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Design, implementation, and assessment of complex engineering problems for the undergraduate engineering programme

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ABSTRACT

In the era of the Industrial Revolution 4.0, Outcome-Based Education (OBE) has been adopted worldwide to meet the growing demand for engineering graduates with the knowledge, skills, and attitudes to solve complex engineering problems. In this work, a methodology is presented for designing, implementing, and assessing students' performance in a Complex Engineering Problem group project, in accordance with the guidelines of the Board of Accreditation for Engineering and Technical Education (BAETE) in Bangladesh. The mapping of course outcomes (COs) to programme outcomes (POs), the knowledge profile, attributes of complex engineering problem-solving, and complex engineering activities is presented. The design and implementation of an effective assessment key to measure students' performance is presented using a case study in the Microprocessor and Embedded System course in the Electrical and Electronic Engineering programme. This contribution will be very useful to the teaching community in developing the OBE curriculum as well as researchers in the field of engineering and technical education.

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Introduction

In the era of the Industrial Revolution 4.0, technological development has had a tremendous impact on the demands placed on engineering graduates in industry. According to the World Economic Forum's Schools of the Future (2020), IR 4.0 has made it imperative that educational institutions and systems change their curricula to meet its demands. Due to the revolution, many of today's engineers will have to work in new job environments that did not exist previously. The gap between engineering programmes and jobs is widening because current teaching/learning systems do not equip students with the new skills needed for IR 4.0. In the wake of reviewing the teaching/learning method, the existing curriculum needs to be revised to create a link between the graduates and the rapidly changing industrial world. To facilitate high-quality learning in IR 4.0, the World Economic Forum (2023) has recently defined "Education 4.0" with eight critical characteristics in learning content - global citizenship skills, innovation and creativity skills, technology skills,

interpersonal skills, personalised and self-paced learning, accessible and inclusive learning, problem-based and collaborative learning, and lifelong and student-driven learning.

In the 21st century, technical and vocational education faces a multitude of challenges, especially amid rapid advancements in information technology and automation, the globalisation of the job market, a broad and unfocused curriculum, and a complex work environment (Le et al., 2022). Based on a comprehensive literature review, the authors recommended a project-based learning model as an effective approach to develop critical 21st-century skills, including 4Cs – creative thinking, critical thinking, communication, and collaboration (Le et al., 2022). Curricula should focus on building specialisation in a particular domain, fostering literacy in information, media, and technology, and integrating life skills such as flexibility, leadership, initiative, productivity, and social skills. They highlight the need for an educational paradigm shift and emphasize the importance of holistic student preparation to address the challenges and opportunities of the 21st century (Le et al., 2022). Baran et al. (2021) also recommended a project-based learning model to foster essential 21st-century skills, including autonomy, cooperation, and environmental awareness. Their findings underscored the positive impact of project-based learning on skills such as communication, collaboration, problem-solving, creativity, critical thinking, responsibility, and information technology literacy. STEM (science, technology, engineering, and mathematics) education is seen as an opportunity for students to acquire 21st-century skills, and engineering design-based activities have been shown to improve these skills, even among middle school students (Uzel & Bilici, 2022).

As education shifts toward a more hands-on, skill-based approach (Ülger & Çepni, 2020), complex engineering problem-solving (CEPS) has become a crucial pillar of Outcome-Based Education (OBE) in engineering education. CEPS projects ensure that students develop critical problem-solving skills aligned with industry demands. As accreditation bodies focus on bridging the gap between theoretical knowledge and real-world challenges, structured methodologies for integrating CEPS have become a priority (Ling, 2024). To make this happen, structured evaluation keys and project-based assessments are being integrated into engineering curricula, helping students enhance both their analytical thinking and hands-on problem-solving skills. This approach ensures that by the time they enter the workforce, they are not just graduates—they are engineers ready to take on the challenges of a rapidly evolving world. With Industrial Revolution 4.0 (IR 4.0) transforming industries at an unprecedented pace, it is more important than ever for engineering education to keep up, adapt, and prepare students for the future. According to the Global Competitiveness Report Special Edition 2020 by the World Economic Forum (2020), complex problem-solving is the top-most important skill for the upcoming IR 4.0. Students with an engineering background would require improved skills in knowledge acquisition, reasoning, problem analysis, and evaluation (Funke & Frensch, 2007). Therefore, engineering students should be able to handle complex problems and solve them. Therefore, both the facilitators/instructors and learners/students must equip themselves with the necessary knowledge, capability, and motivation to think of problems critically and creatively, and solve at the same time, because these factors can strongly influence how effectively the teachers carry out teaching-learning activities and assessments, as well as what the students can achieve.

Outcome-Based Education (OBE) Framework

Outcome-Based Education (OBE) stands at the forefront of modern pedagogical approaches, shifting the educational paradigm from a traditional teacher-centric model to a student-centric philosophy. Embracing the principles of revised Bloom's taxonomy (Anderson et al., 2001), OBE promotes holistic student development, fostering rational thinking, ethical values, and innovative capabilities. As institutions undertake this transition, challenges emerge in today's dynamic educational landscape, among them those related to assessment processes and tools. Accreditation bodies, such as the Accreditation Board for Engineering and Technology (ABET) (2020) and the

Washington Accord (WA) of the International Engineering Alliance (IEA) (2021), have defined Programme Outcomes (POs) to evaluate the effectiveness of engineering education. In Bangladesh, the Board of Accreditation for Engineering and Technical Education (BAETE) (BAETE, 2019) aligns itself with the twelve widely accepted POs or graduate attributes from WA of IEA.

