Enhancing Engineering Education: Exploring the Impact of Problem-Based Learning on Freshman Students' Skills and Engagement – A Case Study

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***Abstract*—This paper examines the impact of problem-based learning (PBL) on freshman engineering students' academic performance, technology enhancement, and leadership skills. With contemporary students gravitating less towards traditional classroom teaching, the study investigates the effectiveness of PBL in engineering education, focusing on learning outcomes and the perceptions of students and faculty members. Through design thinking, PBL is implemented, engaging students in real-world problem-solving and team activities. Results indicate significant improvements in student performance, teamwork, multidisciplinary knowledge, and faculty development. With attendance rates soaring above traditional levels, students recommend broader adoption of PBL across all classes. The study features PBL's efficacy in enhancing skills and knowledge while benefiting faculty multidisciplinary expertise and leadership.**

The study is taken up on the freshmen engineering students at an Indian college with respect to their experience with problem-based learning (PBL) method. The aim of this case study is to investigate the effectiveness of PBL in engineering education by examining the impact on student learning outcomes and also explore the perceptions and experiences of both students and faculty members. The study attempts to answer the following questions. 1. Does the incorporation of PBL enhance the quality of student learning outcomes, achieving higher levels of critical thinking, problem-solving skills, and creativity? 2. To what extent is the integration of PBL courses appropriate and effective in enhancing the learning experience of freshman engineering students at the entry level?

For PBL implementation design thinking is followed. The approach to implementing problem-based learning (PBL) begins with structured activities like brainstorming and role-playing, inculcating teamwork and problem comprehension among students. Real-world contexts, such as nearby villages and non-governmental organizations (NGOs), are integral to the approach, allowing students to identify authentic, real-time problems and ground their learning in practical scenarios. End-user involvement ensures that student solutions align with genuine needs, raising a sense of ownership and responsibility. Faculty members play a key role, drawing upon diverse technical knowledge and leadership skills to guide students effectively and undergo professional development themselves. The approach emphasizes experiential learning, collaborative problem-solving, and real-world application to cultivate technical competencies, critical thinking, creativity, and leadership skills among freshman engineering students.

Reflections gathered through the Driscoll model revealed significant improvements in student performance and engagement. Attendance rates in PBL classes exceeded traditional levels, indicating heightened student enthusiasm and participation. Students reported enhanced teamwork, multidisciplinary knowledge, leadership skills, problem-solving abilities, and creativity. Notably, students expressed a preference for PBL classes, advocating for broader adoption across all courses. Faculty members also benefited, gaining multidisciplinary technical knowledge and leadership skills through their involvement in the PBL approach.

The study highlights the effectiveness of problem-based learning (PBL) in improving student skills, knowledge, and engagement. Elevated attendance rates and positive student feedback support the efficacy of PBL in building critical thinking, creativity, and teamwork. The recommendation for broader adoption of PBL across all classes suggests its potential to enhance conceptual understanding and student learning experience. Additionally, faculty members' development of multidisciplinary technical knowledge and leadership skills further highlights the benefits of the PBL approach. The findings affirm PBL as a valuable pedagogical strategy for enhancing engineering education and student outcomes.

***Keywords*— Assessment; Curriculum Design; PBL; Reflections.**

I. INTRODUCTION

The constant issue in engineering education is to get students ready for the changing needs of the workforce. Conventional lecture-based methods are good at teaching theory, but they frequently fail to develop the engagement and practical skills needed to solve problems in the real world. Educational institutions are increasingly using teaching approaches like Problem-Based Learning (PBL) and Design Thinking to reduce this gap. Problem-based learning (PBL) allows students actively participate in solving challenging, real-world situations. Students in PBL setting work in teams and work towards finding solutions rather than just passively

absorbing material, which inculcates critical thinking, teamwork, and self-directed learning. This method improves their technical proficiency and make them ready to take on the unexpected challenges that come with working in the corporate world.

PBL is enhanced by Design Thinking, which offers an organized yet adaptable framework for innovative problem-solving. This iterative method, which has its roots in the design sector, places a strong emphasis on ideation, empathy, prototyping, and testing. Through the integration of Design Thinking into the curriculum, students are motivated to tackle challenges from a user-centered perspective, which promotes creativity and real-world application of their engineering knowledge.

