Comparative Study of Engineering Design Project Assessment Rubrics to Address the Washington Accord's Complexity Attributes

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Abstract
Over the years, various reports confirmed the importance of complex problem-solving in the workplace. However, in most cases, engineering educators often fail to design assessment rubrics that drive the ability to solve complex problems among the students. Literature review revealed that the studies of assessment rubrics in higher education have been undertaken in a wide range of disciplines but not in the field of engineering. Hence this study attempts to present the gaps in four assessment rubrics which were designed to assess engineering design projects. It applied comparative case studies to analyze and synthesize the similarities, differences and patterns from the assessment rubrics to produce generalizable knowledge about how and why particular assessment rubrics work or fail to work against the attributes of complex engineering problem solving and complex engineering activities defined by the International Engineering Alliance (2013), and the essential features of rubrics proposed by James Popham (1997). The results showed that engineering rubric designers generally fulfilled the requirements of designing a rubric. The shortcomings, however, it was found that not all-important design skills were addressed and limited characteristics of complex engineering problem solving were practiced by engineering educators, and the absence of complex engineering activities in the design of assessment rubrics. The understanding of these shortcomings is expected to benefit engineering educators in enhancing their instructional materials for implementing complex problem solving in engineering design projects and subsequently improve the ability of the engineering graduates to solve complex problems.

Key Words: Assessment rubrics, complex engineering problem solving, complex engineering activities, Washington Accord

Introduction

Over the years, various reports have confirmed the importance of complex problem-solving in the industry. For instance, the World Economic Forum (2016) and the Ministry of Higher Education, Malaysia (Tapsir & Puteh, 2018) have identified that complex problem solving is the top skill needed to thrive in the 4th Industrial Revolution. Complex engineering problem solving is 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 programmes which seek accreditation must prepare graduates for future technological and societal changes, and able to acquire new knowledge to new problems (EAC, 2020). Unfortunately, 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; IEA, 2014b). Regrettably, 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). 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 (Liew et al., 2020). Hence the ability of engineering graduates to solve complex problems and undertake complex activities could be negatively affected. Due to the importance of this ability, in 2013, IEA released the attributes of complex engineering problems and complex engineering activities to guide the signatory countries of the Washington Accord in their implementation of complexity in engineering curriculum (as illustrated in Table 1 and Table 2 respectively) which 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 (IEA, 2014a).

The studies of assessment rubrics in higher education have been undertaken in many non-engineering disciplines and for multiple purposes such as to improve instructional materials and increase student achievement (Reddy & Andrade, 2010). Assessment rubrics are often geared towards assessing the required programme outcomes (Thambyah, 2011; Fiegel, 2013; Ho, 2014; Dulekgurgen et al., 2018) and guided by Popham's (1997) three essential features of designing rubrics. However, in the field of engineering, review of literature revealed that the assessment rubrics designed to evaluate engineering design projects were loosely aligned to Popham's (1997) guidelines on rubric development (Potter et al, 2006; Estell & Hurtig, 2006; Gnanapragasam, 2007; Pop-Iliev & Platanitis, 2008; William et al., 2013; Yousafzai et al., 2015; Lanziner & Strong, 2017). In addition to that, much recent literature such as William et al. (2013), Yousafzai et al. (2015) and Lanziner and Strong (2017) in the development of assessment rubrics in engineering design projects showed limited reference to the attributes of complex engineering problem solving and complex engineering activities as specified by IEA.

In overcoming the challenges faced by engineering educators, the present study aims to investigate the gaps in the existing assessment rubrics adopted in four case studies to improve the instructional materials for implementing complex engineering design projects and subsequently, improving the ability of the engineering graduates to solve complex problems. This was carried out by comparing and contrasting the elements of assessment rubrics to the attributes of complex engineering problems and complex engineering activities specified by IEA (2013), and Popham's (1997) three essential features of designing rubrics.

Conceptual Framework

The conceptual framework of this study is as shown in Figure 1. The constructive alignment model is the theoretical underpinning of the outcome-based curriculum. For the assessment rubrics to be effective, the links between the learning outcomes, delivery methods, and assessment methods of the design projects must be clearly understood (Biggs, 2003). Aligning these will benefit the students by ensuring the validity, reliability, and transparency of the assessment rubrics. Therefore, the constructive alignment model by Biggs (2003) must be used as guiding principles during the development of the assessment rubrics to ensure that they address the targeted programme outcomes as specified by IEA and EAC.

The present study intends to answer the following questions:

RQ1: What are gaps in the assessment rubrics designed to assess design projects with respect to the attributes of complex engineering problems and complex engineering activities, and guidelines on rubric development?

RQ2: What are the expected improvements that could be experienced by engineering educators and students if the gaps were addressed?

