Effective Implementation of Complex Engineering Problems and Complex Engineering Activities in Malaysian Engineering Curricular

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https://doi.org/10.24191/ajue.v17i4.16219

Received: 23 June 2021
Accepted: 25 September 2021
Date Published Online: 31 October 2021
Published: 31 October 2021

Abstract: The Engineering Accreditation Council Standard 2020 requires the stipulated 12 programme outcomes that address complex engineering problems (CEP) and complex engineering activities (CEA) to be incorporated in the engineering programmes. However, the implementation of outcome-based education with regards to CEP and CEA is still in the infancy stage. This study was carried out to give an overview of the implementation of complex engineering problems and activities in Malaysian engineering programmes in relation to the types of assessment used to address CEP and CEA, and the typical weightage and taxonomy level of CEP and CEA employed in these assessments. A survey questionnaire was administered to 256 engineering educators from 25 universities to enquire about the implementation of CEP and CEA in their engineering programmes, particularly in the online teaching and learning during the Covid19 pandemic. The findings showed that most of the programmes addressed complex engineering problems in assignments or projects as compared to final examinations or mid-term tests. Complex engineering activities were found to be addressed in Final Year Project, Industrial Training and Integrated Design Project and laboratory courses. The findings in this study could act as a guideline for educators to enhance the teaching and learning activities incorporating CEP and CEA elements, and hence facilitating the continual quality improvement for an engineering programme.

Keywords: Complex Engineering Problems, Complex Engineering Activity, Engineering Accreditation Council, Outcome-Based Education

1. Introduction

Since 2019, Malaysia has been one of the signatory countries of the Washington Accord (WA) which is part of the International Engineering Alliance (IEA). The WA comprises of the constitutions for recognition or accreditation of tertiary level engineering qualifications (IEA, 2014).Thus, the Engineering Accreditation Council (EAC), Board of Engineers Malaysia (BEM) requires engineering degree programmes which seek for accreditation need to prepare graduates for future technological and societal changes, and able to solve complex engineering problems based on IEA's purview. Under Outcome-based Education (OBE), there are seven (7) programme outcomes (POs) emphasising on complex engineering problems (CEP) and complex engineering activities (CEA) that ought to be incorporated in the engineering curriculum.

However, the authors believe that the OBE implementation with regards to CEP and CEA are still in the infancy stage (Mat Isa, Oh, Liew, Mohd Saman, Che Ibrahim & Yusof, 2021) towards effective Continual Quality Improvement (CQI) of undergraduate engineering programmes. Therefore, this study presents an overview of the implementation of CPS and CEA in Malaysian engineering programmes in relation to the types of assessment used to address CPS and CEA, and the typical weightage and taxonomy level of CPS and CEA employed in these assessments as well as the relevant departmental support. A survey questionnaire was administered to 256 engineering educators from 25 universities to enquire about the implementation of CEP and CEA in their engineering programmes. A quantitative approach was adopted using survey questionnaires administered to engineering educators in Malaysia using purposive sampling on a group of educators' participating during a webinar.

2. Literature Review

The World Economic Forum (2016) and the Ministry of Higher Education, Malaysia (Tapsir & Puteh, 2018) identified that complex problem solving is the top skill needed to thrive in the 4th Industrial Revolution. Complex engineering problem solving was emphasized in the International Engineering Alliance's (IEA) programme outcomes (IEA, 2013) and the Engineering Accreditation Council, Malaysia's (EAC) accreditation standard (EAC, 2020). EAC requires that engineering degree programmes which seek accreditation must prepare graduates for future technological and societal changes, and able to acquire new knowledge through new problems (EAC, 2020). Due to the importance of this skill, IEA released the attributes of complex engineering problems to guide the signatory countries of the Washington Accord in their implementation of complexity in engineering curriculum in 2013 (see Table 1). These attributes can be used by the Higher Learning Institutions (HLIs) to compare and contrast the problems in the classrooms with those in the industry. The Washington Accord is a part of IEA which comprises of the constitutions for recognition or accreditation of tertiary-level engineering qualifications; and Malaysia is part of the accord since 2009 (IEA, 2014).

