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Alternative Assessment for Enhancing Complex Problem-Solving Skills in Mechanical System Design Course

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ABSTRACT

Traditional assessment methods in engineering education, such as exam-based evaluations, often fail to adequately measure complex problem-solving skills and practical application of knowledge, necessitating the exploration of innovative assessment approaches. This paper introduces the Constructive-Teamwork-Experiential-Presentation (CTEP), an alternative assessment approach applied in the Mechanical System Design course (ENT348) for undergraduate mechanical engineering students. The CTEP model is tailored to enhance complex problem-solving (CPS) abilities and engage students in complex engineering activities (CEA). It aligns with the 2020 standards of the Engineering Accreditation Council (EAC) and the Malaysian Qualifications Framework (MQF) 2.0, specifically addressing Programme Outcomes (PO) 3 (Design) and PO10 (Communication). Over four academic terms, this model incorporated interactive design tasks, collaborative teamwork, simulation exercises, and student presentations. The findings indicate notable improvements in achieving PO3 and PO10, with average attainment rates rising to 80% and 78%, respectively. Beyond academic achievements, the model also supported the development of essential skills such as creativity, collaboration, and effective communication. Challenges related to time management and limited resources were mitigated through guided supervision and institutional backing. Future studies aim to evaluate the potential of extending the CTEP model to other engineering disciplines.

Keywords: alternative assessment; complex problem-solving; constructive alignment; engineering education; mechanical system design; experiential learning.

1. INTRODUCTION

The evolving landscape of engineering education underscores the need for assessment methodologies that not only cultivate technical expertise but also foster critical thinking, creativity, and effective communication skills among students. Traditional exam-based assessments have been critiqued for their limited ability to evaluate complex problem-solving skills and the practical application of knowledge [1], [2]. As a response, alternative assessment methods have emerged, aiming to better align educational outcomes with industry needs and modern pedagogical standards.

Alternative assessments encompass a variety of methods, including project-based learning, portfolios, peer assessments, and experiential learning activities. These strategies are designed to evaluate higher-order cognitive skills and competencies, offering a holistic development of engineering students. For example, the implementation of project-based learning (PBL) has been shown to enhance learning outcomes, boosting both technical and non-technical competencies [3]. PBL allows students to engage in collaborative problem-solving activities, which closely resemble real-world engineering tasks, thereby making learning more practical and relevant [4].

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Constructive alignment, introduced by Biggs, plays a crucial role in refining engineering education [5]. It posits that optimal learning occurs when teaching and assessment methods are well-aligned with the intended learning outcomes. In engineering education, applying constructive alignment principles has led to improved student engagement and better learning outcomes [6]. This approach encourages deep learning and ensures that assessment tasks effectively reflect the learning objectives [7].

Experiential learning, defined as "learning by doing," engages students in real-world problem-solving, further enhancing their ability to apply theoretical knowledge to practical settings [8]. Incorporating experiential learning has been found to significantly improve the development of professional knowledge and skills among engineering students [9]. Experiential learning not only deepens understanding but also improves students' ability to work collaboratively, think critically, and communicate effectively [10].

Despite the proven benefits of alternative assessments, their adoption in engineering education faces challenges, such as the need for substantial changes in teaching methodologies, assessment design, and resistance from stakeholders accustomed to traditional evaluation methods [11]. To address these challenges and better prepare students for real-world engineering demands, the Constructive Teamwork Experiential Presentation (CTEP) model was introduced in the ENT348 Mechanical System Design course for Year 3 students in the Bachelor of Mechanical Engineering programme. The CTEP model is aligned with the EAC 2020 standards and MQF 2.0 learning outcomes, specifically targeting Programme Outcomes 3 (PO3-Design) and 10 (PO10-Communication). This alternative assessment aims to bridge the gaps identified in traditional methods and enhance students' competencies in both CPS and CEA.

The following sections detail the CTEP model's methodology, implementation, and outcomes, demonstrating its effectiveness in fostering complex problem-solving skills and professional competencies among engineering students.

2. METHODOLOGY

The Constructive Teamwork Experiential Presentation (CTEP) assessment model was specifically developed to integrate both technical and soft skills required in engineering education. The methodology is centred around four critical elements: constructive alignment, teamwork, experiential learning, and presentation. The assessment model was implemented over a full semester in the ENT348 Mechanical System Design course.