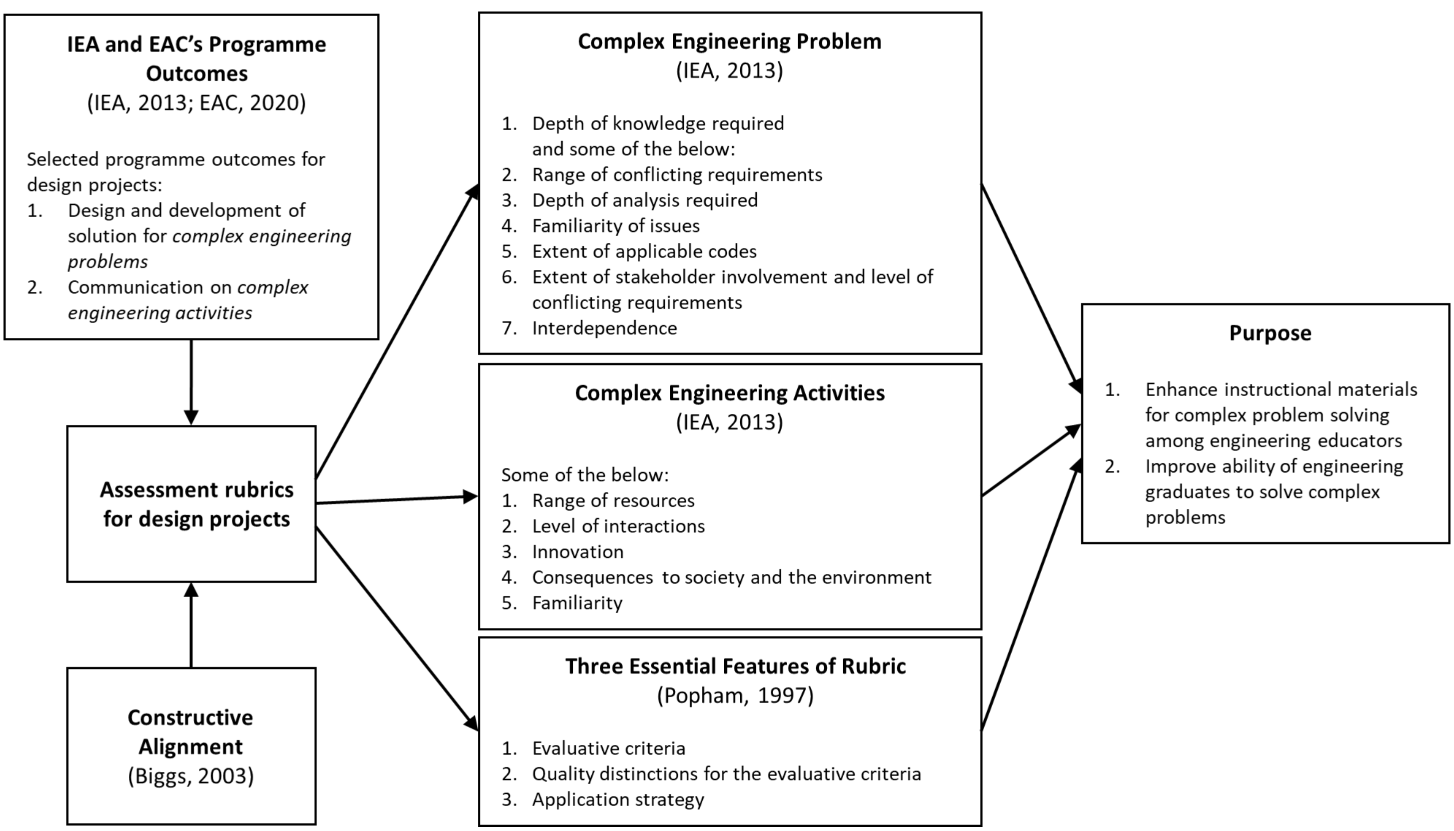

Figure 1. Conceptual Framework

Literature Review

In facilitating the comparison of existing assessment rubrics to Popham's (1997) three essential features of rubrics, and the attributes of complex engineering problem solving and complex engineering activities defined by IEA (2013), the background of assessment rubrics and the attributes of complex engineering problem solving and complex engineering activities were explained. The typical programme outcomes and design skills that can be addressed by engineering design projects were reviewed to determine the areas of focus of the assessment rubrics.

Assessment Rubrics

As highlighted earlier, the studies of rubrics in higher education have been undertaken in a wide range of disciplines and for multiple purposes such as increasing student achievement, improving instruction materials, and evaluating programmes' effectiveness (Reddy & Andrade, 2010). Some studies showed that rubrics can serve as instructional purposes apart from supporting teaching and learning (Reitmeier et al., 2004; Andrade & Du, 2005; Schneider, 2006; Song, 2006). They are often used as part of a student-centered approach to assessment whereby they help students understand the targets for their learning and the standards for a particular assignment. For examples, they are used to provide feedback and grade students' literature reviews, reflective writings, oral presentations, critical thinking, citation analyses, portfolios, projects, and oral and written communication skills (Reddy & Andrade, 2010). Hence a well-constructed rubric can help educators to better understand the nature of high-level cognitive skills that ought to be acquired by their students (Popham, 1997).

The application of rubrics in engineering design projects has been reported as early as the 2000s (Potter et al, 2006; Estell & Hurtig, 2006; Gnanapragasam, 2007) and followed through in the 2010s (William et al., 2013; Yousafzai et al., 2015; Lanziner & Strong, 2017). These rubrics were designed to address the programme outcomes required by the accreditation bodies such as ABET, the Canadian Engineering Accreditation Board (CEAB), and EAC by aligning to the desired evaluative criteria. The work of developing rubrics for engineering design projects is quite extensive because these projects are mostly open-ended in nature. Such open-ended nature has caused difficulties for the students to perform well on their projects and resulted in ambiguity among engineering educators to assess and evaluate their students' work in a fair manner (Pop-Iliev & Platanitis, 2008).

Initial investigation on the literature review (Daniel et al, 2006; Estell & Hurtig, 2006; Gnanapragasam, 2007; Pop-Iliev & Platanitis, 2008; William et al., 2013; Yousafzai et al., 2015; Lanziner & Strong, 2017) indicated that these assessment rubrics designed to evaluate engineering design projects were loosely aligned to the attributes of complex engineering problem solving (IEA, 2013) and Popham's (1997) three essential features: evaluative criteria, quality definitions for those criteria at particular levels and a scoring strategy. The gaps, if not addressed will result in poor instructional materials to implement complex problem solving; and affect the ability of the graduates to solve complex engineering problems.

Popham (1997) illustrated three features of a well-formed rubric which be the basis of comparison in the case studies of assessment rubrics:

1. Evaluative criteria: These are the factors applied in evaluating the quality of students' work or their mastery of skills. The use of rubrics should be restricted to the most important cognitive skills that educators want their students to acquire. The number of evaluative criteria for a rubric ought to be somewhere between three and six to be manageable from both evaluative and evaluation perspectives. A rubric will fail if it is overloaded by too many criteria, which will confuse the students and educators, particularly, during the grading process.
2. Quality distinctions for the evaluative criteria: These are the descriptions of different quality levels of each rubric. Numerical gradations are often used to master high-level cognitive skills by providing quantitative score-point levels or performance-level descriptors for each evaluation criterion.
3. Application strategy: This refers to the use of a rubric's evaluative criteria whether holistically or analytically. Holistically implies that the rubric-user tries to take into consideration all of the evaluative criteria and their accompanying qualitative distinctions to make one holistic judgment. On the other hand, the analytical rubric requires the scorer to make separate judgments when appraising a student's response. This provides diagnostic data on scoring time in comparison to the holistic rubric.

The Attributes of Complex Engineering Problem and Complex Engineering Activities

Engineering problem is a problem that can be solved by the application of engineering knowledge and skills, and professional skills; and engineering activities include but are not limited to: design; planning; investigation and problem resolution; improvement of materials, components, systems or processes; engineering operations and maintenance; project management; research, development and commercialization (IEA, 2011). Students' ability to deal with complex engineering problems is emphasized in seven (out of the twelve) associated Washington Accord's programme outcomes, namely Engineering Knowledge, Problem Analysis, Design or Development of Solutions, Investigation, Modern Tools Usage, Engineer and Society, and Environment and Sustainability; and their ability to undertake complex engineering activities is emphasized in the Washington Accord's programme outcome, communication skills (IEA, 2013; EAC, 2020). The latter essentially means that the activities can be reported or assess in written or verbal communication when apply to design project or industry training.

In this section, the attributes of a complex engineering problem and complex engineering activities illustrated by IEA were reviewed with the documents from two accreditation bodies, CEAB and Engineering New Zealand (EngineeringNZ). The findings could provide some guidance to engineering educators in designing assessment rubrics in implementing or assessing complex engineering problem solving and complex engineering activities in design projects.

Table 1 illustrates the attributes of complex engineering problems for a Washington Accord's compliance undergraduate engineering programme.

Table 1. Range of problem-solving

No.	Attributes	Complex Engineering Problems
1	Depth of knowledge required	It 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	The extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering?
6	The extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.
7	Interdependence	Do high-level problems include many parts or sub-problems?

Source: (IEA, 2013)

In order to be classified as a complex engineering problem, the programme must demonstrate the first attribute, the depth of knowledge, and several other attributes (IEA, 2013). In-depth knowledge means knowledge gained from courses or learning activities beyond the introductory instructional level while the first principles are the fundamental concepts or assumptions on which a theory, system, or method is based (CEAB, 2015). In engineering, the first principle starts directly at the level of established laws of chemistry, physics, and mathematics. For example, in applying detailed theoretical knowledge, one must be able to demonstrate an understanding of the first principles to establish a workable mathematical or theoretical model. This also relates to why natural sciences and mathematics are not used to address complex engineering problem-solving.

The second attribute - a range of conflicting requirements refers to the constraints placed to resolve the problems and conflicting demands in developing a design (Engineering NZ, 2017). For example, graduates need to be able to identify the strength or weakness of the problem-solution; the solution or design required by stakeholders may require innovative and creative solution comparative to the ideal engineering solution; and the critical factors such as the economics of scale, safety, environmental issues, aesthetics, etc. The third attribute, depth of analysis refers to the ability in producing multiple solutions to meet functional specifications and to compare the solutions against the problem objective in selecting the best concept (Engineering NZ, 2017).

According to Engineering NZ (2017), the fourth attribute requires the extent to which the problem is routinely encountered and resolved using well-understood practices. The problem could be a new problem that is not previously encountered or a familiar problem with unique issues that made resolution difficulty level increases. The fifth attribute, the extent of applicable codes refers to how the existing standards or codes dictate the solution (Engineering NZ, 2017). Students may apply engineering skills to address some parts or all of the problems that were not prescribed by standards, codes, or practices.