Table 1 Range of problem solving

No.	Attributes	Complex Engineering Problems
1	Depth of knowledge required	Cannot be resolved without in-depth engineering knowledge at the level of one or more of *(WK3, WK4, WK5, WK6 or WK8) which allows a fundamentals-based, first principles analytical approach.
2	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.
3	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.
4	Familiarity of issues	Involve infrequently encountered issues
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.
7	Interdependence	Are high level problems including many component parts or sub-problems.

*The characteristics of the knowledge embodied in an engineering degree programme (Source: IEA, 2013)

Regrettably, the common problems encountered in engineering programmes are not authentic industry-based but well-defined or classroom problems (Jonassen et al., 2006). Complex engineering problems are often encountered in design-based projects (Johri & Olds, 2011; Hotaling et al., 2012). Unfortunately, in most cases, these projects often lack real issues of industry environment; and engineering educators often fail to design complex engineering problems in assessing students' mastery of the skill (Fatin et al., 2016). According to Liew et al. (2020a), these are largely due to the poor understanding of the attributes of complex engineering problems among engineering educators thus preventing them from constructing design projects that simulate real industry scenarios. In a comparative study on the assessment rubrics designed to assess design-based projects conducted by Liew et al. (2020b) showed that many of the attributes shown in Table 1 are underexplored to provide a wider variety of complex engineering problem-solving to the students. These shortcomings may have implication on the effective implementation of complex engineering problems and activities in the engineering curriculum.

There are intercorrelations between the EAC's complex engineering problem solving, programme outcomes and knowledge profile (see **Fig. 1**).

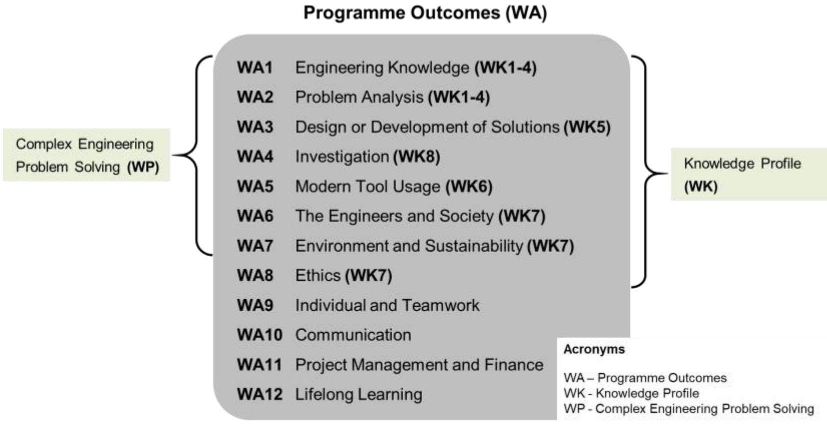


Fig. 1 Programme outcomes, knowledge profile and complex engineering problem solving

It is important to understand these relationships in order to facilitate the implementation of complex problem in the engineering curriculum. Firstly, students' ability to deal with complex engineering problems is emphasised in seven (out of the twelve) associated EAC's programme outcomes, namely, Engineering Knowledge, Problem Analysis, Design or Development of Solutions, Investigation, Modern Tools Usage, Engineer and Society, and Environment and Sustainability (Liew et al., 2020a). Secondly, in order to be classified as a complex problem, the programme must demonstrate the first attribute, the depth of knowledge and several other attributes (IEA, 2013) indicated in Table 1.1. And finally, a complex engineering problem must encompass one or more of components of the knowledge profile embodied in an engineering degree programme. Therefore, in order to develop the seven programme outcomes required from the engineering graduates, they ought to be able to solve complex problems with the engineering knowledge acquired in their undergraduate programme.

This study hopes to shed some light on the current practices adopted by engineering educators in incorporating complex engineering problems and activities in their academic programme as well as the challenges faced by them. This has been carried out through a survey on 265 engineering educators from various universities in Malaysia.

3. Methodology

3.1 Methodology Framework

This section presents the methodology framework developed for this study. It is based on the review of previous studies and research methodologies as depicted in Fig 2.