The impact of incorporating PBL and Design Thinking into the first-year engineering curriculum is examined in this case study. We seek to shed light on the efficacy of these approaches in improving engineering education through an investigation of students' skill development and engagement levels. A cohort of first-year engineering students are the subject of the study, which will look at their experiences, difficulties, and results in a PBL and Design Thinking context.

This case study hopes to add to the current conversation around engineering education by providing teachers with evidence-based suggestions for creating a more dynamic, skill-focused, and interesting learning environment for their students.

II. LITERATURE REVIEW

While designing curriculum for PBL course assessment and evaluation of outcome plays a major role. Through this course design can achieve higher order skills in blooms taxonomy which is not possible regular course. The author stated that by scientists see things and they will ask why it is like that but engineers see things but they could be and ask by why they will not query? Because of the traditional way of curriculum design. The new way of Project Based Learning curriculum design should be incorporated to all the disciplines not only limiting to the technical courses (Dym et al., 2005).

(Atman et al., 2007) the author explained the importance of design process. This study aimed to assess the importance of the design process and incorporated input from 19 industry experts from various disciplines to improve design skills among students. The study collected data from both freshmen (26 participants) and seniors (24 participants) and found a significant improvement in learning approaches. The study found a statistically significant improvement in the learning approaches of the participants. This suggests that the incorporation of the design process, as guided by the industry experts, positively affected how students approached learning and problem-solving.

Through service-learning and real-world projects, the incorporation of EPICS, UBA, EWB, and GCSP into our institution's freshman engineering curriculum has greatly improved students' practical skills, engagement, and career prospects. This method has fostered critical thinking and problem-solving skills while enhancing technical knowledge, communication, teamwork, and leadership abilities. Nonetheless, there are issues that must be resolved, like creating interdisciplinary teams, obtaining materials, overcoming language difficulties, and turning ideas into goods that can be sold. To optimize these programs' long-term influence and efficacy in engineering education, it is also essential to guarantee ongoing participation, thorough evaluation, and scalability (Naik et al., 2023).

The results of this study show that the goals of India's National Education Policy (NEP) 2020 are well-aligned with the pedagogical approach of service-learning. Students who participate in service-learning programs receive a multidisciplinary, comprehensive education, improve their critical thinking, life skills, and intellectual knowledge, as well as a strong sense of civic duty and ethics. Nevertheless, there are obstacles to overcome when incorporating service-learning into the engineering curriculum. These include the requirement for thorough formative assessments, maintaining respect for inclusion and diversity, and encouraging a sense of belonging and pride in India. Among the deficiencies found are the absence of empirical data regarding service-learning's efficacy in accomplishing NEP objectives and the requirement for a uniform framework to evaluate its effects thoroughly. Future studies should concentrate on developing sound procedures to assess service-learning's efficacy and comprehending the subtleties of its curriculum integration (Srinivas et al., 2023).

In this study, the focus is on evaluating student perceptions of problems and project-based learning approaches. The findings indicate that students prioritized personal development and were engaged when addressing real-world problems and societal challenges through problem-based learning (PBL). The researchers recommended incorporating team projects targeting climate change and the integration of Sustainable Development Goals (SDGs) into the academic curriculum curriculum (Servant-Miklos & Kolmos, 2022).

Haack et al. reported in their research by conducting test between PBL course students &a traditional course students. The PBL course students solved the test better than the other students. The results show that PBL has increased students' learnings (Haack & Jambor, 2020).

Xiang et al, in their research study on intercultural PBL, conducted an expert review survey with 31 items and obtained responses from 310 undergraduate students. This survey contains motivation & interest, self-dependence, behaviors, team relationships with members, and outside support. The analysis of this survey shows that PBL motivation & interest plays a major role in the teams (Jiang et al., 2023).

Another researcher explained how today's engineers can fulfill industry requirement through PBL approaches. The research describes the impact of Industrial PBL, where experimental study conducted with 13 students have taken Industrial real time problems as a project. After completions this project feedback has taken, and outcome of this result is all 13 students placed in company (Mohd Salleh & Yusof, 2017).