The sixth attribute, the extent of stakeholder involvement and level of conflicting requirements refers to how the stakeholders' interests and requirements impact the problem (Engineering NZ, 2017), the interaction with affected stakeholders to resolve the conflicts, and so on. Finally, the seventh attribute - interdependence refers to problems that include many sub-problems or sub-systems. The problem should be able to be mathematically broken down into smaller components (CEAB, 2015).

Table 2 illustrates the attributes of complex engineering activities for a Washington Accord's compliance undergraduate engineering programme.

Table 2. Range of engineering activities

No.	Attributes	Complex Activities
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information, and technologies).
2	Level of interaction	Require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, engineering, or other issues.
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.
5	Familiarity	It can extend beyond previous experiences by applying principles-based approaches.

Source: (IEA, 2013)

According to IEA (2014b), some of these attributes might be encountered during integrated design project or a period industry experience. Examples include available resources in implementing the engineering activity and how the students acquired these resources (Engineering NZ, NA). The attribute of the level of interaction relates to the engineering issues that impacted engineering matters related to the project and the unforeseen engineering issues arose during the execution of the project (Engineering NZ, NA). The attribute of innovation takes into account the new techniques, materials, or processes which are utilized in the work process (Engineering NZ, NA). The attribute on consequences to society and the environment includes the impacts of the engineering solution on the society and environment.

Typical Programme Outcomes addressed by Engineering Design Project

Various accreditation bodies specified that design projects shall involve complex engineering problems and design systems, components, or processes by integrating the principles, concepts, and techniques. In addition to meeting the specified needs of the projects, the impact of the solutions to public health and safety, cultural, societal, economic, and environmental shall also be considered (EAC, 2020; ABET, 2017).

Design courses are one of the indicators of outcomes and an ideal milestone where the outcomes of the undergraduate engineering experience can be measured (Daniel et al., 2006; Gnanapragasam, 2007; EAC, 2020). Numerous aspects of the intellectual development of the students can be assessed by measuring technical and communication competencies in these courses. Besides, the assessment of a student's ability to solve problems with realistic constraints can be introduced to stimulate the type of problems encountered in the industry (EAC, 2020). The typical tools for performance assessment include project progress by the course instructor or facilitator, peer evaluation of team member participation, evaluation of project reports by academic staff, presentation evaluation by the public, among others (Scales et al., 1998).

Rose-Hulman Institute of Technology (RHIT, 2012) and Briedis and Warder (2013) highlighted that a major design project would typically address programme outcomes such as Engineering Knowledge, Problem Analysis, Design or Development of Solution, Teamwork and Communication. The relevancy of the first three programme outcomes was cited by Hu Hanrahan (Hordern, 2014) who pointed that the analysis of engineering problems will lead to the synthesis and design of solutions that are enabled by the use of the body of engineering knowledge. The importance of teamwork is also stressed by Marra et al. (2016) and EAC (2017) in design projects because creative solutions to technical problems are not solved by individuals but by a team of people from different technical backgrounds who bring different perspectives to the problem. Lastly, design projects can be used to address some of the attributes of complex engineering activities (IEA, 2014b) whereby students are required to communicate on these activities with the engineering community and with society at large.

It is understandable that programme outcome, Design or Development of Solution is the most important among the five identified programme outcomes for a design project (EAC, 2020; ABET, 2017). Hence, engineering educators often design rubrics that focus on assessing the outcome on design attributes of the students. Liew (2019) established that the evaluative criteria of design skills in assessment rubric should include the abilities of the students to identify the required information from open literature, and all relevant technical and non-technical constraints and requirements to produce multiple potential solutions to meet functional specifications. Students must be able to evaluate the feasibility of the potential solutions in all relevant contexts which may include: technical, suitability for implementation, economic, aesthetic, ethical, health and safety, societal, environmental and cultural, and finally select the best concept. They may be also expected to create, test, and assess the simulations or models or prototypes based on the design specification and requirements, depending on the engineering discipline.

Methodology

This study applied comparative case studies to analyze and synthesize the similarities, differences, and patterns (Goodrick, 2014) from the assessment rubrics on selected literature that focus on engineering design projects. Comparative case studies will produce generalizable knowledge about causal questions (Yin, 2014), namely how and why particular assessment rubrics work or fail to work against the attributes of complex engineering problem solving and complex engineering activities (IEA, 2013) and three essential features of rubrics (Popham,1997).

To carry out the comparative case studies, the specific features of each case (assessment rubric) will be described in depth before the analysis process takes place (Goodrick, 2014). The selected technique is “pattern matching” described by Yin (2014). It began by describing and explaining the similarities and differences across different rubrics. Next, the findings will be correlated to the attributes of complex engineering problem solving and complex engineering activities and three essential features of rubrics prescribed by IEA (2013) and Popham (1997) respectively. And finally, the gaps were highlighted to assist engineering educators in the improvement of their existing assessment rubrics that fulfil the requirements of IEA (2013) and Popham (1997).

The selected case studies include Potter et al.'s (2006), one of the earliest literature which focuses on ABET's student outcomes; Zytner et al. (2015) with focus on CEAB’s programme outcomes; Yousafzai et al. (2015) with focus on ABET’s student outcomes; and Pasya et al. (2015) with focus on EAC’s programme outcomes. ABET and CEAB are selected as they are the founding members of the Washington Accord, whereby their assessment practices and strategies are very much sought after by other countries as a benchmark (Liew et al., 2014).

Results and Discussion

The case studies or assessment rubrics by Potter et al. (2006), Zytner et al. (2015), Yousafzai et al. (2015), and Pasya et al. (2015) were reviewed with a summary of findings and analysis was presented in this section.

Assessment Rubric 1 by Potter et al. (2006)

The first assessment rubric under investigation was designed by Potter et al. from Iowa State University, the United States reported in their article entitled “ABET Outcome Assessment and Improvement in an Industrial Engineering Curriculum” published in 2006. They demonstrated how the capstone design project addressed the ABET outcomes on “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability” and “the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context". These two outcomes have a close resemblance to the Washington Accord's programme outcomes on the design or development of solutions, and the engineers and society. They have designed two sets of rubrics to address the two mentioned outcomes with three criteria each. As the focus of this study is on the outcome on the design or development of a solution, only the rubric of design or development of solutions was considered for comparison.

Appendix A.1 shows the assessment rubric extracted from Potter et al. (2006) mapped to Popham's (1997) three essential features in a well-formed rubric and IEA's (2013) attributes of complex problem solving and complex engineering activities. It is important to note that: the statement of programme outcomes on a design by ABET is largely unchanged until 2019, and the rubric published by Potter et al. is prior to the introduction of complex engineering problem solving by IEA in 2013.

It was found that the rubric generally fulfilled the Popham's requirements with the evaluative criteria, quality distinctions, and application strategy. However, the evaluative criteria lack concise labeling to convey a picture of the focus of each evaluative criterion is. The application strategy employed is analytical whereby the rubric-user would be able to make judgment on each evaluative criterion when appraising a student's work. The rubric was found to be addressing two attributes of complex engineering problem solving which are the first mandatory attribute (WP1: Depth of Knowledge) and WP3 Depth of Analysis. It was also observed that the rubric lacks clear evaluative criteria on the consideration of constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability as indicated in the programme outcome (which is also the complex attribute, WP2 Range of Conflicting Requirements). Therefore, the rubric has deficiency in its instructional evaluative criteria to drive complex engineering problem solving skill among the students. Having said that, two such evaluative criteria were found in the second rubric on the outcome, "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" but in a different context. Finally, the word of “complexity” was found to be absent in Potter et al.'s (2006) programme outcome which could be useful to instill complex problem-solving skills among engineering educators and students.

