Challenge-Based Learning and ICT Integration in Mechanical Engineering Education: A Case Study on Mechanical Engineering Design Courses

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Abstract: This paper presents an innovative, practice-driven approach to mechanical engineering education by integrating Challenge-Based Learning (CBL) and digital tools in two core courses: Mechanical Vibrations and Acoustics (MVA) and Mechanical System Design (MSD). In MSD, a focused design hackathon was introduced, engaging students in real-world, interdisciplinary challenges in pressure vessels, gearboxes, and material handling systems. Students employed ICT tools such as MATLAB, AutoCAD, and ChatGPT to simulate, model, and present integrated design solutions. In MVA, simulation-based and video-driven assessments enabled students to visualize vibratory phenomena and communicate engineering concepts effectively.
Analysis of course-end survey data from 82 students revealed strong outcomes: over 85% reported high achievement of course outcomes, especially in practical application and integration of design standards. Program Outcomes such as teamwork, ethics, and societal awareness were rated as significantly enhanced, alongside Program Specific Outcome 01 (PSO01)—the ability to apply mechanical design principles and codes to real-world problems. Students expressed high satisfaction with the clarity of learning objectives, relevance of assessments, and the creative, collaborative learning environment.
These findings underscore the pedagogical effectiveness of CBL and ICT-enhanced strategies in fostering deep learning, professional skills, and engineering judgment. The approach offers a scalable and replicable model aligned with NEP 2020 and ABET standards, preparing students for complex, multidisciplinary challenges in modern engineering practice.

Keywords: Challenge-Based Learning, ICT Tools, Mechanical Engineering, Hackathon, Vibrations, System Design, AI in Education

1. Introduction

Engineering education is seeing a revolutionary paradigm shift due to the imperative of providing students with more interesting, application-driven, and trans disciplinary methods. Traditional practices based on theory teaching and tests are unable to prepare students with hands-on design thinking, problem-solving capabilities, and integration across domains. Challenge-Based Learning (CBL), supplemented with ICT technologies and online platforms, has been found to be an effective pedagogical model in filling these lacunae (Chien & Tsai, 2021; Savery, 2015). This paper examines the use of CBL frameworks in two mechanical engineering courses—Mechanical Vibrations and Acoustics (MVA) and Mechanical System Design (MSD)—in Pimpri Chinchwad College of Engineering (PCCoE), Pune. These courses used novel formative assessments, such as simulation-based modeling, design hackathons, and video-based product storytelling, with the aim of developing technical knowledge as well as professional skills among undergraduate students.

2. Literature Review

Challenge-Based Learning (CBL) and Problem-Based Learning (PBL) have been widely recognized as effective pedagogical models in engineering education. Kolmos et al. (2016) emphasized that curricula should address authentic problems to foster systems thinking and collaboration, while Brereton et al. (2015) showed design challenges stimulate creativity and mirror professional practice. Savery (2015) distinguished between surface and deep learning, noting that open-ended challenges promote interdisciplinary problem-solving. Extending this view, Chien and Tsai (2021) found that CBL enhances motivation and computational thinking, leading to improved outcomes. The role of information and communication technologies (ICT) in engineering education has been equally significant. Ferguson (2012) highlighted learning analytics as a way to track engagement and personalize instruction. Nouri et al. (2023) showed simulation tools increase technical confidence and communication, while Shanbhag and Al-Ammar (2023) demonstrated that virtual design studios enhance creativity and accuracy. Dillenbourg et al. (2009) also confirmed that computer-supported collaborative learning improves teamwork and communication. Together, these works emphasize the importance of tools such as MATLAB, Python, and AutoCAD in fostering technical and collaborative skills.

Artificial intelligence (AI) tools are now complementing traditional pedagogy. Zawacki-Richter et al. (2019) reviewed AI in education, noting benefits in feedback and learner autonomy, while VanLehn (2011) showed intelligent tutoring systems can approach human tutoring effectiveness. More recent studies highlight ChatGPT's value: Yeo and Quek (2022) found AI-generated feedback boosts participation and performance, Wang and Han (2021) linked chatbot-supported environments to improved metacognition, and Bravo and Cruz-Bohorquez (2024) discussed chatbots' impact on engineering education. Kumar (2021) further noted the potential of educational chatbots for project-based learning. Research on active and cooperative learning confirms its advantages. Prince (2004) showed interactive tasks enhance understanding compared to lectures, and Freeman et al. (2014) demonstrated that active learning reduces failure rates while improving STEM performance. Felder and Brent (2016) advocated cooperative strategies for engagement and retention, while Boud and Falchikov (2007) emphasized sustainable assessment for lifelong learning.