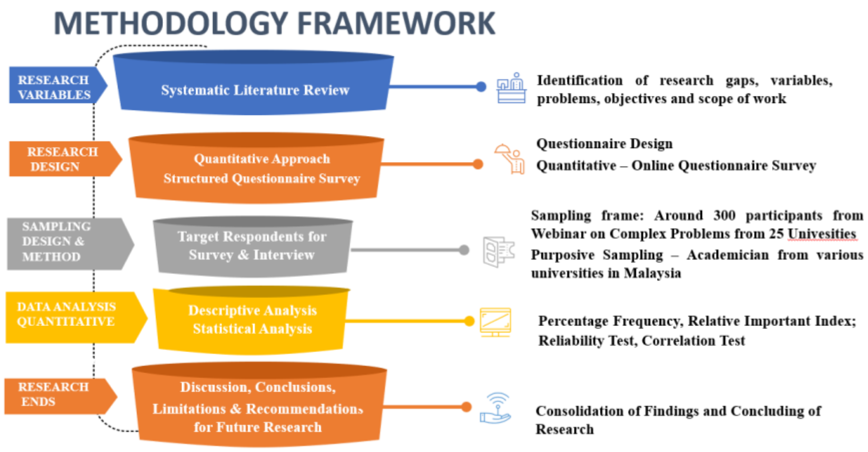


Fig. 2 Methodology Framework

Fig. 2 shows a methodology framework established in this study which are first, to identify and determine relationship between variables. Next, the research approach and instrumentation were developed, where the justification for research paradigm, research design, data collection methods, processes and analysis was outlined. A quantitative approach using survey was adopted; and the details of the processes are presented in the following section

3.2 Research Design

A quantitative approach was adopted using survey questionnaires to elucidate educator's understanding and implementation of complex engineering problems in their programmes.

3.3 Research Instrument Design

In this study, a survey questionnaire was designed and administered to gather information from the respondents to answer the research questions. A reliable and valid questionnaire is of utmost importance to ensure accurate data is collected so that the results are interpretable and generalisable. An online survey questionnaires using a well-structured questionnaire containing closed-ended questions was administered prior and after the webinar session dated 06 July 2020. At the end, two hundred and sixty-five (265) academicians have responded to the survey. The survey questionnaires are framed and designed to draw information that to fulfil research objectives which are to have an overview of the implementation of CPS and CEA in Malaysian engineering programmes in relation to the types of assessment used to address CPS and CEA, and to determine the typical weightage and taxonomy level of CPS and CEA employed in these assessment as well as the relevant departmental support. Therefore the survey are structured into three main sections; Section A: Respondent's Profile, Section B: Implementation of Complex Engineering Problems – Types of Assessment, Assessment Weightage, Taxonomy Level and Section C: Departmental Supports – Resource Person and Training on Skills required to improve the implementation of the complex engineering problems and activities in their programmes. This paper presents only the results from Section A and Section B.

3.4 Sampling Design and Target Respondents

This study adopted a non-probability sampling using as purposive sampling. The sampling frame is based on the number of participants attending a webinar conducted on alternative assessment incorporating complex engineering problems and activities. The speaker is a renowned person in engineering education, currently the Director of Engineering Accreditation Department, Board of Engineers Malaysia. There were 265 respondents, out of around 300 webinar participants. They are currently the lecturers teaching engineering programmes from 25 public and private universities in Malaysia.

3.5 Data Analysis

Analysis was carried out using both statistical and descriptive analysis. The following section describes the results and discussion

4. Results and Discussion

A reliability test was carried out giving a Cronbach Alpha value of 0.729 for 26 items in Section B.

4.1 Respondent's Background

Section A of the survey enquires the respondent's background from a group of Malaysian engineering educators to study the implementation of complex engineering problems and complex engineering activities in engineering undergraduate programmes. They were lecturers from a total of 25 Malaysian public and private universities with most of them (72.8%) affiliated with Universiti Teknologi MARA. Other universities includes University College of Technology Sarawak, Universiti Malaysia Sarawak, Universiti Malaysia Perlis, Swinburne University of Technology Sarawak, SEGI University, MAHSA University, Linton University College, Infrastructure University Kuala Lumpur, INTI University, Universiti Malaya, Universiti Kebangsaan Malaysia, Taylor's University, Manipal International University, Universiti Tunku Abdul Rahman, Universiti Tun Hussein Onn, Universiti Sains Malaysia, Universiti Putra Malaysia, Universiti Pertahanan Nasional Malaysia, Universiti Malaysia Sabah, Universiti Selangor, Universiti Teknologi PETRONAS, Universiti Kuala Lumpur, Multimedia University.