Assessment Rubric 2 by Zytner et al. (2015)

The second assessment rubric under investigation was designed by Zytner et al. from the University of Guelph, Canada reported in their article entitled “Using Rubrics in a Capstone Engineering Design Course” published in 2015. They demonstrated how the capstone design project addressed CEAB's programme outcomes on design, problem analysis, investigation, engineering tools, teamwork, communication skills, the impact of engineering on society and environment, and economics and project management. These outcome statements are very similar to the Washington Accord's programme outcomes. Zytner et al. (2015) designed four sets of rubrics to address the abovementioned outcomes for four assessment components, namely proposal, interim report, final project report and poster presentation with 12, 14, 33 and 12 performance criteria respectively. However, only the rubric on the project proposal was discussed (as it is the only rubric provided by the authors). Unlike Potter et al.'s (2006) where rubrics were designed to focus on individual programme outcome, the present rubric by Zytner et al. (2015) focuses on multiple outcomes such as design, engineering tools, communication skills, and economics, and project management.

Appendix A.2 shows the rubric on project proposal extracted from Zytner et al. (2015) mapped to Popham's (1997) three essential features in a well-formed rubric and IEA's (2013) attributes of complex problem solving and complex engineering activities.

The rubric generally fulfilled the Popham's requirements with the evaluative criteria, quality distinctions, and application strategy. The number of evaluative criteria varies from one to five for different programme outcomes with two programme outcomes having lower than the recommended three criteria. This probably suggests that some significant evaluative criteria may have been omitted. In addition, some evaluative criteria lack concise labeling to convey a reasonable picture of the focus of each evaluative criterion is. The rubric employed qualitative differentiations via performance-level descriptors for each evaluative criterion. The application strategy employed is analytical whereby the rubric-user would be able to make judgment on each evaluative criterion when appraising a student's work. The rubric was found to be addressing some of the attributes of complex engineering problem-solving such as WP1 Depth of Knowledge, WP2 Range of Conflicting Requirements, WP3 Depth of Analysis and WP6 Extent of Stakeholder Involvement and Level of Conflicting Requirements. Therefore, the rubric can enhance complex engineering problem solving skill among the students. Although complex engineering activities are being promoted in the programme outcome on economics and project management, it is generally absent in the evaluative criteria on communication skills where complex engineering activities are greatly emphasized to be conveyed in the forms of written or oral communication.

Assessment Rubric 3 by Yousafzai et al. (2015)

The third assessment rubric under investigation was designed by Yousafzai et al. from the American University of Kuwait, Kuwait reported in their article entitled "A Unified Approach for Assessing Capstone Design Projects and Student Outcomes in Computer Engineering Programs" in 2015. They demonstrated how the capstone design project addressed all of ABET's programme outcomes. Like the earlier case studies, these outcomes have a close resemblance to the Washington Accord's programme outcomes. Yousafzai et al. (2015) have designed rubrics to address all ABET's outcomes based on five categories: 1) content; 2) integrity, values, and impact of engineering solutions; 3) project management and teamwork skills; 4) written communication, and 5) presentation and oral communication.

Appendix A.3 shows the rubrics on three categories, namely 1) content; 2) integrity, values, and impact of engineering solutions; and 3) project management and teamwork skills extracted from Yousafzai et al. (2015) mapped to Popham's (1997) three essential features in a well-formed rubric and IEA's (2013) attributes of complex engineering problem solving and complex engineering activities. The rubric on written communication, and presentation and oral communication was not presented as it does not promote complex engineering activities as the second assessment rubric by Zytner et al. (2015).

The rubric generally fulfilled the Popham's requirements with the evaluative criteria, quality distinctions, and application strategy. It was found that the number of evaluative criteria varies from three to seven for different categories that address all programme outcomes and most of the evaluative criteria do not have concise labeling to convey the focus of each evaluative criterion. Above all, the weakest element of the rubrics is most of the evaluative criteria were designed to address multiple programme outcomes but found to be non-reflective of these outcomes. For example, evaluative criterion no. 2, "identify engineering principles and techniques that are relevant to the project and apply them within specific problem domain" was designed to address five programme outcomes on engineering knowledge, problem analysis, lifelong learning, contemporary issues, and modern tool usage. However, the quality distinctions are not reflective of some of the mentioned outcomes, i.e., the latter three. Although Yousafzai et al. (2015) tried to present a unified method of assessing all programme outcomes using a set of comprehensive rubrics, educators and students may be overloaded by too many criteria (Popham, 1997).

The rubric provides qualitative differentiations via performance-level descriptors for each evaluative criterion, and the application strategy employed is analytical. The rubric was found to be limited to the first three attributes of complex engineering problem solving.

Similar to the second case study by Zytner et al. (2015), the attributes of complex engineering activities are not visible in the evaluative criteria on written communication, and presentation and oral communication.

Assessment Rubric 4 by Pasya et al.

The fourth assessment rubric under investigation was designed by Pasya et al. from Universiti Teknologi MARA, Malaysia reported in their article entitled "Overview of Capstone Project Implementation in the Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia" published in 2015. They demonstrated how a capstone design project could address EAC's programme outcomes on engineering knowledge, problem analysis, design, modern tool usage, communication, teamwork, and project management, and finance. As in the earlier case studies, these outcome statements are very similar to the Washington Accord's programme outcomes.

Pasya et al. (2015) have designed two sets of rubric to address the abovementioned outcomes for three assessment components, namely working progress, ethics, and project outcome. The weightage for the first assessment component, working progress is 20 percent which encompasses logbook; the second assessment, ethics (10 percent) which is evaluated based on the percentage of plagiarism of technical report and attendance of meeting; and finally, project outcome (70 percent) is evaluated by two assessment rubrics shown in Appendix A.4. It shows the rubric on the technical report and project evaluation extracted from Pasya et al. (2015) mapped to Popham's (1997) three essential features in a well-formed rubric, and IEA's (2013) attributes of complex problem solving and complex engineering activities.

The rubric generally fulfilled the Popham's requirements with the evaluative criteria and application strategy. The number of evaluative criteria is six and four for technical report and project evaluation respectively. Unlike the earlier case studies, these evaluative criteria were designed for assessment components (working progress, ethics, and project outcome) rather than the evaluation of programme outcomes. It is unclear which programme outcomes are being targeted by the rubrics. The rubrics provide qualitative differentiations via performance-level descriptors for each evaluative criterion, however, the weakest element of the assessment rubrics is their quality distinctions whereby a large range of marks is allocated for each distinction. Having said that, most evaluative criteria have concise labeling to convey a reasonable picture of what the focus of each evaluative criterion is; and the application strategy employed is analytical. The rubrics were found to be limited to the first three attributes of complex engineering problem solving. However, similar to earlier case studies, they are not promoting complex engineering activities. The rubrics need to be strengthened to drive the ability to solve complex engineering problems and undertake complex engineering activities among the students.

Discussion

Table 3 summarises the characteristics of the assessment rubrics designed by Potter et al. (2006), Zytner et al. (2015), Yousafzai et al. (2015) and Pasya et al. (2015). Though the work by Potter et al. (2006) is a little outdated compared to the others, it provides one of the earliest works on assessment rubrics on design skills among engineering students. Analysis was carried out on these case studies to determine if these rubrics were well-designed and driven towards the implementation of complex engineering problem solving and complex engineering activities.

According to Popham (1997), the number of evaluative criteria for a rubric ought to be somewhere between three and six in order to be manageable from both evaluative and evaluation perspectives. Zytner et al.'s (2015) work has less than the recommended number of criteria on two programme outcomes which suggests some significant evaluative criteria might have been omitted. On the other hand, Yousafzai et al. (2015) designed a set of comprehensive rubrics to assess all programme outcomes in a programme, as a result, the assessment rubrics may be overloaded by too many criteria, and students and educators will tend to get confused with the criteria. As a result of the attempt to address all possible outcomes, a twin problem exists as most of the evaluative criteria were found not reflecting the targeted programme outcomes.