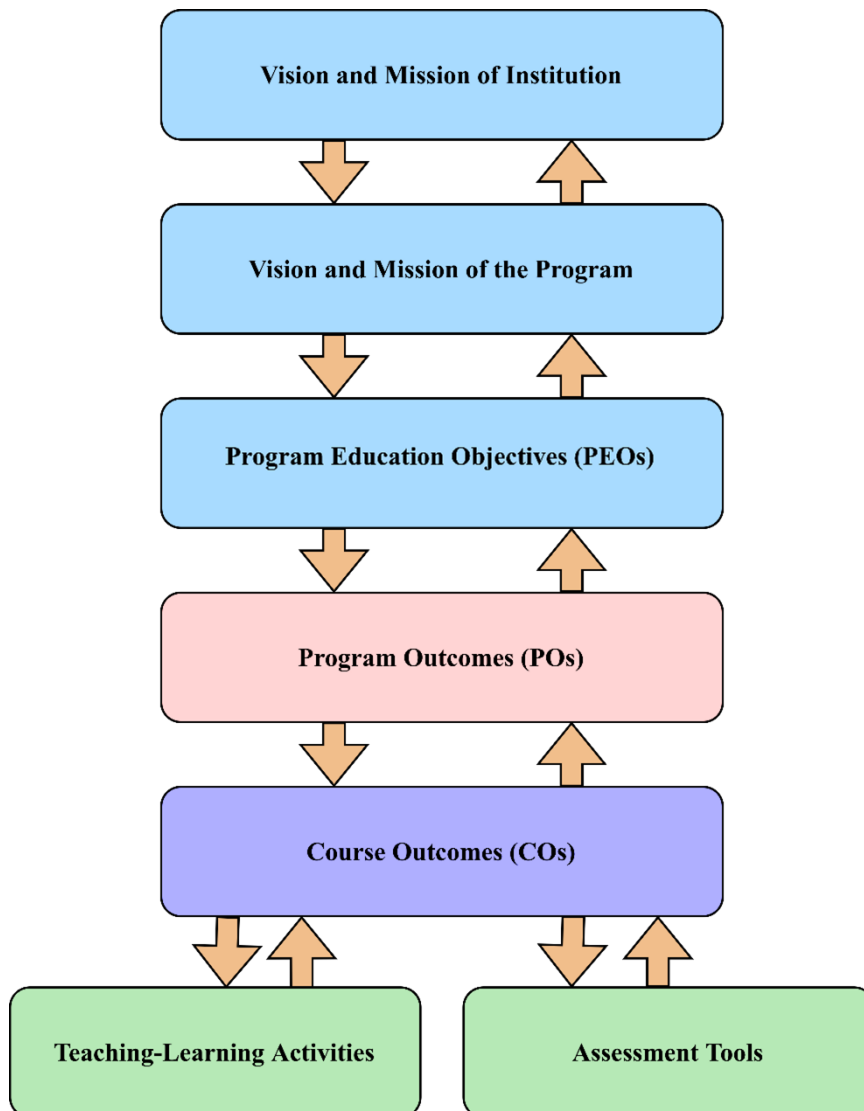
This section briefly explores the fundamental components of OBE, focusing on Programme Outcomes, the attributes of Complex Engineering Problem Solving, and the assessment models used to measure students' achievement. The framework presented here provides a comprehensive understanding of OBE, offering educators and institutions a roadmap to navigate the ever-changing landscape of engineering education.

OBE Model

Figure 1 presents a framework for implementing OBE in undergraduate engineering programmes, depicting its core components.

Figure 1

Outcome-Based Education (OBE) model



There should be positive alignments between components. For example, the programme's vision and mission must align with the institution's. The Programme Educational Objectives (PEOs) are broad statements that describe the career and professional accomplishments the programme prepares graduates to achieve. It is expected that graduates will attain the PEOs within three to five years of graduation, and attainment is judged based on graduates' actual field performance. Programme Outcomes (POs) are statements of the knowledge, skills, and attitudes students acquire as they progress through the programme. PO achievements are evaluated throughout the programme. Course Outcomes (COs) are statements of the knowledge, skills, and attitudes students are expected to acquire by the end of a course.

Once all components are defined, continuous quality improvement (CQI) should be carried out regularly at each level, based on the progress of each component. As part of the CQI, primarily, the modification in teaching learning methods and assessment tools should be done, and if required, COs may be redefined. In OBE, there are four major stakeholders, namely: students, alums, employers, and faculty. In CQI, all stakeholders' opinions/feedback should be collected through regular surveys.

Programme Outcomes

Programme Outcomes (POs) or Graduate Attributes are statements related to the knowledge, skills, and attitudes obtained by students while progressing through the program. Students are expected to know and achieve these graduate attributes by the time of graduation. According to the BAETE manual (BAETE, 2019), edition 2.1, the POs are presented in Table 1 of the Appendix.

Attributes of Knowledge Profile, Complex Engineering Problem Solving, and Activities

The Board of Accreditation for Engineering and Technical Education (BAETE), Bangladesh, has emphasised the Complex Engineering Problems and Complex Engineering Activities in the second edition of the Accreditation Manual for Undergraduate Engineering programmes. Any question, assignment, or project on the Complex Engineering Problem should require in-depth engineering knowledge to be solved. It should also cover a wide range of technical, engineering, and related topics, and there might be no obvious solutions. According to the manual (BAETE, 2019), Complex Engineering Problems exhibit characteristics of P1 and some or all of P2-P7. The attributes are described in Table 2 in the Appendix.

There are 8 Knowledge Profiles (K1–K8) described in the BAETE manual, and any engineering programme that aims to attain the POs should ensure its curriculum covers all of them. The attributes of the Knowledge Profile and their relationship with POs, as given in Table 1, are presented in Table 3 in the Appendix.

Table 3 shows that Complex Engineering Problem Solving is associated with PO1–PO7. According to its characteristics presented in Table 2, a Complex Engineering Problem must have the characteristic of P1, which cannot be resolved without one or more of K3, K4, K5, or K8. Therefore, the COs mapped to one or some of the programme outcomes from PO1-PO7 should be assessed via Complex Engineer Problem Solving. If any of the COs are mapped with PO10, then the assessment should include Complex Engineering Activities. According to the BAETE manual (BAETE, 2019), Complex Engineering Activities should have at least one or all of the attributes shown in Table 4 in the Appendix.

It can be seen from Table 4 that Complex Engineering Activities involve a range of resources, including people, finance, information, and materials, and require understanding the interactions among technical, engineering, and other topics to solve problems in novel ways while considering the consequences for society and the environment.

PO Assessment Model

POs may be assessed directly through COs, indirectly through a survey, or through a weighted combination of direct and indirect methods. In direct assessment, several models exist, such as the culminating, dominant, and accumulating models. In the culminating model of PO measurement, only a few selected final-year courses are used to measure CO and PO achievements. In the dominating model, a few key core courses are considered for CO and PO achievements. In the accumulating model, all core courses are considered for the measurement of CO and PO achievements. The most balanced model is the dominant one, and most engineering programmes at universities in Bangladesh use it to measure PO achievement. In this work, we shall describe how a course, i.e., EEE 3311 – Microprocessor and Embedded Systems, can be designed to contribute to the PO achievement using a dominating model.

Literature Review

Additional engineering education programmes often face criticism that their teaching materials and/or theories have never been translated into practice. On top of that, the current grading system is highly dependent on how well students can memorise. This directly leads to a poor assessment of a graduate's practical abilities. Another important factor is how well the instructors deliver the engineering course lecture materials and assist learners in developing the skills to solve complex problems. Typically, project work is considered a vital tool in developing problem-solving skills. Nevertheless, it is very common for project work to involve simulation-based, limited work and to lack the real-life details of a practical working environment. It is very important to create an environment where students can become creative and solve complex problems by learning engineering skills. At the same time, the instructors should modify the current teaching method and incorporate relevant projects, tools, and/or technology to assist students. In a series of works (D. Jonassen et al., 2006; D. H. Jonassen, 1997; D. H. Jonassen & Hernandez-Serrano, 2002), the authors provided several guidelines for the facilitators to make successful complex problems for students. Briefly, the problem should be grounded in a well-defined conceptual framework, with no obvious solution and multiple possible solutions, so that students need to examine it thoroughly from multiple perspectives.