2.1 Assessment Design

The CTEP framework was designed to align with two specific programme outcomes (POs) as follows:

- PO3 (Design): Focuses on the design of systems, components, or processes to solve complex engineering problems.
- PO10 (Communication): Emphasizes effective communication in engineering contexts, including oral presentations and written reports.

The assessment components were aligned to support the attainment of these outcomes and incorporated multiple evaluation criteria, allowing for a comprehensive assessment of student performance.

2.2 Assessment Design

The implementation of the CTEP assessment was carried out in five distinct phases:

2.2.1 Project Briefing and Group Formation

In the first week of the semester, students were provided with a project brief outlining the scope and requirements of the design task. Students were then grouped into teams of four, encouraging collaborative efforts from the outset. This setup was intended to foster teamwork, which is a critical element of professional engineering practice. Figure 1 illustrates the process flow of the CTEP assessment from briefing to final presentation.

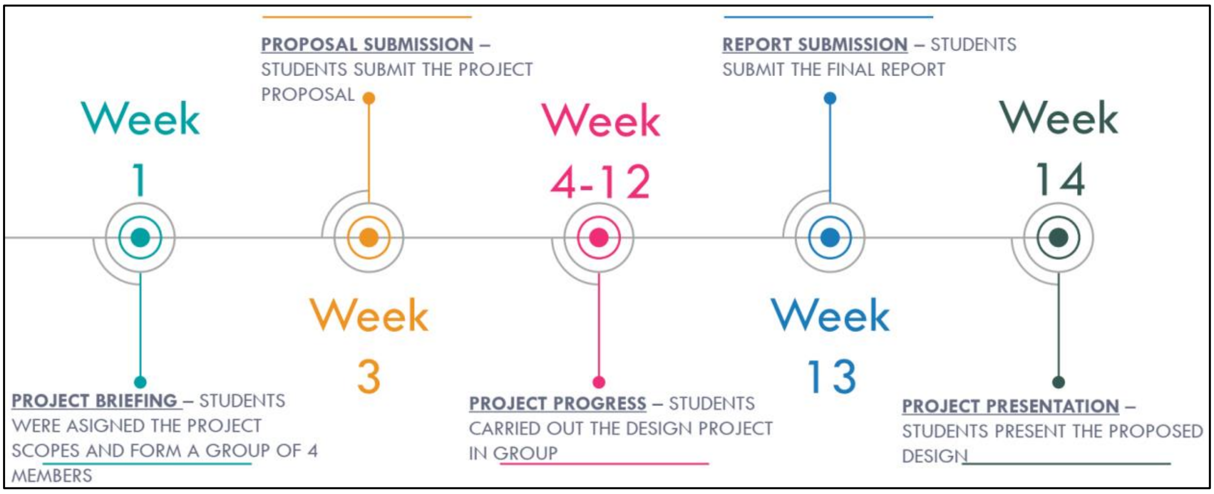

Figure 1. CTEP Implementation Process Flow

2.2.2 Proposal Submission

By the third week, student teams were required to submit a project proposal. The proposal was expected to include a clear problem statement, design objectives, and a preliminary design concept. The proposal was assessed for its alignment with the intended learning outcomes, as well as its feasibility and innovation in addressing complex engineering challenges.

2.2.3 Project Progress and Experiential Learning

During weeks 4 to 12, students engaged in hands-on design, modeling, and simulation tasks. This experiential phase was central to the CTEP model, as it enabled students to translate theoretical knowledge into practical design solutions. Students utilized engineering software to create design models and conduct simulations, which were then evaluated based on technical accuracy, innovation, and adherence to engineering standards. Weekly progress meetings were held, where instructors provided feedback and guided the teams through problem-solving processes. Figure 2 shows examples of design models developed by students during the experiential learning phase.