Fig. 3 shows the qualification and experience of the respondents. The respondents comprised of 3% Professors, 10% Associate Professors, 57% senior lecturers, 19% lecturers and 11% other positions. Among the respondents, 48% held Doctorate qualification, 43% held Master degree qualification and 9% held Bachelor degree qualification. All the respondents were academicians, with 50% of them having served as academicians for more than 10 years in an engineering programme. From the data, 59% of the respondents possessed more than one year industrial experiences. Additionally, 66% of the respondents had taught the same engineering course for more than three semesters. Generally, all the respondents had a tertiary qualification with more than half of them having adequate industrial experience and currently serving at a senior level in an engineering programme.

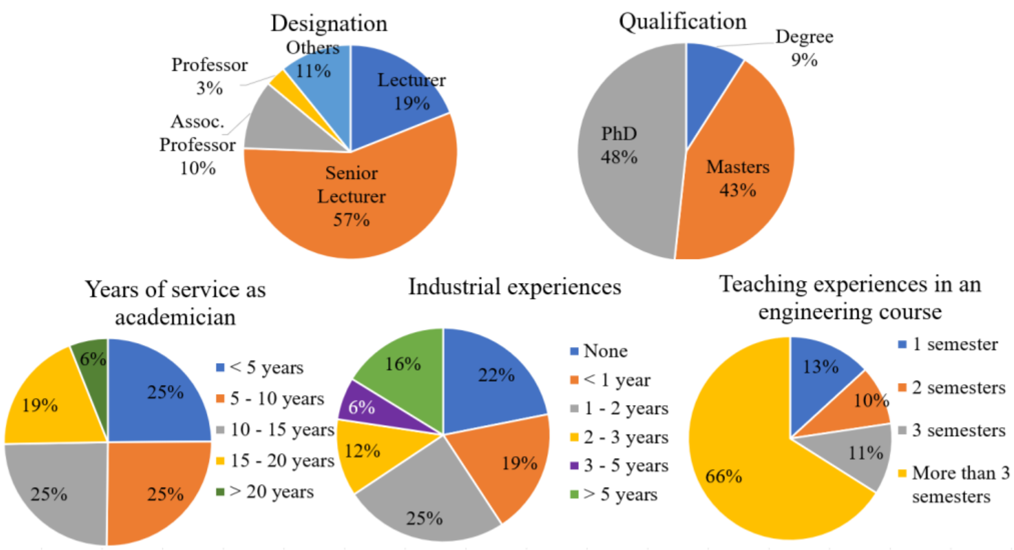


Fig. 3 Respondents' profiles: qualifications and experiences

4.2 Training Background

Fig. 4 shows the frequency of Malaysian engineering educators' participation in training programs relevant to this study. It can be seen that approximately 92% of the respondents had participated in general teaching and learning training programs. For more specific trainings, about 77% and 72% of the respondents had partaken in trainings related to the complex engineering problems and accreditation for engineering programme respectively. It can be noted that the respondents' frequency of participation in training programs on complex engineering problems was considerably low in comparison to their years of service in an engineering programme. Particularly, with more than 50% of the respondents having above ten-year services in an engineering program, only 35.1% of the respondents attended over three times for such training.