Outcome-Based Education (OBE) has been adopted by over 47 countries worldwide to produce engineering graduates capable of solving complex engineering problems. At the outset of adoption, OBE was promoted by the International Engineering Alliance (IEA) and mandated for the accreditation of engineering degree programmes. OBE can be described as a method of curriculum design, teaching, and learning that focuses on what students can actually achieve in terms of specified outcomes for individual student learning. One of the central foci of OBE is to emphasize the importance of complex engineering problems. This emphasis is put into operation through the definition of appropriate graduate attributes, which are then embedded in teaching and learning processes. OBE incorporates innovative teaching and learning practices, such as problem-based learning, oral presentations, capstone projects, professional talks, and industry attachments (Rajak et al., 2018). Although Outcome-based education (OBE) has been adopted internationally for three decades, Bangladesh has only recently actively embraced it to enhance the quality and relevance of engineering education. Despite challenges in implementing OBE in Bangladesh (Hassan, 2012), some universities in Bangladesh began practising OBE independently (Syed et al., 2022). The University Grants Commission (UGC) of Bangladesh and the Bangladesh Accreditation Council (BAC) only began taking significant steps to implement the OBE curriculum in 2018. In March 2018, a committee of seven experts from diverse fields prepared OBE templates. The template for the OBE curriculum was prepared by the Strategic Planning and Quality Assurance (SPQA) division of UGC. It was sent to

all the universities on June 30, 2021, and they submitted their revised OBE curriculum in 2022 (University Grants Commission of Bangladesh, 2020). The Bangladesh Accreditation Council Act was approved in 2017 (Bangladesh Accreditation Council, 2017), and accreditation rules were completed and published in 2022 (Bangladesh Accreditation Council, 2022).

Apart from the design factor in an OBE curriculum, another major factor is the assessment of OBE implementation and complex engineering problems. In the context of OBE, assessment must not only be accurate and measurable but also explicitly aligned with defined course outcomes (COs) and programme outcomes (POs). This distinguishes it from conventional assessment, which may focus primarily on content recall or isolated skills. Typically, the assessment methods are categorised into direct and indirect methods (Easa, 2013). Direct assessment includes a set of indicators to examine the student's knowledge or skills. These indicators typically include final examination, midterm examination, class test, viva voce (oral examination), class performance, presentation, and project. Assessment strategies in engineering education vary widely and can be broadly categorized into formative and summative approaches. Formative assessments include class tests, assignments, or presentations that provide ongoing feedback to guide student learning, while summative assessments, such as final examinations or project evaluations, measure overall achievement at the end of a course. Within both categories, marking key-based evaluations is widely used to ensure transparency and consistency. While key-based assessment provides a structured mechanism for evaluating problem-solving competencies, it is often complemented by assessment of outputs derived from pedagogical approaches such as case-based learning (CBL). Dewi & Rahayu (2023) found that CBL fosters critical thinking by immersing students in authentic problem-solving scenarios. However, in engineering education, structured marking keys remain the preferred tool for ensuring transparent and measurable competency assessments. Isa et al. (2021) presented an overview of the implementation of complex engineering problems (CEP) and complex engineering activities (CEA) in an engineering programme in Malaysia. They observed that most universities use assignments or projects to assess CEP and CEA. They also discovered that a lack of resources and training for educators is one of the challenges to successfully implementing outcome-based education in CEP and CEA (Isa et al., 2021). The importance of ongoing training and access to relevant learning materials for educators cannot be overstated. Although this article primarily aims to contribute to ongoing efforts to implement the OBE curriculum effectively in Bangladesh and to offer educators navigating this changing landscape of engineering education a guideline, it should also be helpful to educators worldwide in a dynamic system such as the OBE curriculum.

The current work is primarily concerned with the marking of key-based assessments of complex engineering problems. Key design for complex engineering problems is an ongoing process that has revealed various strengths and weaknesses. There are many benefits to key-based assessment, as it evaluates a particular project/assignment against multiple criteria, including the project's overall goals, expected outcomes, and opportunities for improvement. Therefore, rubrics can be highly helpful for scoring complex engineering problems using a standard assessment form. Previous research highlights the role of structured learning models in improving students' ability to analyse and synthesise engineering problems (Kasuga et al., 2022). By integrating key-based assessments, educators can systematically measure students' competencies in solving complex engineering problems while maintaining alignment with accreditation standards. Several studies provide an overview of the assessment of student and programme outcomes (Mohammad & Zaharim, 2012; Premalatha, 2019; Wahab et al., 2011). However, to the best of our knowledge, few studies provide designs for the keys to complex engineering problems. The authors in Ali et al. (2017) proposed a set of criteria to evaluate the outcomes of senior design projects at Old Dominion University. A total of 12 categories (such as design methodology, design quality, analysis, testing, etc) were assessed using four grades (unacceptable, marginal, acceptable, exceptional). The authors claimed that the assessment method has led to improvements in attaining the design goals. Another study (Bahsan et al., 2014) presented a marking key for assessing complex engineering problems in a thermal engineering course.

The study utilised 7 categories (such as application of engineering principles, integration of mathematical solutions, interpretation of results, and discussions) and a scale of 1 – 5 for assessment. Recently, a research group presented a simplified key for assessing a capstone project (Basir et al., 2019). The authors proposed using 18 categories (e.g., structural key plan, design using tools, communication skills, presentation), each assessed on a 5-10 scale. Several designs have demonstrated the potential for assessing complex engineering problems. Nevertheless, there is a need for a well-structured key that can be reliably used to assess complex engineering problems.

Research Objectives

The existing literature makes it clear that the significance of continuous training and the availability of appropriate learning resources for educators cannot be emphasized enough. One of the primary purposes of this study was to propose an approach to designing, implementing, and assessing students' performance through a group project on complex engineering problem-solving. Another primary objective was to prepare a marking key and then implement it in assessing the complex engineering problem-solving project. In alignment with the primary aim of this work to contribute to the ongoing efforts on effective implementation of OBE curriculum in Bangladesh, a course-level continual quality improvement (CQI) process - a cornerstone of OBE - is explored. A secondary purpose was to provide an elaborate linkage between complex engineering problem solving and outcome-based education in the context of real-world engineering challenges posed by IR 4.0. This analysis is helpful to the teaching community in developing OBE curriculum, as well as to researchers in the field of engineering and technical education. In order to meet these research objectives, we try to address the following research questions:

- a. How can an effective and clear approach be developed for the design, implementation, and assessment of Complex Engineering Problem Solving within the OBE framework?
- b. How can a well-structured and effective marking key be developed and implemented to reliably assess various aspects of complex engineering problem-solving, and calculate the Course Outcomes (COs) and corresponding Programme Outcomes (POs)?
- c. How can a strong and meaningful linkage be established between complex engineering problem-solving and the principles of outcome-based education, emphasising real-world engineering challenges posed by Industrial Revolution 4.0?
- d. Based on the OBE principle, how can a course-level continuous quality improvement (CQI) cycle be executed in order to continuously improve the quality of course contents and outcomes, teaching-learning activities, assessment tools, and students' attainments?