It was found that most evaluative criteria in the case studies do not have concise labeling to convey a reasonable picture of the focus of each evaluative criterion. Pasya et al. (2015) provide some examples of good labeling such as hardware functionality, software functionality, creativity, and workmanship to give a brief and descriptive title for each evaluative criterion. Most of the case studies under investigation provide quality distinctions for the evaluative criteria to master high-level cognitive skills by providing performance-level descriptors for each evaluation criterion. However, a large range of marks allocated for each distinction should be avoided to minimize subjectivity. For example, Pasya et al. (2015) use a range of marks of 6 to 8 and 3 to 5 to distinguish between satisfactory and unsatisfactory. Finally, it was found that all case studies under investigation employed an analytical rubric which requires the scorer to make separate judgments when appraising a student's response and to provide diagnostic data for improvement.

Table 3. Summary of findings

Rubric designers:	Potter et al. (2006)	Zytner et al. (2015)	Yousafzai et al. (2015)	Pasya et al. (2015)	Remarks
Accreditation body:	**ABET**	**CEAB**	**ABET**	**EAC**	
Popham's (1997) three features of a well-formed rubric					
1. Evaluative criteria	With	With	With	With	All cases come with evaluative criteria
a. Target important cognitive skills	Yes	Yes	Yes	Yes	All cases target important skills
b. Number of criteria for each outcome	3 Satisfactory	Some with lesser than 3 Not satisfactory	3 to 7 Not satisfactory	4 to 6 Satisfactory	Some with more than 6 and some less than 3 criteria
c. Concise label	No	Some	No	Yes	Only 1 case with concise labeling
2. Quality distinctions	Performance-level descriptors	Performance-level descriptors	Performance-level descriptors	Performance-level descriptors	All cases come with performance-level descriptors
3. Application strategy	Analytical	Analytical	Analytical	Analytical	All cases are analytical
IEA's (2013) complex engineering problem solving and complex engineering activities					
1. Complex engineering problem solving	Not fulfilled	Fulfilled	Fulfilled	Fulfilled	In general, the cases encourage complex problem-solving that deals with WP2 and WP3.
WP1: Depth of knowledge	X	X	X	X	
WP2: Range of conflicting requirements		X	X	X	
WP3: Depth of analysis	X	X	X	X	
WP4: Familiarity of issues					
WP5: Extent of applicable codes					
WP6: Extent of stakeholder involvement and level of conflicting requirements		X			
WP7: Interdependence					
2. Complex engineering activities	Not fulfilled	Not fulfilled	Not fulfilled	Not fulfilled	Often limited to the EA1 range of resources, not fulfilled by all cases.

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From the assessment rubrics, it was found that the students are generally assessed on their ability to acquire information from open literature, and all relevant technical and non-technical constraints and requirements to produce multiple potential solutions to meet functional specifications by the rubric designers. Even though all case studies under investigation included some evaluative criteria to judge the quality of students' mastery of this skill, the assessment rubrics by Zytner et al. (2015) and Yousafzai et al. (2015) stood out due to higher taxonomy requirement. The rubrics by the authors detailed out that the students must be able to evaluate the feasibility of the potential solutions in all relevant contexts and select the best concept. Meanwhile, Pasya et al. (2015) provides commendable evaluative criteria on testing and assessing design prototypes based on the design specification and requirements.

On the attributes of complex problem solving, almost all of the case studies under investigation addressed the first three attributes of complex problem solving, namely depth of knowledge, conflicting requirements, and depth of analysis. Other attributes are underexplored which could provide a wider variety of complex problem-solving to the students. For example, the extent of stakeholder involvement and level of conflicting requirements, how the actual stakeholders' interests and requirements impact the problem and the interaction with them to resolve the conflicts. Another example is the extent of applicable codes, students may be tested to apply engineering skills to address some parts or all of the problems that were not prescribed by standards, codes, or practices.

Above all, there is a striking absence of complex engineering activities documented in the assessment rubrics. As highlighted in the earlier sections, some of these activities might reasonably be encountered by an engineering programme during an integrated design project or a period of industry experience (IEA, 2014b). Therefore, the attributes of complex engineering activities illustrated in Section 3.2 can be incorporated in the communication skills assessment rubrics whereby the students are normally required to communicate the final deliverables of their projects to the engineering community and society. For examples, the written report or presentation to the public can include how students acquire the necessary resources to implement the engineering activity, the unforeseen engineering issues arose during the execution of the project, the new techniques, materials or processes which are utilized in the work process and so on (Engineering NZ, NA).

Conclusion

The results show that some case studies addressed a limited number of design skills and missed out some higher-level skills. Incorporating some of these high-level design skills into the assessment rubric is part of the requirements of a well-formed rubric. These design skills (examples provided in Section 3.3) can be expressed in the form of evaluative criteria in the assessment rubric and check against the attributes of complex engineering problems and complex engineering activities. The present assessment rubrics adopted by the engineering educators could also be enhanced by limiting the number of evaluative criteria to be between three and six in order to minimize confusion among the engineering educators and students, and each evaluative criterion should be concisely labelled to convey a reasonable picture of the area of focus. In addition, the large range of marks allocated for each quality distinction of each evaluation criterion should be avoided to minimize subjectivity.

On the attributes of complex engineering problem solving, the results indicated that most case studies under investigation addressed the minimum number of attributes required of a complex engineering problem. It is recommended that the underexplored attributes to be incorporated in the design projects to provide a wider variety of complex engineering problem-solving to the students. It was also observed that there is an absence of complex engineering activities discovered in most of the case studies. The attributes of complex engineering activities can be incorporated in the communication skills' assessment rubrics whereby the students are normally required to communicate the final deliverables of their projects to the engineering community and society.

The above proposed amendments in the existing assessment rubrics are expected to improve the instructional materials for implementing complex engineering design projects for the engineering and subsequently, improving students' ability to solve complex engineering problems. A well-constructed rubric can help engineering educators to better understand the nature of high-level skills that ought to be acquired by their students and to provide diagnostic data for improvement as well. The findings from this comparative study are expected to drive further research on the design of assessment rubrics that addresses the complexity requirements as defined by IEA and EAC in other courses and different varieties of assessment.

The proposed approach to implement an assessment rubric that fulfilled Popham's (1997) and IEA's (2013) requirements for engineering design project as shown in Figure 2. The analysis and discussion, and proposed approach highlight the enhancements needed in the present assessment rubrics practiced by the HLIs and how these enhancements can improve the instructional materials for implementing complex design projects among engineering educators.