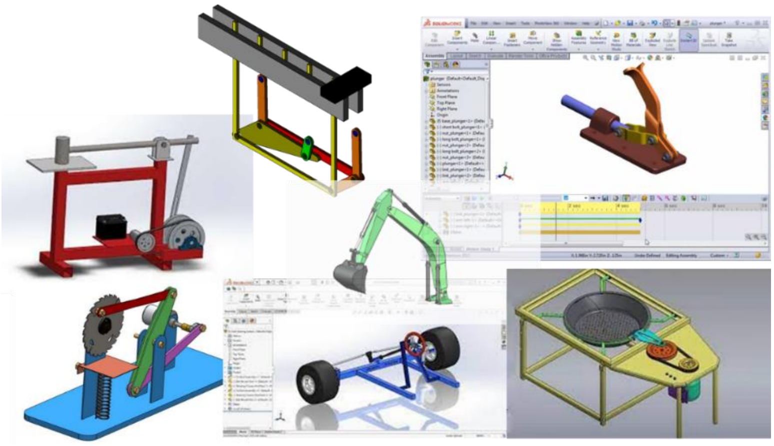

Figure 2. Examples of Student Design Models

2.2.4 Report Submission

By the end of week 13, teams were required to submit a comprehensive report detailing their design process, findings, and final solutions. The report was assessed based on clarity, depth of analysis, quality of technical content, and overall organization. This component specifically addressed PO10, as it measured students' ability to communicate complex technical information effectively.

2.2.5 Oral Presentation

In the final week of the semester, student teams presented their design projects to a panel of instructors and peers. The presentation was evaluated on criteria such as clarity, technical depth, presentation skills, and the ability to respond to questions. This phase aimed to further develop students' communication skills and confidence in defending their design decisions.

2.3 Assessment Criteria

The CTEP assessment was structured around five components, each contributing to the overall course marks, as listed in Table 1.

Table 1 Assessment components and the marks contribution

Assessment component	Contribution (%)	Description
Design Analysis	18.75	Evaluated the depth of knowledge and analytical skills demonstrated in the design concept.
Design Drawing	18.75	Assessed the technical accuracy and innovation of the design drawings produced by the teams.
Design Evaluation	18.75	Focused on the feasibility and effectiveness of the proposed design solutions.
Report Quality	18.75	Measured the clarity, structure, and depth of analysis in the final report.
Oral Presentation	25.00	Evaluated the effectiveness of the teams' communication, technical presentation skills, and ability to answer questions.
TOTAL	**100.00**	

The design project developed by the students was assessed based on the rubrics shown in the **APPENDIX**. The rubrics for ENT 348 in Mechanical System Design evaluates design analysis, drawing, evaluation, report quality, and oral presentation. Design analysis examines the thoroughness, standards used, and accuracy of calculations. Drawings are assessed on orthographic and isometric details and alignment with calculations. Design evaluation involves performance analysis, interpretation, and design justification. Report quality considers layout, clarity, and reliable sourcing.

Oral presentation criteria include courtesy in attire and behavior, clarity and fluency without over-reliance on slides, audience interaction, and a clear definition and explanation of design problems. Design analysis in the presentation assesses resource use and solution justification. Motion analysis evaluates system operability. Finally, responsiveness to questions is rated on defending arguments with accurate facts and handling criticism gracefully. Each area is scored from 0 (poor) to 4 (excellent).

3. RESULTS AND DISCUSSION

The CTEP assessment was first introduced in the 2019/2020 academic session, with evaluations conducted over four consecutive sessions (2018/19 to 2021/22). The assessment focused on measuring the students' attainment of the two targeted POs (PO3 and PO10) using detailed rubrics based on the criteria outlined in the EAC 2020 standards.

3.1 Assessment Design

Figure 3 presents the attainment trends for both POs over four academic sessions, showing a steady rise as a result of the CTEP model. The results of the CTEP model's implementation demonstrated a consistent improvement in student performance across both PO3 and PO10. Specifically, PO3 improved from 65% in the 2018/19 session to 80% in 2021/22, representing a 23% increase. Similarly, PO10 rose from 60% to 78% during the same period, showing a 30% improvement. These trends underscore the effectiveness of the CTEP model in enhancing student competencies over time.

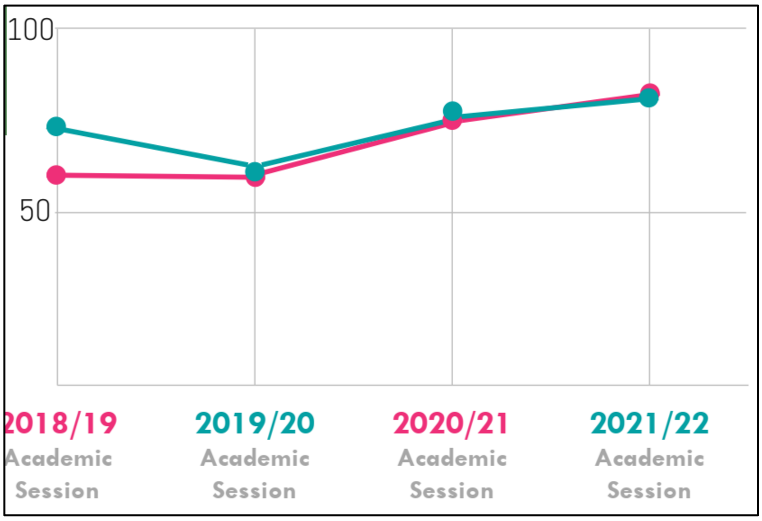

Figure 3. Attainment Trends for PO3 (red dots) and PO10 (green dots)