Methods

Research Design

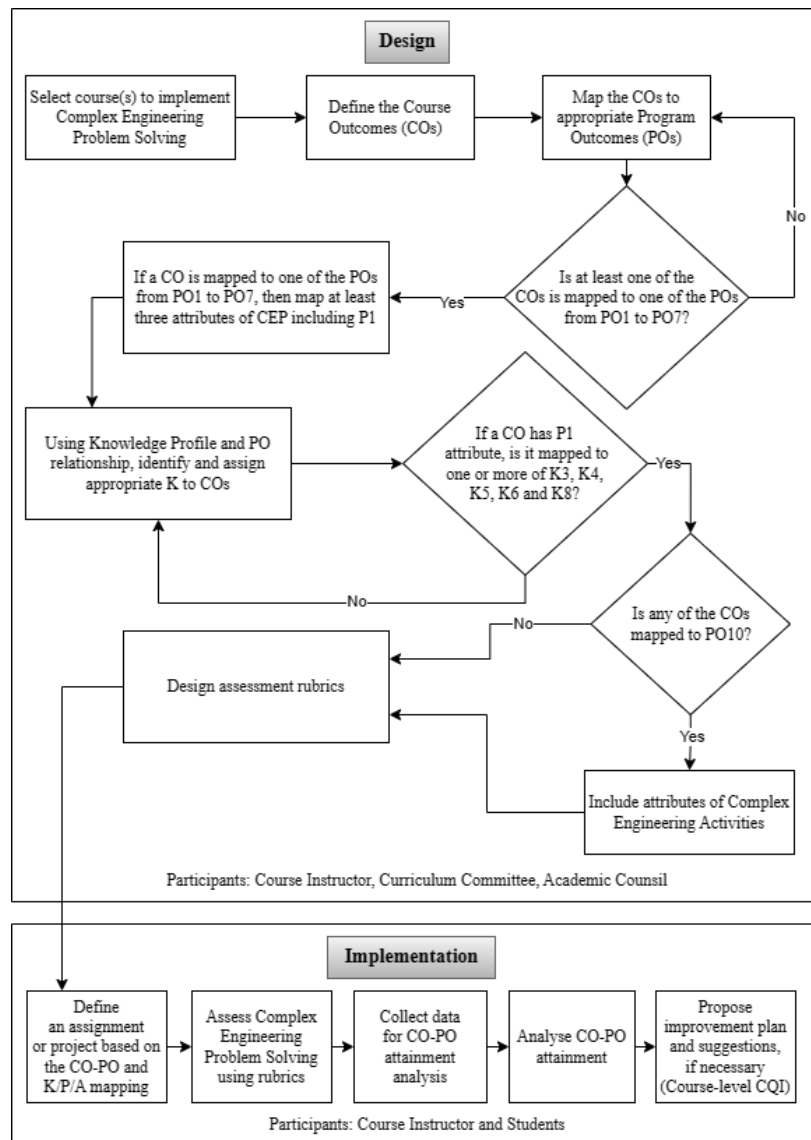
This work primarily aims to demonstrate an effective approach to designing, implementing, and evaluating students' performance in group projects focused on Complex Engineering Problem Solving. With an emphasis on outcome-based education principles, the study also aims to establish a clear link between these principles and complex engineering problems. real-world engineering challenges. Based on OBE principles, this work also demonstrates how a course-level continuous quality improvement (CQI) cycle can be implemented to enhance teaching and learning quality.

In the dominating model, a set of core courses is selected to measure PO attainments. Among these courses, a few specific courses are chosen to implement complex engineering problem-solving. First, the COs of such a course are defined and mapped with appropriate POs. As discussed earlier,

any CO mapped to one of the PO from PO1 to PO7 is assessed via Complex Engineer Problem Solving. If this criterion is not met, the CO-PO mapping must be revised to make necessary changes. A crucial element of implementing complex engineering problem-solving is ensuring that assessment strategies align with accreditation standards. In the next step, the appropriate Knowledge Profile is identified based on its relationship, as presented in Table 3. Including P1 as a mandatory attribute, a Complex Engineering Problem Solving must have at least three attributes from P1 to P7. The characteristic of P1 cannot be resolved without one or more of K3, K4, K5, K6, or K8. Therefore, if required, the CO-PO, Knowledge Profile, and Complex Engineering Problem attributes mapping are revised again. If any CO is mapped to PO10, then appropriate Complex Engineering Activities are included. Once all criteria are satisfied, the assessment rubric is finalized. The marking key should provide the instructor with benchmarks for marking and guide students to achieve better marks. In this work, the design of a sample assessment rubric is discussed in the results section and provided in full in the Appendix. A well-defined rubric not only provides benchmarks for assessment but also guides the formulation of problem statements and project design. The CO-PO attainments are recorded and analysed in the course-level continuous quality improvement (CQI) process.

Figure 2

Stages of designing and implementing complex engineering problem-solving



Participants

All three stages, i.e., design, implementation, and assessment of complex engineering problem solving, were carried out in the course of the Bachelor of Science (BSc) in Electrical and Electronic Engineering (EEE) programme at the University of Liberal Arts Bangladesh (ULAB), a private university, based in the city of Dhaka in Bangladesh. The course instructors were primarily responsible for creating appropriate course content, course outcomes (COs), mapping COs to programme outcomes (POs), designing teaching-learning activities, developing assessment tools, and preparing marking keys. All courses were then presented and discussed at the departmental curriculum committee meetings. Upon this committee's recommendation, the curriculum was placed before the Academic Council for approval. The course instructor followed the approved methodology presented in this work to design and implement a group project on complex engineering problem-solving. Forty-one undergraduate students, aged 18 to 25, were assessed using a well-defined marking key that included clearly articulated criteria, performance levels (poor to excellent), and weightings for the project's components to ensure transparency and consistency in grading. After analysing the CO-PO attainments, the course instructor is also developing quality improvement plans and making suggestions for the course.

A Case Study – EEE 3311: Microprocessor and Embedded Systems

To demonstrate the effectiveness of the methodology described in Figure 2, we applied it in EEE 3311 – Microprocessor and Embedded Systems. This is a core course offered to the third-year students of a 4-year undergraduate programme in the Department of Electrical and Electronic Engineering. The objective of this course is to study the architecture of computer systems, to understand the design and function of the various units, and interpret the instruction sets of digital computers. Another aim of this course is to prepare students with the competence to design and understand embedded systems. A summary of the course contents related to embedded systems is shown in Table 5 in the Appendix.

As presented in Table 6, there are a total of 6 COs in the EEE 3311 - Microprocessor and Embedded Systems course. It also shows the definitions of COs, their mapping to Programme Outcomes (POs), the knowledge profile (K), and the attributes of complex engineering problem-solving (P) and complex engineering activities (A).

Table 6

Course outcomes (COs) and their mapping with POs, K, P, and A, and Bloom's taxonomy domain and level

CO	Description	POs	K/P/A	Bloom's Taxonomy Domain/Level	Assessment Tools
CO1	Analyse the design specifications of a microcontroller-based embedded system.	PO2	K4/ P1, P3, P4	Cognitive/L4	
CO2	Identify the need for, and search for and find appropriate research literature relevant to the problem.	PO12		Cognitive/L2	
CO3	Develop a methodology outlining principles and a general procedure based on what information is known and what needs to be determined, with a relevant literature review.	PO4	K8/P1, P2, P6	Cognitive/L3	Group Project on Complex Engineering Problem
CO4	Design a microcontroller-based embedded system	PO3	K5/ P1, P2, P5	Cognitive/L6	
CO5	Implement the microcontroller-based embedded systems	PO5	K6/ P1, P2, P7	Psychomotor/L3	

CO6	Write a comprehensive report and orally present the key concepts and results of the embedded system you designed effectively.	PO10	A2, A3	Affective/L3
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The COs are associated with levels 2 to 4 of the cognitive domain, and level 3 of the psychomotor and affective domains in Bloom's Taxonomy. Table 6 shows that CO1, CO2, CO3, CO4, CO5 and CO6 are mapped to PO2, PO12, PO4, PO3, PO5, and PO10 respectively. Since CO1, CO3, CO4, and CO5 are mapped to POs from PO1 to PO7, they are assessed through a CEPS project. The CO6, which is mapped to CO10, is assessed from CEA.