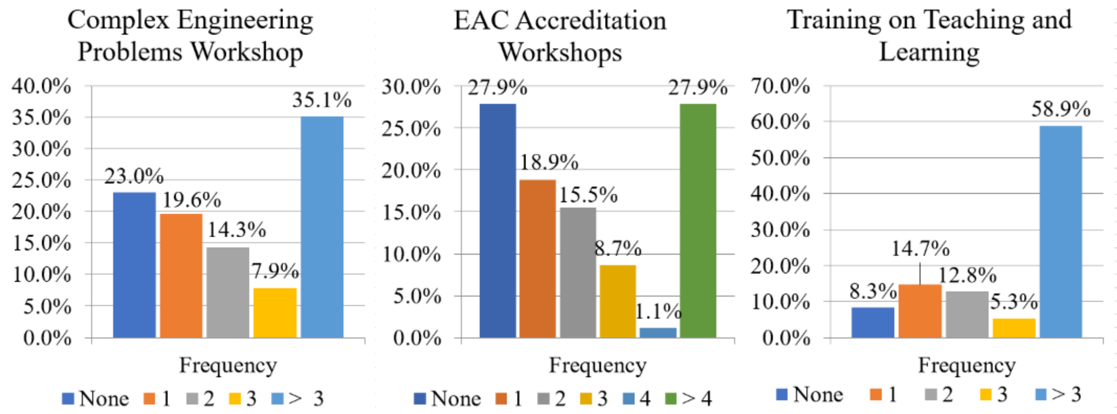
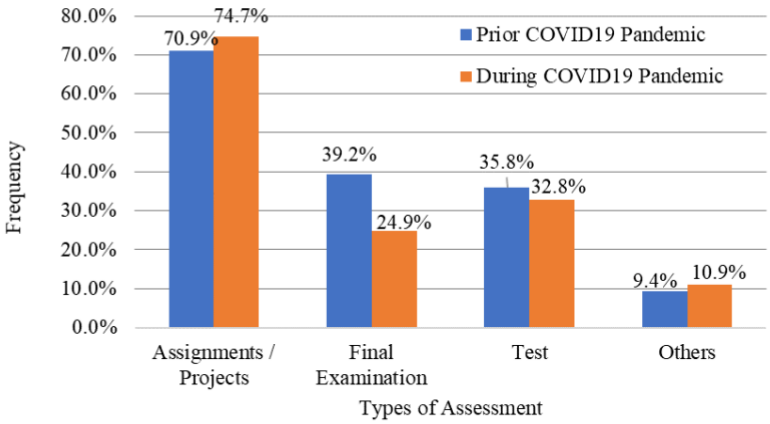


Fig. 4 Numbers of attended training programs (a) complex engineering problems workshop, EAC accreditation workshops and (c) teaching and learning

4.3 Implementation of Complex Engineering Problems and Activities

4.3.1 Types of Assessment

Fig. 5 shows the allocation of CEP and CEA in the assessments at semesters prior and during COVID19 pandemic. Having allowed for more than one choices in the survey questions, more than 70% of the engineering educators claimed to have incorporated the complex engineering problems in their assignments and projects prior to and during the pandemic semesters. About 36-39% of the respondents addressed the complex engineering problems in summative assessments such as final examination and test for semester prior to, whereas only about 25-33% during the pandemic. While, about 10% of the respondents incorporated them in the form of assessments. The analysis results reveal that assignments and projects are the most favourite assessment methods used to assess the students' complex engineering problem-solving skills. Bielefeldt (2013) stated that tasks such as design projects, case studies, and impact analysis employing computational software that are complex can develop students' higher order cognitive skills and facilitate them to think holistically in meeting the challenges.



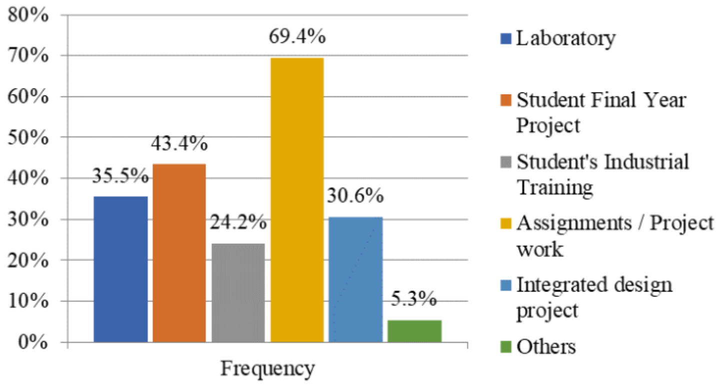


Fig. 5 Types of assessment incorporating (a) complex engineering problems at semesters prior and during COVID19 pandemic, and (b) complex engineering activities

The data also shows a significant shift to the incorporation of complex engineering problems in final examination to other assessments during the pandemic semester, with a drop from 39.2% to 24.9% for final examination. This differences in percentage reveals that there was a modification in the assessment methods in the curriculum during the pandemic, particularly prioritising formative assessments. . On the other hand, many Malaysian engineering educators (about 70%) addressed complex engineering activities in assignments and projects. Some respondents (about 24-43%) had experience in assessing students' complex engineering activities in Final Year Project, Industrial Training laboratory courses, and Integrated Design Project. These courses as pointed out by Liew et al. (2020a) are located typically at advanced level and suitably chosen for complex engineering exercises since the tasks given are often related to real-world contexts and dealt with collaborative learning.

