectively deploys staff and resources to achieve these goals. Often, strategic management includes strategy evaluation, internal organization analysis, and strategy execution throughout the organization.	Strategic management for cross-curricular
S7: Educational research, critical evaluation, and evaluation	developing job performance standards and measuring job performance via a loop system of assessment and suggestion. Course teachers also get benefit from the assessment practices. To summarise, assessment can be described as the following four-step cycle. 1) It formulates the course objectives.	Assessment and feedback

	2) It ensures provides learning opportunities for students to attain the course objectives. 3) It assesses students' performances and finds out how far they achieve course objectives. 4) It uses assessment results to redesign the instruction of a course to benefit students' learning if any.	
S8: Professional Learning (training)	Involved Mediating factors. Identify training needs and benefits to become a knowledge-creating organization."	organizational training benefit

Figure 3: Overview of Themes and Sub-themes



The overview of themes and sub-themes significantly showed the gap in the training of engineering educators in three specific areas which are teaching and learning practice, engineering learning mechanism dan systems, and development programs. For practices such as Outcome-Based Education (OBE) and Conceive Design Implement Operate (CDIO) are the innovative educational framework that can be implemented in the training of engineering educators in the 21st century. Various development programs at university levels are the main channels to create a more comprehensive training impact for engineering educators. Lastly, engineering learning mechanisms and systems must be discovered by the management team at the university level such as design structure matrix (DSM) based methodology in an academic setting. Those gaps and opportunities can be filled with well-planned training initiatives to maximize the outcome among engineering educators

Conclusion

The challenges in the 21st Century call for the need to transform the current engineering education. The most important agent of this transformation is the engineering educators. Thus, a comprehensive program must be planned and executed to train engineering educators with the 21st Century pedagogical knowledge. The inclusion of pedagogical approaches makes a difference in the way how engineering students learn, where they should be equipped with the skills and knowledge for long life learning to suit the industrials' needs. This research is conducted to chart the gaps in Malaysian engineering education towards preparing 21st-century engineers, particularly in educators' training, values, and institutional eco-system. Later, as shown in Figure 2, interviews and FGD will be carried out with various stakeholders on the practical measures to transform engineering educators to design and implement innovative teaching and learning. Observations, discussions, and surveys will be carried out during educators' training and their implementation of the new method of teaching and learning to study the transformation. Benchmarking visits will be carried out to discover the best practices. The qualitative data will be analyzed using thematic analysis to identify the measures. Delphi method will be employed to finalize the standards. Based on the result, a framework for transforming engineering education to support the development of the 21st Century Engineers in Malaysia will be formulated. This work-in-progress paper reports the research result of the first objective based on document analysis that focused on training. It will then follow by values and the institutional ecosystems before the Framework for Transforming Malaysia Engineering Educators is finalized to be used in the policy development for Malaysia Higher Education.

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