A detailed example of the complex engineering problem-solving project assigned to students, including the scope, problem statement, and tasks, is provided in the Appendix. This example illustrates how the CO-PO mapping and assessment keys were applied in practice. It also demonstrates how to establish a strong, meaningful linkage between complex engineering problem-solving and the principles of outcome-based education, emphasising the real-world engineering challenges posed by Industrial Revolution 4.0.

Data Collection and Analysis

Building on the mapping framework, data were collected using a single instrument: students' marks in the project on complex engineering problem solving. The students had 5 weeks to complete the project in groups of 4. While the project output was prepared collaboratively, the assessment was conducted at both the group and individual levels. Most marks were awarded at the group level, but a component of CO6 related to communication was assessed individually through oral presentation and viva voce. The marks obtained by each student are recorded and analysed. As shown in (1), a student's marks are divided by the total marks to determine the student's attainment.

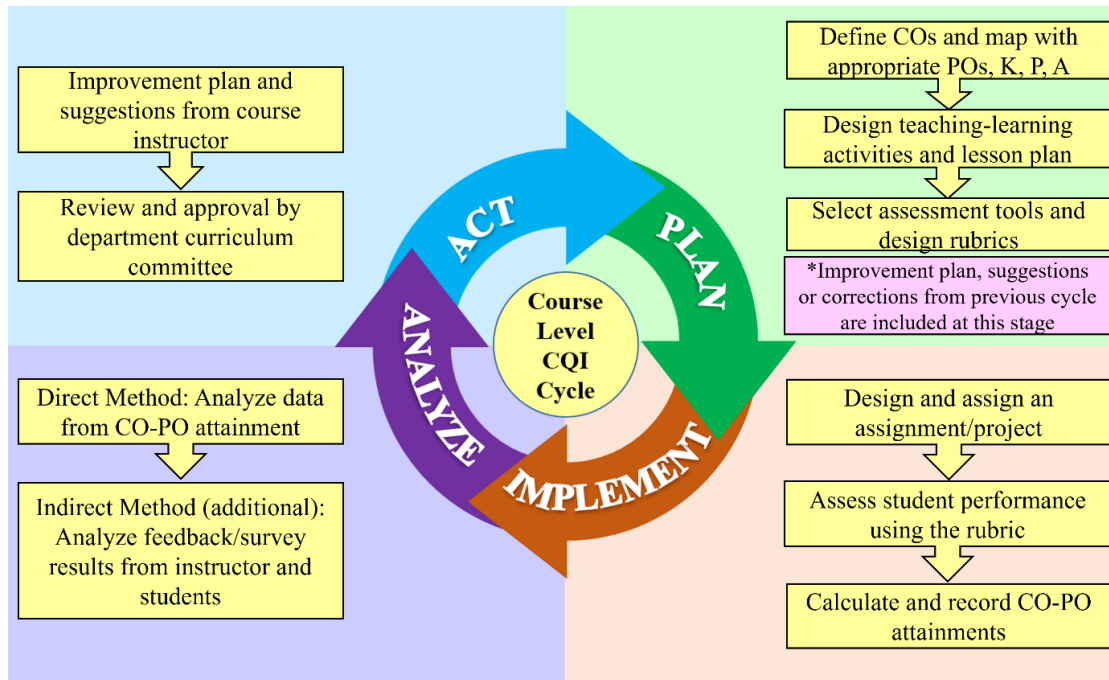
$$\text{marks in percentage} = \frac{\text{Obtained marks for a CO}}{\text{Total Marks for a CO}} \times 100$$

The BSc in EEE programme at ULAB has set a benchmark of 55% in achieving a CO and corresponding PO. A course is considered successful in achieving its course outcomes (CO) if 60% of students attain each CO.

Course-level Continuous Quality Improvement (CQI) Process

Every OBE-based education system should have a continuous quality improvement (CQI) mechanism at three levels, i.e., PEOs, POs, and COs. In this work, we suggest a CQI cycle at the course level.

The CQI process at the course level should demonstrate an established system for collecting and analysing the attainment levels of COs and POs for each course at the end of each semester. The outcomes should be measured and analysed using both the direct and indirect methods. Once the shortcomings and limitations are identified, action should be taken, if necessary, to refine and improve the course contents and outcomes, CO-PO mapping, teaching-learning methods, and assessment tools. In the BSc in EEE programme at ULAB, direct methods, i.e., assignments or group projects on complex engineering problem-solving, are used to assess attainment of CO and the corresponding PO. The process has been depicted in Figure 3.

Figure 3*Course level continuous quality improvement (CQI) process*

Results

The effectiveness of the proposed methodology, implemented in EEE 3311 – Microprocessor and Embedded Systems, was evaluated by analyzing student performance and attainment data. The results focus on the application of the assessment rubrics, the measurement of course outcome (CO) and programme outcome (PO) attainment, and the course-level continuous quality improvement (CQI) process.

Designing Assessment Keys

According to the BAETE manual, POs should be assessed using direct methods, which involve the direct examination or observation of students' knowledge or skills against measurable performance indicators or rubrics. In addition, indirect methods based on stakeholder opinions or self-reports may be used to assess PO. Therefore, assessing student performance is essential to the teaching and learning process and is a cornerstone of continuous quality improvement (CQI). The evaluation is done using an assessment form with well-defined rubrics based on the mapping of COs with POs, K, CEP, and CEA. Generally, marks, in conjunction with qualitative remarks, are used in assessment against a certain benchmark (Ali and Hui Natalie Chuang, 2017; Bahsan et al., 2014; Pejcinovic, 2020). The assessment rubrics are presented in Table 7 in the Appendix.

As shown in Table 7, each project criterion is rated on a scale of 1 to 4, with qualitative remarks of poor, satisfactory, good, and excellent, respectively. The marking key provides the benchmarks for each standard. In some cases, a criterion is divided into sub-criteria, and the mark is calculated using a weighted average. This form, with an assessment rubric, is explained to students and provided while assigning the group project, which accounts for 20% of the total marks in the course. The students are required to submit project reports and present their work. The students'

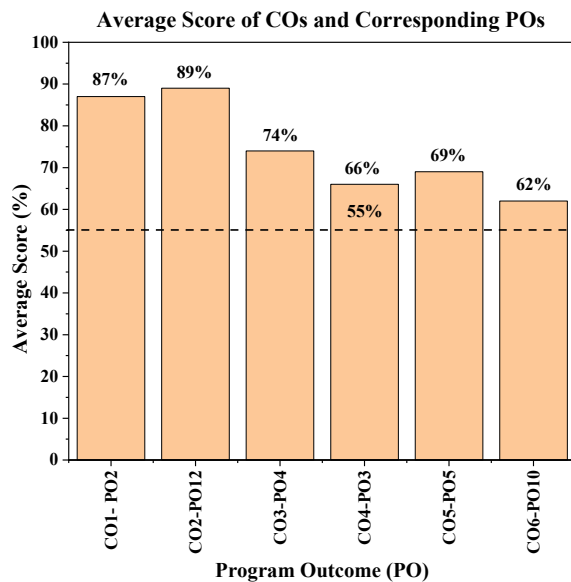
performance regarding problem analysis (CO1-PO2), design/development of solutions (CO4-PO3), investigation (CO3-PO4), application of modern tools (CO5-PO5), and engagement in life-long learning (CO2-PO12), reflected in their ability to identify research needs and consult relevant literature, is evaluated via the report. The report also allows for assessing their written communication skills (CO6-PO10). During the presentation, viva voce (oral examination) is conducted to measure their oral communication skill (CO6-PO10).