Design thinking and reflective practice also underpin modern engineering pedagogy. Adams et al. (2003) showed iterative projects strengthen reflective thinking, while Biggs and Tang (2011) stressed constructive alignment between goals, activities, and assessment. Schön (1983) argued that reflection-in-action is essential for professional growth, reinforcing the role of project-based learning. Finally, the rise of simulation and digital twins demonstrates the importance of ICT-driven training. Hussain and Kamarudin (2024) highlighted how interactive simulations deepen understanding in mechanical contexts, and Kritzinger et al. (2018) classified digital twins as critical for bridging theory and practice. Similarly, Lee et al. (2024) and Calvani et al. (2021) reinforced the importance of computational thinking and digital competence in higher education.

Collectively, these studies underscore that CBL, ICT, AI, and active learning approaches converge toward preparing students with technical expertise, collaboration, and reflective practice—competencies central to modern engineering education.

3. Methodology and Course Context

This study was conducted in two undergraduate mechanical engineering courses—Mechanical Vibrations and Acoustics (MVA) and Mechanical System Design (MSD)—at Pimpri Chinchwad College of Engineering (PCCoE), Pune, with ~60 students each. Both courses followed NEP 2020's experiential learning approach, integrating simulations, hackathons, and digital storytelling. In MVA, students modeled real-world vibration scenarios (e.g., bridge oscillations, vehicle suspensions) using MATLAB/Python and analyzed responses of single-degree-of-freedom systems. A second task required short promotional videos on vibration/noise-control products, emphasizing professional communication. In MSD, a design hackathon engaged teams in challenges such as gearbox layouts, pressure vessel sizing, and conveyor systems. Evaluation was based on technical accuracy, innovation, and teamwork under time constraints.

4. ICT Tools and Digital Pedagogy

Students used a range of ICT and AI tools to support simulation, modeling, design, and communication. MATLAB and Python enabled vibration analysis and automation, while AutoCAD/SolidWorks were applied for schematic layouts in MSD. ChatGPT supported idea generation, logic validation, and report drafting, complementing traditional instruction. For presentations, Canva and PowerPoint were employed in both courses. Instead of a static table, this integration is summarized as a workflow where simulation tools enhanced conceptual clarity, CAD platforms aided design accuracy, AI tools improved reasoning, and visual tools strengthened communication. Collectively, these resources ensured alignment with Challenge-Based Learning, enabling both technical fluency and professional communication skills..

5. Results and Student Feedback

5.1 Student Engagement and Skill Development

Survey responses showed strong engagement: 89% agreed that the MVA simulation improved conceptual clarity, 78% rated the MSD hackathon as highly engaging, and 85% felt the video assignment enhanced communication skills. However, more than 70% reported time management as a challenge. As illustrated in Figure 1, these perceptions were reflected in self-assessed skill growth. Communication improved from 2.0 to 4.6 on a five-point scale, ICT proficiency from 2.3 to 4.4, and teamwork from 2.8 to 4.7, while time management also showed modest gains.

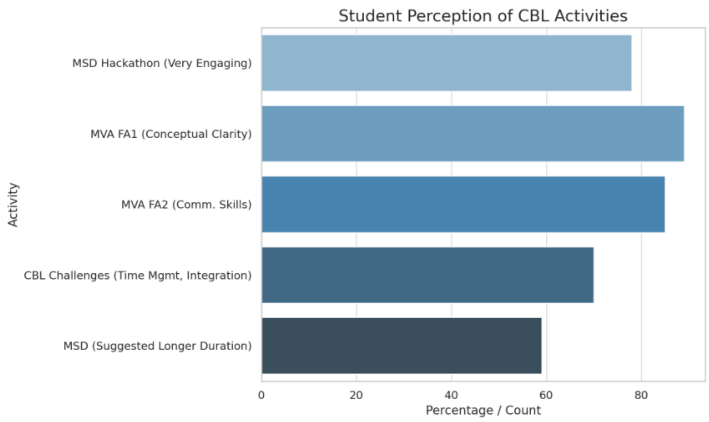

Figure 1. Student Perception of Various CBL Activities in Terms of Engagement and Skill Development.

5.2 Hackathon Performance and Conceptual Gains

Hackathon performance, evaluated through a rubric (innovation, technical accuracy, teamwork), yielded average scores of 8.1, 7.6, and 8.4 respectively, showing that students delivered both innovative and technically sound solutions under time constraints. Complementing this, the MSD pre- and post-test on stress analysis and gearbox kinematics showed scores rising from 42% to 76%, a 34-point improvement. Together, these results

(Figure 2) demonstrate measurable conceptual gains alongside professional skill development.