3.2 Skill Development and Student Feedback

Figure 4 visualizes the skill improvements reported by students before and after the implementation of the CTEP model. The implementation of the Constructive Teamwork Experiential Presentation (CTEP) model not only improved students' attainment of the targeted Programme Outcomes (POs) but also facilitated significant development in broader skills essential for engineering practice. Among these skills, the most notable improvements were observed in creativity, teamwork, and analytical thinking, all of which are crucial for addressing complex engineering challenges in professional settings.

Figure 4. Student Skill Development After CTEP

During post-assessment interviews and feedback sessions, many students reported a marked increase in their confidence when dealing with design problems. This growth in confidence was attributed to the CTEP model's iterative and hands-on approach, which allowed students to actively engage with complex engineering issues and present their ideas in a supportive, collaborative environment. Students felt more comfortable articulating their design solutions, defending their work, and responding to peer and instructor feedback. This sense of assurance not only helped them perform better academically but also prepared them for real-world engineering situations where clear communication and decisiveness are vital.

Teamwork was another area where the CTEP model had a substantial impact. The group-based nature of the design project created a collaborative learning environment, fostering stronger interpersonal relationships among team members. Students noted that working in teams allowed them to distribute tasks efficiently, share diverse perspectives, and leverage individual strengths to enhance the overall quality of their projects. This collaborative setup not only improved the final outcomes but also provided students with valuable experience in managing group dynamics, resolving conflicts, and taking collective responsibility for tasks.

Additionally, the experiential phase of the CTEP model significantly stimulated creativity among students. By engaging directly in design, modeling, and simulation tasks, students were encouraged to think outside the box and explore multiple design pathways. The opportunity to experiment, iterate, and refine their ideas enabled them to generate innovative solutions that were both technically viable and aligned with the project's goals. This focus on creative problem-solving was particularly effective in helping students approach engineering design not just as a technical task but as a process that requires innovation, adaptability, and original thinking.

3.3 Challenges and Lessons Learned

While the CTEP assessment model led to significant improvements in skill development and programme outcomes, its implementation was not without challenges. One of the most prominent issues encountered was time management. The CTEP model's emphasis on extensive design and simulation tasks demanded significant time investment from students. For many, balancing these requirements with other academic responsibilities proved difficult. Students found it challenging to allocate sufficient time to each stage of the design process, from ideation to modeling and final presentation. This led to rushed work during certain phases, potentially compromising the depth and quality of their projects. In response, instructors provided additional guidance on project scheduling, breaking down tasks into smaller, manageable milestones to help students better plan and manage their time.

Resource constraints also emerged as a critical barrier during the CTEP implementation. The model required access to specialized software for design modeling and simulation, as well as appropriate hardware to run these programs effectively. Teams with limited access to such technical resources faced difficulties in completing the project to the expected standard. Some students reported challenges related to outdated software versions or insufficient computing power, which hindered their ability to conduct simulations efficiently. To mitigate this issue, the institution offered supplementary support by providing access to computer labs equipped with the necessary software and hardware, as well as technical workshops to help students familiarize themselves with the tools required for the project.

Another challenge was the initial resistance to change observed among some students. As the CTEP model diverged significantly from traditional examination-based assessments, a portion of the student body was initially hesitant to embrace the new approach. This resistance stemmed from uncertainty about the assessment criteria, the increased emphasis on collaborative work, and the hands-on nature of the tasks. Some students expressed concerns about the fairness of group-based evaluations, particularly in terms of individual contributions being adequately recognized. However, as the semester progressed, receptivity improved. Students began to appreciate the hands-on learning experience and the skills they were developing, such as teamwork, problem-solving, and communication. Continuous instructor support, coupled with clear explanations of the assessment process and criteria, helped students adapt to the new model and recognize its value in enhancing their learning outcomes.