Analysis of CO and PO Attainment

The attainments of COs by individual students are calculated using equation (1), and the attainments of corresponding POs are obtained subsequently. Fig. 4 shows the average marks obtained by the 41 students in each CO and the corresponding POs in the project, based on complex engineering problem-solving over one semester.

Figure 4

Average Score of COs and Corresponding POs



Course-level CQI Process

Once the attainment levels of the COs and POs in this course are calculated, the results are analysed at the end of the semester as part of an established course-level CQI cycle. Table 8 shows the percentage of students achieving Course Outcomes (COs).

Table 8

Percentage of students achieving course outcomes (COs)

Course Outcomes (CO)	Criteria for Achievement	Percentage of Students Attaining COs
CO1		90%
CO2		90%
CO3	60% of the students to achieve 55% of the allocated mark	78%
CO4		68%
CO5		68%
CO6		71%

Since at least 60% of the students in the semester found this course successful in achieving the course outcomes (CO), no improvement plan was necessary.

Discussion

The present study focuses on the design, implementation, and assessment of complex engineering problems for undergraduate engineering programmes. The findings from student attainment data suggest that the presented methodology can effectively contribute to shaping the outcome-based education (OBE) curricula in engineering and technical education.

One of the significant findings arises from mapping course outcomes (COs) with programme outcomes (POs), the knowledge profile, attributes of complex engineering problem-solving, complex engineering activities, and their attainment levels. Complex engineering problem-solving is associated with PO1-PO7, and COs to be assessed via complex engineering problem-solving should be mapped to one or more of these programme outcomes. The results show that all six COs reached the benchmark of at least 60% of students achieving $\geq 55\%$ marks, with stronger performance in problem analysis (CO1, 90%) and lifelong learning skills (CO2, 90%), and lower attainment in design (CO4, 68%) and implementation (CO5, 68%). These differences indicate that, while students are generally effective at analysing problems and reviewing the literature, more support is needed in translating designs into functioning implementations. When any of the COs is mapped to PO10, the assessment should include complex engineering activities. In line with BAETE's framework, such activities involve a range of resources, including people, finance, information, and materials, and require understanding the interactions among technical, engineering, and other topics to solve the problem in novel ways while considering the consequences for society and the environment. In this study, these criteria served as guiding standards for assessment design. This aligns with a prior study by Liew et al. (2020), which highlights complex problem-solving as a necessary ability to address the evolving socio-technical challenges of the 21st century (WEF, 2020). Both studies highlight the need to properly map course outcomes to programme outcomes to design effective assessments and conclude that project-based teaching-learning approaches are most appropriate for addressing complex engineering problem-solving. However, the current research contributes a detailed, step-by-step methodology for individual courses, offering guidance on assessment rubric design and student attainment level analysis.

Another important contribution of this study is the design of an effective assessment rubric to measure students' performance in COs and POs. While rubric development represents a methodological contribution rather than an empirical finding, its application provided valuable evidence on student performance and attainment. The marking key provides the instructor with a benchmark for assessing student work and guidance for students to achieve better marks and improve their outcomes. Our study aligns with the findings of Lanziner & Strong (2016), who also discussed the development of rubrics for assessing engineering design, professional practice, and communication. Their emphasis on alignment with course outcomes (COs) and mapping to Canadian Engineering Accreditation Board (CEAB) graduate attributes resonates with our own research, as we also have carefully mapped our assessment to the standards set by the Bangladesh Accreditation and Evaluation Agency (BAETE, further ensuring the relevance and applicability of our methodology. This study is also in line with the work of Ayadat et al. (2020) as both studies emphasize the design, implementation, and assessment of complex engineering problems within the framework of OBE for undergraduate engineering programmes. In addition to an important similarity in the detailed methodologies for mapping COs to POs, both studies underline the importance of assessment rubrics in evaluating students' performance in solving complex engineering problems. While Ayadat et al. (2020) provide an institutional-level analysis within civil engineering, this study focuses on electrical

and electronic engineering. By including a specific example—a project on designing an embedded system —this work offers a specialized perspective within this discipline. Other researchers and instructors can use the sample rubric presented in this study to reliably and effectively assess complex engineering problems.

At the course level, the outcomes should be measured and analysed each semester, and any shortcomings or limitations should be identified to refine and improve the course contents, teaching-learning methods, and assessment tools, if necessary, as part of the CQI process. The results of this study also point to areas for continuous quality improvement (CQI). Specifically, lower attainment in CO4 (design) and CO5 (implementation) suggests the need for additional instructional support in system design and for more opportunities to use tools hands-on in future iterations.

However, the study presented in this paper has several limitations that should be considered. Firstly, while the methodology presented in this paper can be applied to a range of engineering courses, it has only been verified in the context of the Microprocessor and Embedded System course in the Electrical and Electronic Engineering programme. Future studies should test the methodology presented in this paper across a range of engineering courses to validate its effectiveness further. Secondly, while measuring students' attainment of a CO and corresponding PO, a benchmark of 55% marks has been set as the achievement criterion. However, it can vary depending on the specific course and context. Therefore, further research is needed to explore the impact of varying the achievement criteria on the results obtained. Finally, the study has focused on a single cycle of the CQI process. The effectiveness of the methodology presented in this paper needs to be investigated over multiple cycles of the CQI process.

Despite these limitations, the major findings of this study indicate that the presented methodology can be beneficial to the teaching community in developing and implementing OBE curricula and researchers in the field of engineering and technical education. The study provides a comprehensive guide to designing, implementing, and assessing complex engineering problems in undergraduate engineering programmes. This can hopefully help produce engineering graduates with the necessary knowledge, skills, and attitudes to solve complex engineering problems in the era of Industrial Revolution 4.0.

Conclusions

This study presented a structured methodology for integrating CEPS into an undergraduate Electrical and Electronic Engineering programme. Using the BAETE framework for CO–PO mapping, knowledge profiles, and CEP/CEA attributes, the approach was applied in a Microprocessor and Embedded Systems course. A structured assessment rubric was developed and applied to measure attainment of COs and corresponding POs.