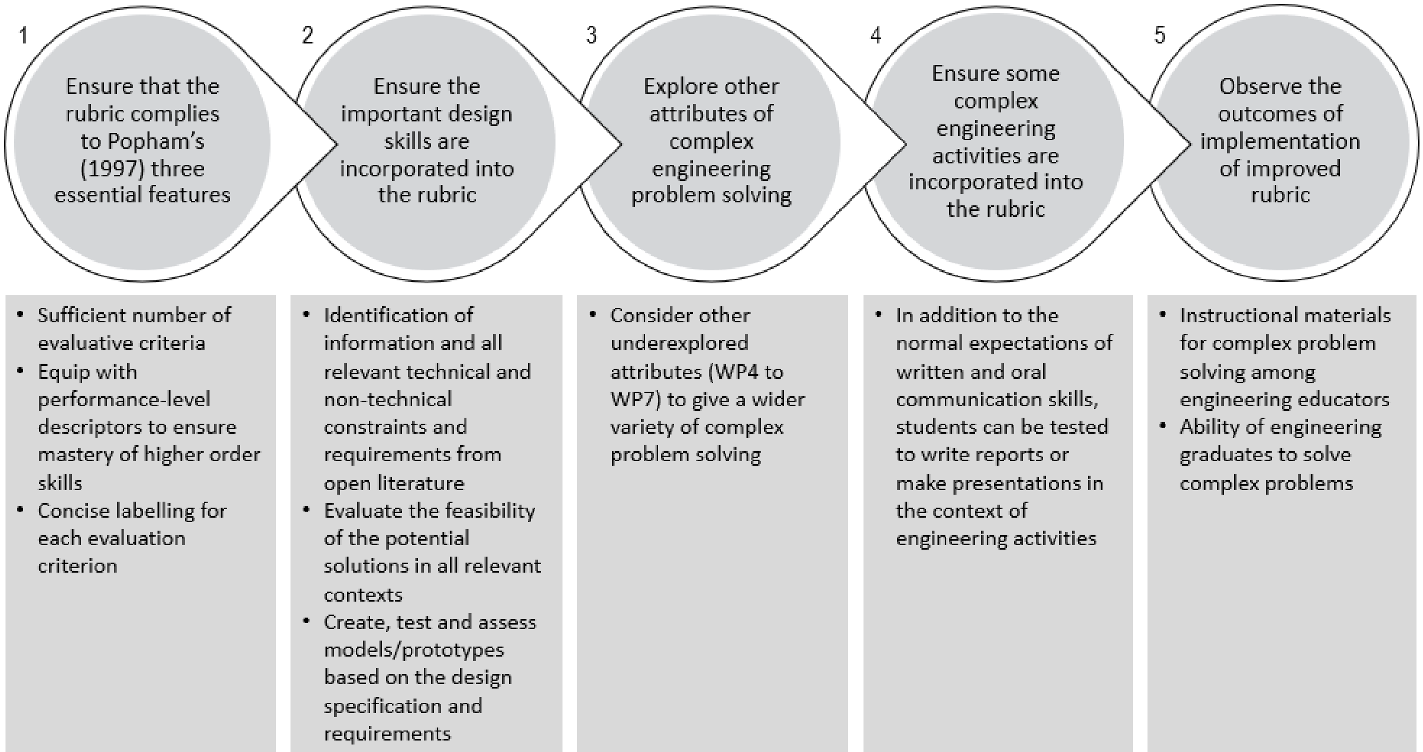

Fig. 2. An approach to implement an assessment rubric that fulfilled Popham (1997) and IEA's (2013) requirements for engineering design project

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APPENDIX A

Appendix A.1. Assessment rubric by Potter et al. (2006) mapped to Popham (1997) and IEA (2013)

<table>
<tr><td colspan="1">PROGRAMME OUTCOME:

DESIGN OR DEVELOPMENT</td><td colspan="2">Potter et al. (2006)
An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.</td><td colspan="2">IEA (2013)
Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations. (WK5)</td></tr>
<tr><td rowspan="2">Evaluative criteria</td><td colspan="3">Quality distinctions: performance-level descriptors</td><td rowspan="2">Complex problem solving or complex engineering activities</td></tr>
<tr><td>Exemplary 5-6</td><td>Acceptable 3-4</td><td>Poor 1-2</td></tr>
<tr><td>1. Ability to state the problem and constraints</td><td>Problem and constraints statement is clearly defined, measurable objectives developed, and deliverables are clearly defined and relate to objectives</td><td>Problem and constraints statement is generally understandable, most objectives are measurable but may not be completely specific or quantifiable, and deliverables generally relate to the objectives</td><td>Problem and constraints statement is vague or ambiguous, objectives are not measurable and deliverables are not clear and do not directly relate to the objectives</td><td>WP1: Depth of knowledge</td></tr>
<tr><td>2. Ability to determine applicable Industrial Engineering tools or methodologies and utilize them to correctly design a process or evaluate process alternatives</td><td>Chooses most applicable tools/methodologies, utilizes the tools correctly and consistently</td><td>In general, applicable tools are chosen and correctly applied, with some exceptions or inconsistencies</td><td>Inappropriate tools are chosen and/or the tools are not applied correctly</td><td>WP1: Depth of knowledge</td></tr>
<tr><td>3. Ability to compare and make a selection between design alternatives</td><td>Multiple alternatives developed, the performance of each alternative rigorously evaluated, a reasonable methodology for selection of alternative utilized and reasons for final selection is clear and credible</td><td>Minimal number of alternatives developed, evaluation of each alternative shows some rigor, and reasons for selection are generally clear but some explanation may be missing</td><td>Insufficient number of alternatives developed, method of comparison unclear and reason for final selection missing or unclear</td><td>WP3: Deep of analysis</td></tr>
<tr><td colspan="5">Application strategy: analytical</td></tr>
</table>

Appendix A.2. Assessment rubric by Zytner et al. (2015) mapped to Popham (1997) and IEA (2013)

PROGRAMME OUTCOME 1: DESIGN OR DEVELOPMENT		**Zytner et al. (2015)** Design: An ability to design solutions for complex, open-ended engineering problems and to design systems, components, or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural, and societal considerations.		**IEA (2013)** Design or development: Design solutions for complex engineering problems and design systems, components, or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations. (WK5)		
Evaluative criteria:		**Quality distinctions: performance-level descriptors**				**Complex problem solving or complex engineering activities**
		Exceeds expectations	Adequately meets expectations	Minimally meets expectations	Fails to meet expectations	
1. Construct design-specific problem statements		Constructs complete problem identification with a thorough discussion on the expected design components that is consistent with the readily available information.	Constructs complete problem identification with a light discussion on the expected design components that is consistent with readily available information.	Constructs problem identification with no discussion and does not consider all available information.	Problem identification is not consistent with available information.	WP1: Depth of knowledge
Construct design-specific problem statements	2. Literature review	Prepares an excellent literature review of the problem	Prepares a good literature review of the problem	Prepares a fair literature review of the problem	No literature review provided	WP1: Depth of knowledge
	3. Constraints, criteria, and assumptions	Identifies and discusses all constraints, criteria, and assumptions	Identifies and discusses the major constraints, criteria, and assumptions	Identifies the constraints, criteria, and assumptions	Fails to identify the constraints, criteria, and assumptions	WP2: Range of conflicting requirements
	4. Social, environmental and economic, health and safety perspective	Anticipates and explains needs and impacts in social, environmental, and economic, health, and safety terms beyond the immediate client and users.	Anticipates needs and impacts on social, environmental, and economic, health, and safety terms for clients and users.	Explains the problem in social, environmental, economic, health and safety terms	Fails to consider the problem in social, environmental, economic, health and safety terms	WP6: Extent of stakeholder involvement and conflicting requirements
5. Implement engineering design solutions - identifies possible solutions from a proposal perspective.		Discusses the possible design approach, identifying some possible solutions, and recognizing available resources.	Discusses the possible design approach, identifying some possible solutions but does not recognize available resources.	Presents a possible design approach and does not recognize available resources.	No design approach or possible design solution provided.	WP3: Depth of analysis

PROGRAMME OUTCOME 2: **MODERN TOOL USAGE**	**Zytner et al. (2015)** An ability to create, select, apply, adapt, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.		**IEA (2013)** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to complex engineering problems, with an understanding of the limitations. (WK6)		
Evaluative criteria:	**Quality distinctions: performance-level descriptors**				**Complex problem solving or complex engineering activities**
	Exceeds expectations	**Adequately meets expectations**	**Minimally meets expectations**	**Fails to meet expectations**	
6. Select appropriate engineering tools from various alternatives - a proposal perspective	Identify the hardware tools (physical, hand, and prototyping) and software tools that may be used in the development of the design, with a critical discussion on how these tools will benefit the design.	Identify the hardware tools (physical, hand, and prototyping) and software tools that may be used in the development of the design. Some basic discussion provided to support the tool selection.	Identify the hardware tools (physical, hand, and prototyping) and software tools that may be used in the development of the design, with some supporting documentation.	Only rudimentary tools were identified for possible use in the design, with no supporting documentation.	WP1 – Depth of knowledge