4. CONCLUSION

The implementation of the CTEP model resulted in significant improvements in Programme Outcome attainment, with PO3 rising from 65% to 80% and PO10 increasing from 60% to 78% over four academic sessions. These results highlight the model's ability to enhance complex problem-solving and communication skills, aligning well with EAC 2020 standards. By integrating hands-on design tasks, collaborative teamwork, and experiential learning, CTEP not only supports academic achievement in terms of programme outcomes but also fosters the development of critical professional skills such as creativity, teamwork, and effective communication. This holistic approach prepares students for real-world engineering challenges, equipping them with practical problem-solving abilities and the confidence to innovate within team environments. The promising outcomes of the CTEP model highlight the potential of alternative assessment methods to transform engineering education. It emphasizes the importance of moving beyond traditional, examination-centric approaches to create more engaging, skill-oriented learning experiences. However, to fully realize the benefits of CTEP, further research is needed to explore its scalability across various engineering disciplines. Future studies could also focus on refining assessment criteria to capture a broader spectrum of skills, such as leadership, adaptability, and critical thinking, which are increasingly essential in the dynamic field of engineering. Additionally, investigating strategies to overcome resource constraints and improve time management within the model could enhance its effectiveness and applicability in diverse educational settings.

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APPENDIX

	CRITERIA	PO / WK / WP / EA	PERFORMANCE CRITERIA 4	3	2	1	0
DESIGN ANALYSIS	Details of calculation	**PO3 (Design)** **WK5 (Engineering Design)** **WP1 (Depth of Knowledge):** 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 fundamental-based, first principles analytical approach.	The calculation provided on the size/dimension selection for all systems /components are complete using the kinematic analysis.	As criteria (4), but calculation on a few size/dimensions are missing	As criteria (4), but calculation for a few systems/components are missing.	The analysis on size /dimension provided was quite brief.	No or very few of analysis on size/dimension selection was provided, or not using the kinematic analysis.
	Use proper standard/ reference	**PO3 (Design)** **WK5 (Engineering Design)** **WP5 (Extent of applicable codes):** Are outside problems encompassed by standards and codes of practice for professional engineering.	The references used for calculation/ formulation were completely mentioned and from the proper standard.	Some references used for calculation/ formulation were not mentioned and from the proper standard.	Some references used for calculation/ formulation were not mentioned and from the proper standard.	Only a few calculation/ formulations were referred from the proper standard	No standard was referred for the calculation.
	Reliability and accuracy		All values were correctly calculated based on the standard formulation.	As criteria (4) except a few values were wrongly calculated.	As criteria (4) except some values were wrongly calculated.	As criteria (4) except many values were wrongly calculated.	The calculation provided was totally incorrect.
DESIGN DRAWING	Orthographic with dimension	**PO3 (Design)** **WK5 (Engineering Design)**	The technical drawings (orthographic) were prepared for all system/components, complete with all criteria; (1) dimension, (2) title block with details and (3) tolerance.	As criteria (4) but not all components were drawn.	As criteria (4) or (3) except missing one of the criteria.	As criteria (4) or (3) except missing two of the criteria.	No technical drawings were provided.
	Assembly isometric		The isometric drawings were prepared for all system/components, complete with all criteria; (1) part list/ legend (2) assembly/ dismantle view and (3) title block with details.	As criteria (4) but not all components were drawn.	As criteria (4) or (3) except missing one of the criteria.	As criteria (4) or (3) except missing two of the criteria.	No isometric drawings was provided.
	Tally with calculation		All dimensions used were tally with the calculation provided.	A few dimensions used did not tally with the calculation provided.	Some dimensions used were not tally with the calculation provided.	Many dimensions used were not tally with the calculation provided.	All dimensions used were not tally with the calculation provided.