4.3.2 Assessment Weightage and Taxonomy Level of Difficulty

Decision on assessment weightage and taxonomy level of difficulty are essential in ensuring satisfactory exposure of the complex engineering problems among students throughout the curricula of a programme. Approximately 70% of the respondents affirmed that the percentage of complex engineering problems incorporated in an assessment had been prescribed by their faculty while the remaining determined the percentage by themselves or by other sources (refer **Fig. 6a**). Despite the different ways in deciding the weightage of a complex engineering problem, either in a controlled and planned or in a flexible and open manner, a percentage allocation of between 20% to 40% complex problems in an assessment was a common practice (see **Fig. 6b**). There was only a very small percentage (1%) of the respondents who incorporated more than 60% of complex engineering problems in their course assessment.

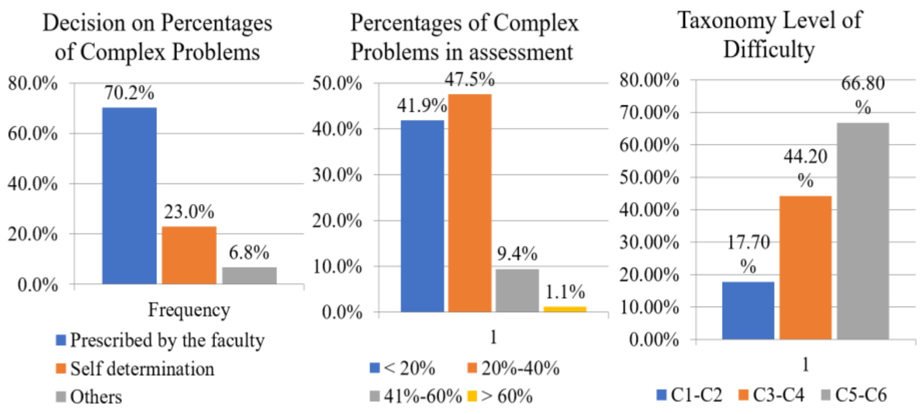


Fig. 6 Implementation of complex engineering problems in an assessment (a) mechanism in determining the weightage, (b) weightages used and (c) taxonomy level

Fig. 7c shows the mapping of taxonomy level of difficulty to the complex engineering problems in an engineering programme. Most of the respondents (about 67%) designed their assessments incorporating complex engineering problems with taxonomy level of C5-C6 (Synthesis and Evaluation), whereas about 44% at range the range of C3-C4 (Application and Analysis). Less than 20% mapped with taxonomy level at the range of C1-C2 (Knowledge and Comprehension). This finding has good agreement with Bielefeldt (2013) which emphasized the requirements of having higher level cognitive domain (C5-C6) in dealing with complex levels of knowledge. The cognitive domain represents intellectual and increasingly complex levels of knowledge.

5. Conclusion

The findings show that most of the programmes addressed complex engineering problems in assignments or projects as compared to final examinations or mid-term tests. Less than half of the respondents addressed CEP and CEA in summative assessments such as final examination and mid-term test while the rest addressed CEP and CEA in projects or assignments. However, during the COVID-19 pandemic, the percentage of addressing CEP in final examination and mid-term test decreased due to changes in assessment methods. Meanwhile, around three-quarter of them addressed CEA in assignments and projects. Most of the engineering educators designed their assessments incorporating CEP to be mapped with taxonomy level of the range of C5 to C6 (Synthesis to Evaluation). This indicates the emphasis on the requirements of having higher level cognitive domain in dealing with complex levels of knowledge. Thus, the cognitive domain represents intellectual skills and increasingly complex levels of knowledge. A very small percentage of the educators assessed more than 60% CEP skills in their course, while most of them assessed in the range between 20-40% of the CEP skills as determined by their faculties. This survey results also show infrequent participation in training programs on CEP and CEA among Malaysian engineering educators. Getting better understanding of the CEP and CEA from relevant trainings could certainly lead to more effective implementation in the engineering curriculum and hence enhance the student complex engineering solving skills. This study contributes to the understanding on the current practices that would assist in the CQI for an engineering programme and may be used as a guideline to enhance the teaching and learning activities to incorporate CEP and CEA. This study is limited to a quantitative approach using questionnaire survey which could be extended for future research using qualitative method based on case studies of different engineering programmes in various universities to establish an assessment framework on CEP and CEA skills