In this research study, the author stated that by integrating PBL & Data learning course students have learnt data analysis by doing real-time project by taking problem statements from the Farmer. Students have developed good technical knowledge by taking up a multidisciplinary problem (Núñez-del-Prado & Goméz, 2017). An engineering drawing course integrated with a PBL animation & PBL graphic online activity implemented

for 68 mechanical engineering polytechnic students. This PBL pedagogy implemented to understand the isometric projection of models. A pretest and posttest to conducted in between PBL – A & PBL-G groups to know which pedagogy is given best results. While the PBL animation group all scored good in the assessment when compared to the graphics group (Ariffin et al., 2017).

Results of a study on the Engineering Projects in Community Service (EPICS) program show considerable advancements in learner outcomes, job opportunities and skill development, especially when it comes to leadership abilities, teamwork skills, problem solving skills and technical competence. The progression of EPICS as a non-credit course to mandatory then credit course highlights its growing importance in the syllabus. The report indicates that 60% obtained placements, 35% furthered their education while 5% ventured into self-employment all underscoring the efficacy of this initiative. Despite its accomplishments, there is a major gap noted concerning the short time given to students for conversion of prototypes into marketable products. This gap could be realized if they extend their curriculum into second, third and fourth years with stronger industry ties to increase its impact on engineering students so as to produce more successful entrepreneurs (Naik et al., 2024)

Before entering graduate study, they were taught only how to prepare for the exam and passing of exam with good grades. After students enter to the undergraduate study, at the start of the two weeks' class PBL was implemented to apply their prerequisite knowledge to solve the problems. Through this approach, students have learnt new ways of learning and understanding concepts (Dabir et al., 2022).

To enhance the learning outcome of the students PBL and peer learning incorporated for instructing the software engineering course. The learning outcome of these students increased while compared to the previous year's students. Students have given feedback that through this course they learnt the importance of software engineering in industry (Alva et al., 2018).

By applying and integrating sustainable development goals with PBL in India, an engineering students can solve the real time problem like climate change, poverty, hunger etc. The author also stated that method teaching should improve by adopting PBL type pedagogy where students will learn real time problems and SDG goals (Thakur et al., 2021).

After studying this literature, by incorporating PBL in curriculum and by doing hands on experience or solving real time, SDG problems will improve the outcome of the students.

III. METHODOLOGY

This study uses a qualitative methodology to explore the effectiveness of the intervention Problem-Based Learning (PBL) in enhancing the educational outcomes of freshman engineering students. Through the use of case studies, reflective practices based on the Driscoll model, and feedback surveys, the research collects insights into the students' and faculty members' perceptions of PBL. Analysis of the data involves qualitative assessments of reflective reports and survey results, which reveal significant enhancements in critical thinking, problem-solving skills, and teamwork among students. The study utilizes real-world applications by integrating community-based projects, allowing students to apply their theoretical knowledge in practical settings. The PBL intervention implemented is described as follows:

A. EPICS (Engineering Project in Community Service)

Design thinking process followed for implementation of PBL integrated Design Thinking course shown in figure.1.

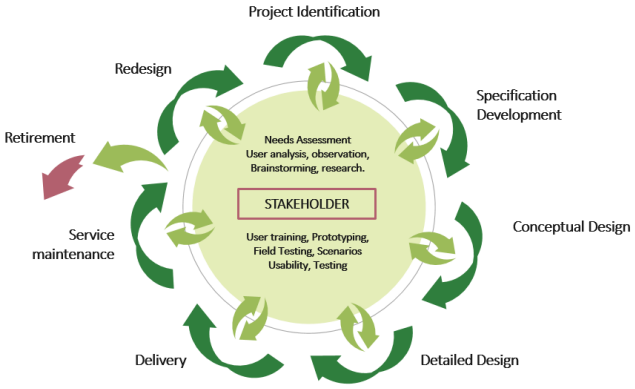

Fig.1 Design Thinking Process

In 2016 EPICS was introduced at engineering college which is located in India. At first it was introduced as activity-oriented initiative. After seeing the impact and students' interest and involvement in this initiative it was then introduced as a mandatory PBL oriented class for all engineering students. Due to the affiliated system credits were not given to the course. In 2021, EPICS was successfully implemented for freshman engineering students as a credit-based course.

At the beginning of the course, brainstorming and role play activities are conducted to help us to understand the real time problem and how to connect or communicate with people. After these activities. Students are divided into teams and these teams will be taken to villages & NGOs for problem identification.

Few of the glimpses are shown in this article with the consent of the participants.