DESIGN EVALUATION	**Performance analysis**	**PO3 (Design)** **WK5 (Engineering Design)** **WP3 (Depth of analysis):** Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	Analysis to compare the performance between existing and improved design was presented with following details; (1) graph/table, (2) rate of improvement, and (3) three kinematic parameters.	As criteria (4) but missing one of the details.	As criteria (4) but missing two of the details.	As criteria (4) but missing all the details.	No performance analysis was provided
	Interpretation/ discussion	**PO3 (Design)** **WK5 (Engineering Design)** **WP4 (Familiarity of issues):** Involve infrequently encountered issues.	The performance of the improved system was completely interpreted and discussed.	The performance of the improved system was moderately interpreted and discussed.	The performance of the improved system was fairly interpreted and discussed.	The performance of the improved system was briefly interpreted and discussed.	No interpretation and discussion on the performance.
	Design justification	**PO3 (Design)** **WK5 (Engineering Design)** **WP2 (Range of conflicting requirements):** Involve wide-ranging or conflicting technical, engineering and other issues.	The proposed design was well justified.	The proposed design was moderately justified.	The proposed design was fairly justified.	The proposed design was briefly justified.	No justification on the proposed design.
REPORT QUALITY	**Layout and organization**	**PO3 (Design)** **WK5 (Engineering Design)**	Distribution of title, subtitle and contents was appropriate. Figures and tables were properly arranged.	Few elements of criteria (4) were inappropriate.	Some elements of criteria (4) were inappropriate.	Many elements of criteria (4) were inappropriate.	The report was poorly organized and arranged.
	Clarity		Sentences used were clear, understandable, concise, and accurate and has no grammatical error.	Criteria as (4) accept some grammatical errors.	Sentences used were quite clear and understandable but requires some additional explanation. Some errors on words spelling and selection.	Sentences used were not clear and confused. Too many grammatical errors.	Sentences used could not convey the message.
	References		List of references from reliable sources is more than 10 and cited in the main text with appropriate format.	List of references from reliable sources is more than 5 but below 10 and cited in the main text with appropriate format.	List of references from reliable sources is below than 5 and cited in the main text with appropriate format.	List of references from reliable sources is below than 5 but not cited in the main text.	No references from reliable sources was provided.
ORAL PRESENTATION	**Courtesy**	**PO10 (Communication)**	Formally and neatly dressed and shown courtesy behavior throughout presentation	Dressed formally but with less neat and shown courtesy behavior throughout presentation	Dressed informal but neat and shown courtesy behavior throughout presentation	Dressed informal and not neat but shown courtesy behavior throughout presentation	Improper dress and shown disrespecting behavior
	Clarity/ Fluency	**PO10 (Communication)**	Ability to present fluently without dependency on slides and scripts.	Ability to present fairly without dependency on slides and scripts.	Ability to present with frequent dependency on slides or scripts.	High dependency on slides or scripts.	Reading from the slides.

	Interaction	**PO10 (Communication) EA2 (Level of interactions):** Require resolution of significant problems arising from interactions between wide ranging or conflicting technical, engineering or other issues.	Ability to interact with audience during presentation with good posture and eye contact maintained throughout presentation.	Ability to interact with audience during presentation with good posture and eye contact but fail to maintain control throughout presentation.	Ability to interact with audience during presentation with poor posture and eye contact throughout presentation	Interact with audience during presentation with poor posture and no eye contact throughout presentation.	Fail to interact with audience. (One way presentation).
	Design Problem	**PO10 (Communication) EA3 (Innovation):** Involve creative use of engineering principles and research-based knowledge in novel	Design problem was clearly defined and explained.	Design problem was clearly defined but not explained properly	Design problem was defined but not explained.	Design problem was briefly defined but not explained.	Design problems were very weak, incomplete or not relevant.
	Design Analysis	**PO10 (Communication) EA2 (Level of interactions):** Involve the use of diverse resources (and for this purpose resources includes people, money, equipment, materials, information and technologies).	Complete and in-depth analysis of the design using reliable sources and data.	Good analysis of the design using appropriate sources and data.	Fair analysis of the design using appropriate sources and data.	Fair analysis of the design using inappropriate sources and data.	Poor analysis of the design using irrelevant sources and data.
	Solution & Justification		The proposed solution was excellent and strongly justified.	The proposed solution was good (with some mistakes) and justified.	The proposed solution was moderate with fair justification.	The proposed solution was fair with weak justification.	The proposed solution and justification were poor.
	Motion Analysi	**PO10 (Communication)**	The system was successfully linked and operate (in motion).	The system was fairly linked and operate (in motion).	The system was unlinked but can operate (in motion).	The system was linked and could not operate (in motion).	The system was unlinked and could not operate (in motion).
	Ability to respond	**PO10 (Communication) EA2 (Level of interactions):** Require resolution of significant problems arising from interactions between wide ranging or conflicting technical, engineering or other issues.	Defended arguments well, presented accurate and logical facts with supporting examples/proof and able to accept criticism with courtesy.	Defended arguments well, presented accurate and logical facts but lack supporting proof.	Defended arguments well and able to show examples but could not present accurate facts.	Defended arguments but not backed by facts or supporting example.	Did not try to answer questions.