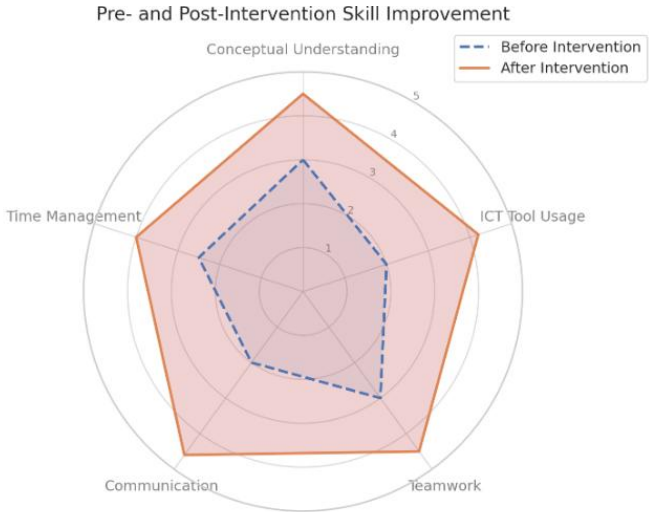

Figure 2. Radar chart of student skill levels before and after CBL interventions in MVA and MSD.

5.3 Course and Program Outcomes

As shown in Figure 3, more than 85% of students reported achieving MSD Course Outcomes at a "High" level, with CO1 (material handling systems) and CO2 (pressure vessel analysis) exceeding 90%. Broader Program Outcomes were also reinforced: over 90% of students noted gains in solution design (PO3), societal awareness (PO6), and ethics (PO8). Teamwork (PO9) was particularly strong, highlighted by 95% of respondents. Program Specific Outcome 01 (PSO01)—application of mechanical design principles and codes to real-world challenges—was validated by 92%, underscoring the industry-readiness of the courses.

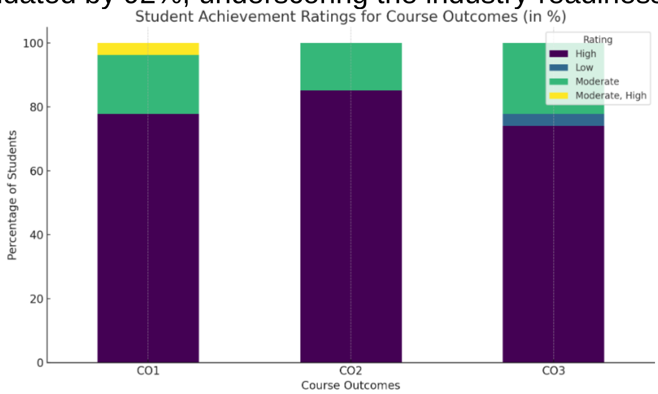

Figure 3. Student Ratings of Course Outcome Achievement for MSD (N=82).

5.4 Activity Glimpses and Ethical Considerations

Student participation was highly interactive and collaborative, as shown in Figures 4 and 5. In MVA, students created promotional videos to communicate vibration and noise-control concepts (Figure 4). In MSD, design hackathons featured innovative projects such as compressed-air-powered gearboxes, pneumatically powered conveyors, and CNG-powered conveyor vehicles (Figures 5). All activities were conducted with informed consent, and identifiable student faces were blurred to comply with ethical standards

Figure 4. FA2 Activity of the course MVA video making to advertise the Noise and Vibration Measuring Instruments.

Figure 6. Students involved in Design Hackathon for the course MSD

In compliance with ethical publication standards, all identifiable student faces in these images have been blurred, and informed consent for participation and documentation was obtained.

6. Challenges and Future Scope

Key challenges included varying student proficiency with tools, limited hackathon time, and subjectivity in rubric scoring, along with suggestions to add automation in conveyor design. Future iterations should include pre-hackathon training, longer design sessions, and integration of automation and sensors. Greater use of AI, standardized rubrics, and pre/post-tests across courses can enhance consistency, while multi-semester projects and virtual labs would further build real-world readiness.

7. Conclusion

This study shows that integrating Challenge-Based Learning (CBL) with ICT and AI tools significantly enhanced student learning in Mechanical Vibrations and System Design courses. Activities such as simulations, video storytelling, and hackathons improved conceptual understanding, communication, teamwork, and ICT fluency. Over 85% of students reported high achievement of Course Outcomes, and more than 90% affirmed gains in Program Outcomes related to solution design, ethics, and teamwork, with strong validation of PSO01. The use of tools like MATLAB, Python, AutoCAD, and ChatGPT supported both technical accuracy and professional communication, aligning with NEP 2020 and ABET standards. While time constraints and varied digital proficiency posed challenges, these can be addressed through extended hackathons, pre-activity training, and AI-assisted feedback. Overall, the approach offers a scalable model to prepare students for multidisciplinary, industry-relevant engineering challenges.

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