Fig. 2 Resource & Village Mapping Activity

For identification of problem in the village, students are divided into multiple teams and given the task to study demography and various livelihood activities and observing the village by walking. After identifying resources in the village, teams will draw the village map showing figure.2 with the help of villagers. Through this activity students have learnt the importance of teamwork and observation.

Fig.3 NGOs interaction meet

To understand the problems of NGOs, interaction meet with the students was organized. There are a total of 15 NGOs who participated to interact with the students shown in figure.3 & table.1. Consent was taken to use the picture.

TABLE.I
NGOS INTERACTION MEET

Sl. No	Details	Objective
1	15 NGOs participated	To explain the need of the NGOs and technical problems

B. Curriculum Design

While designing curriculum, it is important to focus on the outcomes. assessment and instruments used for student's learnings. Often, we neglect time allocation diligently for completing the module but in preparing PBL courses timelines should be given higher priority because students will be involved in teamwork and hands experience activities.

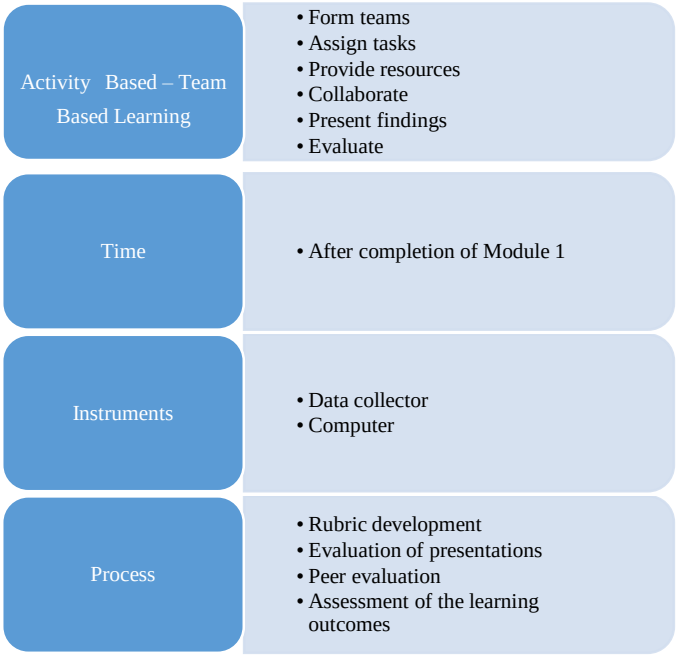

Fig.4 Sample Activity Design

The sample activity design shown in Figure 4 outlines the plan and process for implementing activity-based Problem-Based Learning (PBL) in the classroom. This design specifies the types of activities required and the processes necessary to achieve the desired learning outcomes.

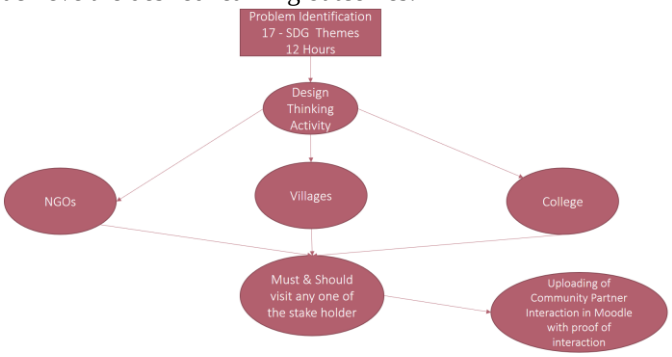

Fig.5 Design Thinking Module 1 Design

Figure.5 shows the plan of Design Thinking PBL course first module design. While doing the module design the role of instructor and role of students for the activity were clearly defined.

C. Assessment

To assess the students' performance in the course a rubric is prepared shown table.2. & table.3. These assessments parameters are given to the students before commencement of the course. The students understand what the parameters of assessment are and how to accomplish it.