PROGRAMME OUTCOME 3: COMMUNICATION		**Zytner et al. (2015)** An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.		**IEA (2013)** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.		
Evaluative criteria:		**Quality distinctions: performance-level descriptors**				**Complex problem solving or complex engineering activities**
		Exceeds expectations	**Adequately meets expectations**	**Minimally meets expectations**	**Fails to meet expectations**	
Develop and deliver clear, key concepts using methods appropriate for the intended audience	7. Supporting material, including a letter of transmittal and executive summary	Clearly and concisely indicates purposes of the report using professional language appropriate for the target audience. Provides context of deliverables. Properly addressed and signed.	Clearly and concisely indicates the purpose of the report. It provides the context of the overall project. Properly addressed and signed.	The purpose of the report is vague. Context of deliverables as part of the project stated. Properly addressed and signed.	Purpose of the report not clear or obvious. A letter is bound within the report, and improperly addressed or signed.	Not applicable
	8. Organization of Report	The objectives and scope of the project are completely provided and in thoughtful order. Key report elements are integrated and mutually reinforcing.	The objectives and scope of the project are clear. Complete order with evidence of logical thinking.	Aspects of problem objectives or scope unclear. Reasonable presentation in all sections, with some thought and effort.	Random order to structure the report. Little effort or thought.	Not applicable
	9. Figures and Formatting	Clear, informative figures with excellent formatting. Enhance presentation consistently and are of professional quality.	Clear figures with good formatting. Most aid the report presentation and are of professional quality.	Clear figures with good formatting. Some aid in the report presentation; professional quality could be improved.	Unclear figures. Formatting detracts from the presentation.	Not applicable
	10. Literacy	Flawless English with no punctuation errors.	A few flaws in English grammar or spelling. Punctuation errors are infrequent.	Some flaws in English grammar, spelling, and punctuation, but do not severely inhibit reading of the report.	Very seriously flawed English spelling, grammar, and punctuation. The report is difficult to read.	Not applicable

PROGRAMME OUTCOME 4: **PROJECT MANAGEMENT AND FINANCE**		**Zytner et al. (2015)** An ability to appropriately incorporate economics and business practices including project, risk, and change management into the practice of engineering and to understand their limitations		**IEA (2013)** Demonstrate knowledge and understanding of engineering management principles and economic decision-making and apply these to one's work, as a member and leader in a team, to manage projects and in multidisciplinary environments.		
Evaluative criteria:		**Quality distinctions: performance-level descriptors**				**Complex problem solving or complex engineering activities**
		Exceeds expectations	**Adequately meets expectations**	**Minimally meets expectations**	**Fails to meet expectations**	
Apply project management techniques and manage resources within identified constraints -	11. Method of approach suitable for a proposal.	Construct and critically discuss the project timeline	Construct and briefly comment on the project timeline	Construct a project timeline	Poor project timeline	EA1 – Range of resources
	12. The estimated cost of completing the design; appropriate for a proposal.	Excellent cost analysis supported with discussion.	Very good cost analysis supported with discussion.	Good cost analysis.	Poor cost analysis.	EA1 – Range of resources
Application strategy: analytical						

Appendix A.3. Assessment rubric by Yousafzai et al. (2015) mapped to Popham (1997) and IEA (2013)

PROGRAMME OUTCOME: MULTIPLE	**Content (Yousafzai et al., 2015)**				
Evaluative criteria: seven (number)	**Quality distinctions: performance-level descriptors**				**Complex problem solving or complex engineering activities**
	Accomplished	**Competent**	**Developing**	**Beginning**	
1. Literature review: summarises, compares and evaluates various concepts, research findings and current theories and models in core content areas of computer and electrical engineering	The literature review is complete; sufficient detail is provided to support assertions; assertions supported with evidence; includes original and relevant insight or analysis of the topic.	The literature review is brief but complete; review focuses only on issues related to question; review is factually correct; assertions are supported with evidence and appropriate use of logic.	The literature review is brief, with insufficient detail; unrelated issues are introduced and/or minor errors in the content; some assertions are made without adequate support from evidence.	The literature review is incomplete and/or omits important research findings, includes an excessive discussion of unrelated issues; significant errors in the content; assertions are made without adequate support from evidence.	WP1: Depth of knowledge
2. Identify engineering principles and techniques that are relevant to the project and apply them within a specific problem domain	Project is completely grounded in engineering principles and techniques; applies them to problem correctly and establishes their relevance.	Provides a good engineering framework for the project; applies principles and techniques correctly to a problem domain.	Basic engineering principles and techniques relevant to the project are included, but some are missing; fail to develop a complete theoretical or design framework for the project.	Basic understanding of engineering principles; fails to apply them within the specific problem domain.	WP1: Depth of knowledge
3. Novelty and the adequacy of the design approach	The approach to the problem is highly adequate and innovative.	The approach to the problem is adequate and somewhat novel.	The approach to the problem has some deficiencies and is not novel.	The approach to the problem has serious deficiencies.	WP3: Depth of analysis
4. Alternative designs	Final design achieved after reviewing reasonable alternatives.	Alternative approaches identified to some fair degree.	Shortcomings in exploring and identifying alternative designs.	Only one design presented or infeasible alternative given.	WP3: Depth of analysis
5. Identification, mastering, and use of hardware/ software tools	Hardware and software tools are mastered and used highly effectively to develop and analyze designs; the final product is highly professional.	Hardware and software tools are mastered and used with effectiveness to develop designs. Further improvement could be made.	Minimal application, mastering, and/or use of appropriate hardware and software tools.	Serious deficiencies in understanding the correct selection and/or the mastering and use of hardware and software tools.	WP1: Depth of knowledge

6. Robustness of conducting, analyzing, testing and interpreting experimental results	Testing is thorough; analysis and results are robust and usable.	Testing is adequate; analysis and results are acceptable and complete.	Testing of the design is somewhat fair; results are inconclusive and not usable for further investigation.	Almost all the experiments and tests are inconclusive; results are disappointing or incomplete.	WP1: Depth of knowledge
7. Further improvements	Several novel directions for important expansions of the current ideas are thoroughly explained.	Several ideas, of which one or two are novel, for further improvements are explained.	One or two ideas for future expansion are listed but may not be practical or novel.	No direction for further improvement is provided.	WP1: Depth of knowledge
PROGRAMME OUTCOME: MULTIPLE	**Integrity, values, and impact of engineering solutions (Yousafzai et al., 2015)**				
Evaluative criteria: three (number)	**Quality distinctions: performance-level descriptors**				**Complex problem solving or complex engineering activities**
	Accomplished	**Competent**	**Developing**	**Beginning**	
8. A clear understanding of and adherence to scientific and professional ethics.	Clear documentation of compliance with all relevant ethical guidelines; clearly establishes authorship of the project work.	Exhibits understanding and complies with principles of scientific, professional, and/or academic integrity.	Exhibits incomplete understanding but still complies with principles of scientific, professional, and/or academic integrity.	Lack of understanding of scientific and professional ethics.	WP2: Range of conflicting requirements
9. Aware of the impact of engineering solutions in a global, economic, environmental, and/or societal context	Clearly articulates the impact of engineering solutions in a global, economic, environmental, and/or societal context	Articulates the impact of engineering solutions in a global, economic, environmental, and/or societal context	Limitedly articulates the impact of engineering solutions in a global, economic, environmental, and/or societal context	No articulation of the impact of engineering solutions in a global, economic, environmental, or societal context	WP2: Range of conflicting requirements
10. Evaluate engineering solutions that consider global, economic, environmental, and/or societal factors	Evaluates the impact of engineering solutions in a global, economic, environmental, and/or societal context	Evaluates the impact of engineering solutions in a global, economic, environmental, and/or societal context	Limitedly evaluates the impact of engineering solutions in a global, economic, environmental, and/or societal context	No evaluation of the impact of engineering solutions global, economic, environmental, or societal context	WP2: Range of conflicting requirements