The assessment results showed that all six COs met the minimum attainment benchmark of 60% of students achieving $\geq 55\%$ marks. Strong performance was observed in CO1 (problem analysis) and CO2 (lifelong learning/research skills), with 90% attainment in each. In contrast, CO4 (design) and CO5 (implementation/tool use) showed lower attainment at 68%. These findings demonstrate that while students are generally capable of analysing problems and reviewing literature effectively, they face challenges in translating designs into functioning implementations. Individual oral assessments complemented the group projects, ensuring that collaborative skills were assessed alongside individual accountability. This combination strengthened the validity of the rubric-based evaluation.

The CEPS project required students to carry out realistic design and implementation tasks, moving beyond theoretical exercises toward practical problem-solving. In doing so, the study showed how outcome-based education can be directly linked to real-world engineering challenges aligned with Industry 4.0 demands. This highlights the need to prepare students not only for analytical problem-solving but also for the technological, social, and environmental complexities of modern engineering practice.

Finally, by grounding CQI actions in empirical attainment data, this methodology provides a replicable model for other engineering programmes seeking to implement OBE requirements.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

Table 1

Programme outcomes (POs) or graduate attributes

PO	Attribute	Description
PO1	Engineering Knowledge	Apply knowledge of mathematics, natural science, engineering fundamentals and an engineering specialization as specified in K1 to K4 respectively to the solution of complex engineering problems.
PO2	Problem Analysis	Identify, formulate, research literature & analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences (K1 to K4)
PO3	Design / Development of Solutions	Design solutions for complex engineering problems and design systems, components, or processes with appropriate consideration for public health and safety, cultural, societal, and environmental considerations (K5)
PO4	Investigation	Conduct investigations of complex problems using research-based knowledge (K8) and research methods including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions
PO5	Modern Tool Usage	Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering problems, with an understanding of the limitations (K6)
PO6	The Engineer and Society	Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solutions to complex engineering problems (K7)
PO7	Environment and Sustainability	Understand and evaluate the sustainability and impact of professional engineering work in the solution of complex engineering problems in societal and environmental contexts. (K7)
PO8	Ethics	Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice. (K7)
PO9	Individual and Teamwork	Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings
PO10	Communication	Communicate effectively on complex engineering activities with the engineering community and with society at large, including comprehending and writing effective reports and design documentation, making effective presentations, and giving and receiving clear instructions.

PO11	Project Management and Finance	Demonstrate knowledge and understanding of engineering management principles and economic decision making and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments
PO12	Lifelong Learning	Recognize the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.

Table 2*Attributes of complex engineering problem solving*

P	Attribute	Description
P1	Depth of knowledge required	Cannot be resolved without in-depth engineering knowledge at the level of one or more of K3, K4, K5, K6 or K8 which allows a fundamentals-based, first principles analytical approach
P2	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering, and other issues
P3	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models
P4	Familiarity of issues	Involve infrequently encountered issues
P5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering
P6	Extent of stakeholder involvement and conflicting requirements	Involve diverse groups of stakeholders with widely varying needs
P7	Interdependence	High level problems including many component parts or sub-problems

Table 3*Knowledge profile (K) and program outcome (PO) relationship*

K	Attribute	Description	PO
K1	Natural Sciences	A systematic, theory-based understanding of the natural sciences applicable to the discipline	
K2	Mathematics	Conceptually based mathematics, numerical analysis, statistics and the formal aspects of computer and information science to support analysis and modelling applicable to the discipline	PO1,
K3	Engineering Fundamentals	A systematic, theory-based formulation of engineering fundamentals required in the engineering discipline	PO2
K4	Specialist Knowledge	Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline	
K5	Engineering Design	Knowledge that supports engineering design in a practice area	PO3
K6	Engineering Practice	Knowledge of engineering practice (technology) in the practice areas in the engineering discipline	PO5
K7	Comprehension	Comprehension of the role of engineering in society and identified issues in engineering practice in the discipline: ethics and the engineer's professional responsibility to public safety; the impacts of engineering activity; economic, social, cultural, environmental and sustainability	PO6 PO7 PO8
K8	Research Literature	Engagement with selected knowledge in the research literature of the discipline	PO4

Table 4*Range of complex engineering activities*

A	Attribute	Description
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A1	Range of resources	Involve the use of diverse resources (and for this purpose resources include people, money, equipment, materials, information and technologies)
A2	Level of interaction	Require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, engineering, or other issues
A3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.
A4	Consequences for society and the environment	Have significant consequences in a range of contexts, characterized by the difficulty of prediction and mitigation
A5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches

Table 5

Course contents related to embedded systems

Serial No.	Topics
1	Embedded Systems Descriptions: Characteristics, Terminologies, Technologies, Architecture, and Design Challenges
2	Embedded System Design and Development Lifecycle Model
3	Design Considerations in Embedded Systems: Specification/Requirements, Selection of Development Tools, Issues related to energy, cost, and power, Trade-offs
4	Interfacing with Embedded System Peripherals: Hardware and Software Requirements.
5	Designing Embedded Systems.

Table 6

Assessment keys for the group project on complex engineering problem solving in EEE 3311 – microprocessor and embedded systems

CO-PO	Remarks	Poor (1)	Satisfactory (2)	Good (3)	Excellent (4)
CO1-PO2: Analyse the design specifications of a microcontroller-based embedded system.	K4 (Engineering Specialisation)				
	Understanding the design and development process of an embedded system by successfully analysing the design specifications and determining the requirements, and understanding the design challenges of optimizing various design metrics	No understanding of the problem statement.	The problem statement shows some understanding of the problem.	The problem statement shows almost full understanding of the problem.	The problem statement clearly shows a full understanding of the problem.
CO2-PO12: Identify the need for, and search for and find appropriate research literature in the context of the problem	Recognize the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.	Little evidence of ability to identify the need for, and search and find appropriate research literature independently, and to discuss	Evidence of ability to sometimes identify the need for, and search and find appropriate research literature independently, and to discuss the results of 2 references in the	Evidence of ability to usually identify the need for, and search and find appropriate research literature independently, and to discuss the results of 3 references in the	Evidence of ability to always identify the need for, and search and find appropriate research literature independently, and to discuss the results of 4 references in the