TABLE.II
INTERNAL REVIEW

Design Thinking
Project Review & Schedule for Freshman Engineering Students

Review – 1 (Poster Presentation) Rubrics

Assessment Parameter		Good	Average	Poor
Problem Identification (20 M)	Interaction with the Community (10 M)	Clear Documentation of Community interaction with visual proofs (10 M)	Clear Interaction with community with an appropriate document (5 M)	Oral representation of community interaction (no proof) (1 M)
	Problem identified (10 M)	Clearly addressing the problem by linking with SDG & community partner (10 M)	*Mentioned without linking with SDG representation.* (5 M)	*Does not mention the clear need of the community* (1 M)
Specification Development (20 M)	*Measurable requirements* (5 M)	Clearly describes at least 5 measurable requirements depending on the project (5 M)	Less than 4 described specifications or the ones described are not measurable (3 M)	*At least 2 specifications listed* (1 M)
	Identification of existing solutions (5 M)	Identification of existing solutions addressing similar problems with appropriate documentation (5 M)	Identification of existing solutions addressing similar problems with no appropriate documentation.	*No clear identification of existing solutions.* (1 M)
	Gaps in existing solutions (5 M)	A clear explanation/ analysis of gaps with the documentation by using the appropriate case studies. (5 M)	A marginal explanation/ analysis of gaps by using the appropriate case studies. (3 M)	*No appropriate case studies for justification of gaps.* (1 M)
	Poster Presentation (Mandatorily) (5 M)	Creative poster presentation (5 M)	Good oral presentation (2 M)	*Neither Creative poster nor oral presentation* (1 M)

Table.III
External review

Review – 2 (Porotype Presentation) Rubrics

Assessment Parameter		Good	Average	Poor
Conceptual Design (20 M)	Decision Matrix (10 M)	Minimum 4 Possible solutions for one idea (10 M)	Minimum 2 Possible solutions for one idea (5 M)	No Solutions (1 M)
	Community Partner Interaction (10 M)	Taken feedback with community partner / Persona (10 M)	*Partially taken feedback (5 M)*	*Not Taken (1 M)*
Working Prototype & Report (40 M)	*Prototype demonstration (30 M)*	Porotype demonstration (30 M)	Without prototype demonstration only video presentation (5 M)	*No video or prototype demonstration (1M)*
	Project Report Submission (10 M)	Report with all proof & detailed design (10 M)	Partially submitted report without any proof (3 M)	No Report submitted (1 M)

Two reviews and assessments are conducted. The first assessment, worth 40 marks, is an internal review detailed in Table 2. The second, conducted by an external evaluator, is for 60 marks as shown in Table 3. These reviews are designed to evaluate the design thinking projects of first year engineering students, emphasizing the importance of community engagement, problem identification, specification creation, conceptual design, and prototype demonstration. In the first review, students are assessed on their ability to identify and document community needs, link these needs to the Sustainable Development Goals (SDGs), and develop measurable specifications while identifying gaps in existing solutions. The second review focuses on the refinement of conceptual designs, integration of community feedback, and the presentation of a functional prototype and comprehensive report. This review process equips students with essential skills in problem-solving, community involvement, and effective communication, helping understanding of design thinking and its application in engineering projects

III. RESULTS AND DISCUSSION

In the first semester of first year level PBL Design Thinking course, 300 students enrolled and completed 66 projects. In the second semester, 166 students enrolled and successfully completed 37 projects, as illustrated in Figure 5. A feedback survey was conducted, gathering 455 responses from students who expressed a keen interest in further developing their prototypes into product stages.

A. Does the PBL enhance quality of students learning outcomes, higher levels of critical thinking, problem solving skills, and creativity.

A refection report is collected from students through Moodle platform shown in figure.6. Students are asked to make notes during their visits to the community of users and record all possible observations which are shared with their peer teams as reflections in the classroom. Driscoll method is followed to collect the reflections.

Fig. 5 Glimpses of project expo Review – 2

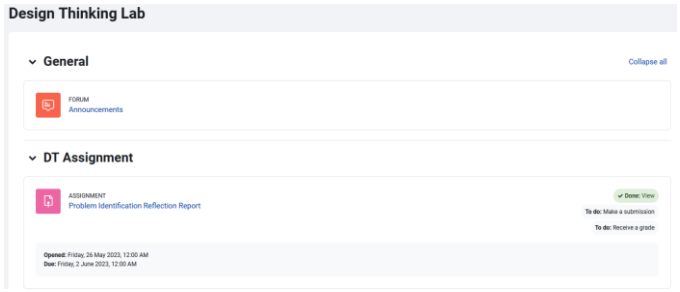

Fig. 6 Moodle – Reflection Report

Sample reflection report

What – Identified a problem a children's and youths are getting malaria, typhoid and infections due to drinking of unhealthy waters.