PROGRAMME OUTCOME: INDIVIDUAL AND TEAMWORK	**Project management and teamwork skills (Yousafzai et al., 2015)**				
Evaluative criteria: three (number)	**Quality distinctions: performance-level descriptors**				**Complex problem solving or complex engineering activities**
	Accomplished	**Competent**	**Developing**	**Beginning**	
11. Work individually, or as part of a team where appropriate, to formulate, analyze, design, and implement a significant engineering project	Well-formulated, designed, and implemented project; completes project according to timeline; implementation represents a significant engineering project; demonstrates effectiveness as a team member (if applicable).	Project work contains no faults, but retains areas for significant improvement; major milestones in the timeline are met within the acceptable timeframe; implementation represents a significant engineering project with minor mistakes; demonstrates effectiveness as a team member (if applicable).	Project work contains some faults; some milestones in timeline not met; implementation exceeds minimum requirements but does not represent a significant engineering project; demonstrates marginal effectiveness as a team member (if applicable).	Project work contains numerous faults; significant milestones in timeline not met; implementation falls below expected minimum standards; unable to work effectively as a team member (if applicable).	EA1: Range of resources
12. Contribution to the team project/work	Collects and presents to the team a great deal of relevant information; offers well-developed and clearly expressed ideas directly related to the group's purpose.	Collects basic, useful information related to the project; occasionally offers useful ideas to meet the team's needs.	Collects information when prodded; tries to offer some ideas, but not well developed, and not clearly expressed, to meet the team's needs.	It does not collect any relevant information; no useful suggestions to address the team's needs.	Not applicable
13. Taking responsibility	Performs all tasks very effectively; attends all meetings and participates enthusiastically; very reliable.	Performs all assigned tasks; attends meetings regularly and usually participates effectively; generally reliable.	Performs assigned tasks but needs many reminders; attends meetings regularly but generally does not say anything constructive; sometimes expects others to do his/her work.	Does not perform assigned tasks; often misses meetings and, when present, does not have anything constructive to say; relies on others to do the work.	Not applicable
Application Strategy: analytical					

Appendix A.4 Assessment rubric by Pasya et al. (2015) mapped to Popham (1997) and IEA (2013)

Technical Report Rubric (mapped to multiple programme outcomes)					
Evaluative criteria: six (number)	**Quality distinctions: performance-level descriptors**				**Complex problem solving or complex engineering activities**
	Good	**Satisfactory**	**Unsatisfactory**	**Poor**	
	9 - 10	**6 - 8**	**3 - 5**	**0 - 2**	
Introduction: Problem of Statements, Objectives, Scope of Project	Clearly states the Problem of Statements, Objectives, Scope of Project	Problem of Statements, Objectives, Scope of Project reasonably stated.	Problem of Statements, Objectives, Scope of Project is not clearly stated.	Problem of Statements, Objectives, Scope of Project is not given or unacceptable.	WP1: Depth of knowledge
General Description: System Functions, User Interface, General Constraint	The overview and operation of the system are clearly described. The details are given and well-organized.	The overview and operation of the system are reasonably described. The level of detail is reasonable and sufficiently organized.	The overview and operation of the system are not properly described, either because they are not described in-depth, or lacking in organization.	Information on system description and operation was not given or unacceptable.	WP1: Depth of knowledge
Assumptions and Dependencies	The project scope is clearly defined.	The project scope is adequately defined.	The project scope is inadequately defined.	The project scope is not provided or unacceptable.	WP1: Depth of knowledge
Requirement Details: Customer Requirements, Engineering Equipment, System Input, System Output, System Processes	Hardware schematics are provided. Circuit design considerations and reasoning are provided in detail. The circuit is correctly designed.	Hardware schematics are provided. Circuit design considerations and reasoning are given and satisfactorily explained. The circuit has few design flaws that do not affect its overall functionality.	Hardware schematics are provided. Circuit design seriously lacks considerations and proper reasoning. The circuit has serious design flaws that impede the overall functionality of the system.	Hardware schematics are not provided or unacceptable.	WP2: Range of conflicting requirements

Project Schedule and Milestones	Flowcharts and software listing is provided. The flowchart is correctly designed and explained. The program is written correctly. The programme is explained in detail.	Flowcharts and software listing is provided. The flowchart is designed with minimum errors and explained. The program has few mistakes. The programme is explained in reasonable detail.	Flowcharts and software listing is provided. The flowchart has some serious design flaws that impede the overall functionality of the program. The flowchart is not explained in the report. The program has serious mistakes. Programme is not sufficiently explained.	Flowcharts and software listing are not provided or are unacceptable. The flowchart is unacceptable. The program is unacceptable. The program is inadequately explained.	EA1: Range of resources
Conclusions and Recommendations	Clearly summarised important design features and test results. Recommendations are relevant and described in sufficient detail.	Satisfactorily summarised important design features and test results. Recommendations are relevant but the details are insufficiently described.	Unsatisfactorily summarised important design features and test results. Recommendations are relevant but unsatisfactorily described.	Does not summarise important design features and test results. Recommendations are not relevant or significant lack in detail.	WP1: Depth of knowledge

Project Evaluation Report (mapped to multiple programme outcomes)					
Evaluative criteria: four (number)	**Quality distinctions: performance-level descriptors**				**Complex problem solving or complex engineering activities**
	Good	**Satisfactory**	**Unsatisfactory**	**Poor**	
	9 - 10	**6 - 8**	**3 - 5**	**0 - 2**	
Hardware functionality	The circuit fulfills the Requirements. The whole circuit works correctly	The circuit fulfills most of the requirements. A large part of the circuit works correctly.	The circuit fulfills only part of the requirements. Only a small part of the circuit works correctly	The circuit does not meet the requirements. The circuit is unacceptable or does not function at all	WP1: Depth of knowledge
Software functionality	The program fulfills the requirements. The program works correctly. The program flow is clear. Efficient usage of instructions, branching, and subroutines.	The program fulfills most of the requirements. A large part of the program works correctly. The program flow is clear with minimal confusion. Acceptable usage of instructions, branching, and subroutines.	The program fulfills only part of the requirements. Only small parts of the program work correctly. The program flow is unclear with several major confusions. Inefficient usage of instructions, branching, and subroutines.	The program does not meet the requirements. The program does not function at all. The program flow is extremely confusing to the reader. Wrong usage of instructions, branching, and subroutines.	WP1: Depth of knowledge
Creativity	Significant additional features are included in the project.	Additional features are included in the project, but not very significant.	Additional features are included in the project. Offer no significant improvement in the project.	No additional features are included in the project.	WP1: Depth of knowledge
Workmanship	The circuit layout is done using PCB. The circuit layout is designed with optimum circuit area and number of connections. The components are neatly arranged and soldered.	The circuit layout is done using PCB/Vero board. The circuit layout is designed with a reasonable circuit area and several connections. The components are reasonably arranged and soldered.	The circuit layout is done using a Vero board. The circuit layout is badly designed. A lot of connections are made using jumper wires. The components are not neatly arranged and badly soldered.	The circuit layout is done using a breadboard. Connections are done using only jumper wires.	WP1: Depth of knowledge

	A model/prototype is designed nicely using engineering techniques and materials.	A model/prototype is designed with minor defects. Using proper engineering techniques and materials.	A model/prototype is design but low of quality and bad design. Lack of engineering techniques and improper materials.	No model/prototype presented. I/O components are left connected to the PCB without any cover.	
Application strategy: analytical					