		the results of 1 reference in the context of the project.	context of the project.	context of the project.	context of the project.
CO3-PO4: Develop a methodology outlining principles and a general procedure based on what information is known and what needs to be determined, with a relevant literature review	K8 (Research Literature), P1 (Depth of Knowledge), P2 (Conflicting Requirements), P6 (Extent of stakeholders) Background Study – 30%	No or very little information with a relevant literature review.	To some extent, states what information is known and what needs to be determined, with a relevant literature review.	Mostly states what information is known and what needs to be determined with the literature review.	Clearly and completely states that the reported information is known, with a relevant literature review.
	Methodology – 35%	No methodology, instead, tries things out unsystematically.	Describes the methodology by outlining principles and a general procedure, but with errors in the principles or procedure.	Describes the methodology with a clear presentation of correct principles and procedure, but with some minor errors in the equations.	Describes the methodology with a clear presentation of correct principles, procedure, and equations.
	Analysing and Interpreting Results – 35%	No correct conclusion can be reached by analyzing and interpreting results.	Some correct conclusions can be drawn by analysing and interpreting results.	Mostly correct conclusions by analysing and interpreting results.	Fully correct conclusions by analysing and interpreting results.
CO4-PO3: Design a microcontroller-based embedded system	K5 (Engineering Design) Design – 40% Consideration of Social and Environmental Issues – 20% (if applicable*) Final Solution / Implementation – 40%	Design done with mistakes. Design has no consideration for relevant public health and safety, cultural, societal, and environmental considerations. The final solution is incorrect or not provided.	Design done without mistakes, but no design/detailing sketches. Design considers relevant public health and safety, as well as cultural, societal, and environmental factors. The final solution is not correct. Major corrections are required.	Design done without mistakes and unclear sketches/ drawings. Design considers most public health and safety, cultural, and environmental considerations. The final solution would be correct if the minor errors were corrected.	Design done without mistakes and complete sketches or drawings. Design considers all relevant public health and safety, cultural, societal, and environmental considerations. Final solution is correct. No errors or some very minor calculation errors.
	*Otherwise, 50% each				
	P1 (Depth of Knowledge), P2 (Conflicting Requirements), P5 (Extent of applicable codes) Compare the conflicting technical, engineering, and other issues arising to solve the problem. – 50% Assess the conflicting requirements and	Considers only 1 issue and provides a satisfactory solution to the problem.	Compare 2 issues with acceptable discussion. Assess 2 conflicting requirements and provide a satisfactory solution to the problem.	Compare 3 issues with good discussion. Assess 3 conflicting requirements and provide a satisfactory solution to the problem.	Compare 3 or more issues with excellent discussion. Assess 3 conflicting requirements and provide an optimum solution to the problem.

	propose a satisfactory solution to the problem. – 50%				
CO5-PO5: Implement the microcontroller-based embedded systems	K6 (Engineering Practice), P1 (Depth of Knowledge), P2 (Conflicting Requirements), P7 (Interdependence) Selection – 10% Expertise – 60% Analyzing Results – 30%	Little evidence of ability to select and use appropriate tools, techniques, and skills to effectively solve problems or design systems, and draw correct conclusions of results gained from the tool.	Evidence of the ability to sometimes select and use appropriate tools, techniques, and skills to effectively solve problems or design systems, and draw correct conclusions of results gained from the tool.	Evidence of ability to usually select and use appropriate tools, techniques, and skills to effectively solve problems or design systems, and draw correct conclusions of results gained from the tool.	Evidence of ability to always select and use appropriate tools, techniques, and skills to effectively solve problems or design systems, and draw correct conclusions of results gained from the tool.
	Design and integration of several interdependent sub-systems	Can design only one sub-system is partially	Can design more than one sub-system completely, but there is no integration.	Can design all subsystems completely; however, integration is incomplete.	Can design all subsystems completely and successfully integrate them.
	Organization, Formatting, Errors, and Effectively Comprehend and Write / Present	Poor organization and formatting, and contains errors. Cannot communicate key concepts.	Some organization: proper formatting and relatively error-free. Communicates the key concepts to some extent.	Well organized, properly formatted, and error-free. Mostly communicates the key concepts.	Well organized, properly formatted, and error-free. Communicates the key concepts effectively.
CO6-PO10: Write a comprehensive report and orally present the key concepts and results of the designed embedded system effectively	A2 (Level of interactions) (Related to P2) Gives solutions to significant problems arising from interactions between wide-ranging or conflicting technical, engineering, or other issues; and justifies the solutions achieved arising from the level of interactions involving wide-ranging or conflicting technical, engineering, or other issues.	Considers 1 issue, gives a solution, and justifies	Considers 2 issues. Gives solutions considering 2 issues, and justifies the solutions	Considers 3 issues. Gives solutions to significant problems arising from interactions between 3 issues, and justifies the solutions satisfactorily	Considers 3 or more issues. Gives solutions to significant problems arising from interactions between 3 issues, and justifies the solutions excellently
	A3 (Innovation) Involves creative use of engineering principles and research-based knowledge in novel ways. Justify creativity	Improves one feature with creative use of engineering principles and justifies with research-based knowledge	Improves two or more features with creative use of engineering principles and justifies with research-based knowledge	Introduces one new feature or improves three or more features with creative use of engineering principles, and justifies the	Introduces one or more new features using engineering principles and justifies the creative principle used with research-based

towards the achievement of novelty	creative principle used with research-based knowledge	knowledge
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An Example Project on Complex Engineering Problem Solving

In this section, we look at an example in which students were assigned a Complex Engineering Problem-Solving task focused on designing an embedded system. The students had 5 weeks to complete the project in groups of up to 4 students.

Scope of the Project

In this project, students have the opportunity to design and implement an embedded system to address local issues, including but not limited to farming, aquaculture, and energy, while considering relevant environmental and social impacts. In the group project, the students analyse the design specifications, review the published literature, and propose their own methodology to develop the solution, and finally implement and verify their system by analysing the results. In addition, the students address trade-offs to optimize the system for energy, cost, size, and power, which often have conflicting requirements. The students also demonstrate their written and oral communication skills through reports and presentations.

Problem Statement

The world population is estimated to reach 9.6 billion by 2050. In addition, urbanization, declining water supply, and ongoing climate change due to global warming have reduced the amount of land available for agriculture. As a result, there is a growing need to modify agricultural practices and adopt technologies to maximize crop yields and reduce labor requirements. Moreover, technologies are expected not only to improve productivity but also to protect the environment through sustainable cultivation. Urban smart vertical farming is the practice of planting plants in vertically stacked layers to optimize land use and enable implementation in indoor environments. The main idea of vertical farming is to use a sensor-based monitoring and control system that allows all environmental factors, such as temperature, humidity, light intensity, soil moisture, pH, and CO₂ concentration, to be controlled for optimal plant growth.

Tasks	Course Outcome	Corresponding PO/K/P/A
Analyze the specifications and identify the various elements of the monitoring and control system.	CO1	PO2 / K4 / P1, P3, P4
Identify the need for, and search for and find appropriate research literature.	CO2	PO12
Develop a methodology grounded in embedded system design and development principles, supported by a relevant literature review.	CO3	PO4 / K8 / P1, P2, P6
Design a microcontroller-based embedded system to monitor and control the important parameters for urban smart vertical farming in real time.	CO4	PO3 / K5 / P1, P2, P5
Implement the designed system using appropriate tools and components	CO5	PO5 / K6 / P1, P2, P7
Write a comprehensive report describing the key concepts, literature review, methodology, procedure, and results.	CO6	PO10 / A2, A3

To address the challenges of modern agriculture, the following criteria should also be taken into consideration:

Cost: Farmers will be more likely to adopt the system if it is inexpensive. Therefore, the design must be low-cost to make it accessible to farmers, especially those in developing countries.

Simplicity: The design should be user-friendly and require minimal human input. This will reduce the need for specialized knowledge or training, making it easier for farmers to adopt the technology.

Renewable Energy: The design should use renewable energy. This is crucial to ensure that the system is sustainable and has a minimal environmental impact.

Durability: The design should also be durable to ensure the system withstands harsh environmental conditions and continues to operate effectively over an extended period.

Energy Efficient: The design should be energy efficient. This is important to ensure the system operates with minimal energy consumption, reducing overall environmental impact and ensuring it is cost-effective to operate.