So, what – Due to this health problem many youths are not able to go to work and children are not going to school.

Now What – By design a potable water purifier, were it purifiers dirty water and gives the pure water. By supplying portable water purifier to a village, it will overcome clean water access problems.

The feedback collected from 455 students is shown in figure.7. 90% of students felt that PBL implementation increases the learning outcomes teamwork, communication, critical thinking and other skills. The students are shown more interest in solving community oriented or real time problems by applying technical knowledge. Interestingly core branches like EEE & Mechanical student teams have had software related problems and emerging branches have taken hardware type problems.

B. To what extent is the incorporation of PBL courses appropriate and effective for enhancing the learning experience of freshman engineering students at the entry level?

As per students' feedback 90% of students felt that doing engineering is better than only studying engineering. For the freshman entry level, as per now only one course is completely a PBL oriented course and other courses are activity-based type courses. After comparing students' attendance in the other courses and PBL course, students' attendance gradually increased in PBL courses. If students are trained in solving SDG goals by incorporating this into traditional courses, students' interest and motivation towards engineering will increase. Also industry needs problem solving students by adding PBL into all courses it solves unemployability issues. It's better 100% of converting traditional courses into a PBL based course.

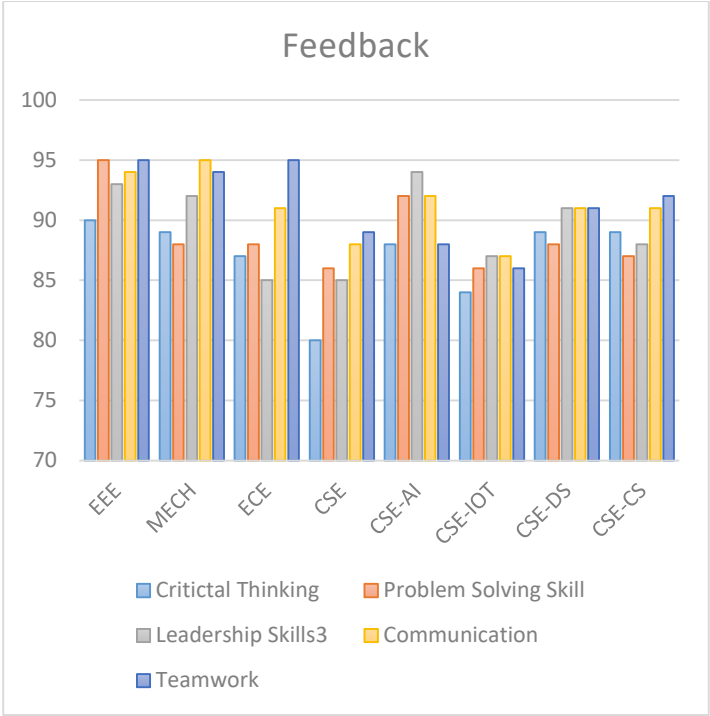

Fig.7 Feedback

(Servant-Miklos & Kolmos, 2022) & (Dabir et al., 2022) by following this research study PBL increases students learning outcomes by doing hands on experience. This research article, on the other hand, focuses a lot of attention on the curriculum design, evaluation techniques, problem identification, and reflection process. It illustrates how students are effectively guided from problem identification to the construction and refinement of a prototype through the use of an organized two-review process that focuses on problem identification, specification development, conceptual design, prototype production, and feedback integration. Through constant reflection and iterative improvement, this all-encompassing approach guarantees that students acquire a holistic understanding of the PBL process while also improving their technical and problem-solving abilities.

IV. CONCLUSION

Enhancing students' learning outcomes through implementation of PBL via design thinking process, which deploys engineering principles to convert problems into prototypes. The method encourages generations of novel ideas that may enable students to transform prototypes into marketable products and potentially become entrepreneurs. This program helps in refining the curriculum and embedding PBL, thus raising students' motivation and interest in community engagement for responsible citizenship and addressing unemployability. One issue is how first year

engineering students can deal with real world issues and provide viable solutions to it. In order to do this, second- and third-year engineering students need a continuity of experiential learning activities for design thinking courses when they are already aware of basic principles of design thinking. Through continuous trials and testing, students can deliver viable solutions to the community. While this process is time-consuming, refining the curriculum will effectively address these challenges.

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