6. References

EAC (2020). Engineering Programme Accreditation Standards 2020. Malaysia: Engineering Accreditation Council.

Bielefeldt, A. R. (2013). Pedagogies to achieve sustainability learning outcomes in civil and environmental engineering students. Sustainability, 5(10), 4479-4501.

Hamisah Tapsir, S. and Puteh, M. (2018). Framing Malaysian Higher Education 4.0: Future-Proof Talents. Malaysia: Ministry of Higher Education Malaysia.

Hotaling, N., Fasse, B. B., Bost, L. F., Herman, C. D., & Forest, C. R. (2012). A quantitative analysis of the effects of a multidisciplinary engineering capstone design course. Journal of Engineering Education, 101(4), 630–656.

IEA (2013). Graduate Attributes and Professional Competencies Ver 3: 21 June 2013. Retrieved from http://www.ieagreements.org/assets/Uploads/Documents/Policy/Graduate-Attributes-and-ProfessionalCompetencies.pdf. (Accessed: 29 May 2018).

IEA (2014). Agreements constitution Ver 1.2: September 2014. International Engineering Alliance. Retrieved from https://www.ieagreements.org/assets/Uploads/Documents/Policy/Graduate-Attributes-and-Professional-Competencies.pdf. (Accessed: 29 May 2020).

Johri, A. and Olds, B. (2011). Situated Engineering Learning: Bridging Engineering Education Research and the Learning Sciences. Journal of Engineering Education, 100(1), 151–185

Jonassen, D., Strobel, J. and Lee, C. B. (2006). Everyday Problem Solving in Engineering: Lessons for Engineering Educators. Journal of Engineering Education, 95: 139–151.

Liew C.P., Hamzah S.H., Puteh M., Mohammad S., Badaruzzaman W.H.W. (2020a) A Systematic Approach to Implementing Complex Problem Solving in Engineering Curriculum. In: Auer M., Hortsch H., Sethakul P. (eds) The Impact of the 4th Industrial Revolution on Engineering Education. ICL 2019. Advances in Intelligent Systems and Computing, vol 1134. Springer, Cham. https://doi.org/10.1007/978-3-030-40274-7_86

Liew C.P., Puteh M., Hamzah S.H. (2020b). Comparative Study of Engineering Design Project Assessment Rubrics to Address the Washington Accord’s Complexity Attributes, ASEAN Journal of Engineering Education, 4(1), 71-94

Mat Isa, C.M., Oh, C.L., Liew C. P., Mohd Saman, H., Che Ibrahim, C. K. I, & Yusof, Z. (2021). Effective Implementation of Complex Engineering Problems and Activities in Engineering Curricular from Educators’ Perspectives in Malaysia. *International Conference on Technology and Quality Management of Tertiary Education 2021* (ICTQM-TEd 2021).

Phang, F. A., Anuar, A. N., Aziz, A. A., Mohd Yusof, K., Syed Hassan, S. A. H. and Ahmad, Y. (2018). Perception of Complex Engineering Problem Solving Among Engineerıng Educators. In: Auer M., Kim KS. (eds) Engineering Education for a Smart Society. GEDC 2016, WEEF 2016. Advances in Intelligent Systems and Computing, 627, 215–224.

World Economic Forum (2016). The 10 Skills You Need to Thrive in the Fourth Industrial Revolution. Retrieved from https://www.weforum.org/agenda/2016/the-10-skills-you-need-to-thrive-in-the-fourth-industrial-revolution/. (Accessed: 3 March 2018).