Integration of Self-Regulated Learning in a first-year PBL course

[1]Radhika Amashi [2]Preethi Baligar [3]Vijayalakshmi M.
KLE technological University, Hubli – 580031
[1]radhika.amashi@kletech.ac.in@kletech.ac.in [2]preethibaligar@gmail.com [3]viju11@kletech.ac.in

Abstract—

Project-based learning or Problem- based learning (PBL) is an effective student-focused, inquiry-driven teaching method which helps in enhancing knowledge acquisition and retention. PBL is identified with 5 principles: Problem identification and analysis, Project organization, Teamwork, Student-centeredness, and Project assessment. For the PBL implementation to be successful, it is important to have the course aligned with these 5 PBL principles.

The context of this study is an undergraduate engineering course in its first year called; "Design Thinking for Social Innovation" offered in the author`s university. While the course majorly followed the PBL pedagogy, it lacked student ownership of learning and followed classroom teaching. Therefore, this study aims to promote student ownership of learning and assess its effect on their capacity to self-regulate their learning by developing content for students' self-study in the online mode.

To address the gap, the content of three modules was curated for online access and deliver the sessions in a flipped mode. This online intervention of learning material was offered to 35 students while the remaining 35 students took up the in-person version of the course. Both groups solved societal problems with immersive community engagement. A two-group design was used to study the impact of the intervention. The difference in self-regulated learning was measured using the existing questionnaire administered online at the end of the semester. Quantitative analysis using Mann-Whitney test was performed on the data.

Results of the study reveal that statistically significant differences in SRL between the two groups for specific constructs, notably in Monitoring and Evaluation, where the flipped classroom showed an advantage in monitoring skills, while the in-person classroom demonstrated better performance in evaluation and planning skills. However, the faculty experience of conducting the course in flipped mode revealed that students owned their learning, which was evident through in-class discussions. Further, the authors aver that the success of PBL courses, especially at first-year of undergraduate engineering largely depends on the effort and time the faculty can invest, often beyond scheduled class hours.

The authors conclude that that students' capacity to self-regulate their learning was unaffected by the implementation of flipped learning in a course that was already using the PBL format.Further refinement of the flipped PBL approach may be needed to optimize performance across all SRL constructs.

***Keywords*-Problem-based learning, flipped classroom, design thinking for social innovation, student ownership, PBL principles.**

I. INTRODUCTION

Design thinking courses in first-year engineering programs can effectively develop socially responsible students who can solve real-world problems (Dickrell & Virguez, 2018; Patil et al., 2023; Yelamali & Kotabagi, 2023). These courses develop students' empathy, critical thinking, and problem-solving ability (Ghanavati et al., 2020; Yelamali & Kotabagi, 2023). Integrating design thinking with service-learning projects improves students' confidence in technical and professional engineering skills(Bandi et al., 2021). The approach emphasizes understanding stakeholder needs and the iterative nature of the design process (Parmar, 2014; Siniawski et al., 2016). Implementing design thinking courses in engineering curricula has shown positive results, including improved identification of problem, design research, and new product development skills (Parmar, 2014).

As these problems belong to the real world, the courses often follow Problem-based pedagogy (J. Chen et al., 2021) as it allows learners to follow an independent inquiry using design methods and tools, develop creativity, lifelong learning (Acharya, 2024; Asojo & Vo, 2021). and self-directed learning. In combination with societal problems, the PBL approach also allows for establishing community-connect and empathetic understanding of the problem through stakeholder engagement (Baligar et al., 2024).

Designing a PBL course, irrespective of the context of the course, requires the incorporation of 5 principles: problem orientation, project organization, teamwork, student-centeredness, and project assessment(Barrows, 1996), each of which requires a sound understanding of the principles and how to operationalize them in the course appropriate to the student`s level of cognitive readiness and the competency development.

The proposed study is conducted in a design course at first-year undergraduate engineering education that follows the PBL approach focusing on societal problems. As a part of course design, students undergo two phases – the problem identification phase and the solution generation phase, resulting in projects, processes, or services. While the principles of problem orientation, project organization, teamwork and project assessment are well represented, the faculty progressively observed limitations in student-centeredness. Although the design allowed agency for it, the first-year engineering students were limited in their ability and readiness to own their learning. This can be attributed to the cognitive and emotional readiness as this is their first experience in team-based design problem-solving (Baligar et al., 2021).

Thus, to address this issue, the course instructors developed specific learning material for students' self-consumptions and application to design problems. The content was hosted on the in-house Moodle learning management system. Using a two-group post-test-only design, the students were assessed for the changes in self-regulated learning.

The subsequent sections describe the related literature, research questions, methodology, results and discussion and conclusion.

II. Literature Review

A. Self-Regulated Learning in the flipped and In-person modes of delivery:

A key idea in educational psychology is self-regulated learning (SRL), which involves students actively controlling their education by establishing objectives, monitoring their progress, and considering their results (Zimmerman, 2002). In the context of flipped classrooms, SRL becomes especially important as students are required to engage with instructional materials independently outside of class (Bishop & Verleger, 2013).

In a flipped classroom model, students access lecture content through videos or online resources outside the classroom, freeing up class time for interactive and problem-solving activities. This shift places a greater responsibility on students to manage their learning outside the classroom, enhancing the need for SRL skills (Bishop & Verleger, 2013). According to research, flipped classrooms can improve SRL by giving students the chance to go over and comprehend material more thoroughly (Van Alten et al., 2019). However, the effectiveness of SRL in flipped settings depends on students' ability to self-motivate and effectively use learning strategies (Pintrich, 2004). Research also suggests that the flipped classroom can improve SRL by giving students the freedom to study at their own speed and revisit content as needed (Y. Chen et al., 2014).

In contrast, traditional in-person instruction typically involves direct teaching during class time, with students expected to engage with the material presented by the instructor. While this mode offers more structured guidance, it may not promote the same level of autonomy and self-regulation as the flipped model (Karabenick & Knapp, 1991) Nonetheless, SRL remains crucial in traditional settings as students must still engage in self-directed study outside of class, complete assignments, and prepare for exams (Zimmerman, 2008).

B. Problem-Based Learning (PBL) for Social Innovation

PBL is a student-centered method in which students work through open-ended problems to solve them and learn new information. PBL is particularly effective in courses aimed at social innovation or community-based projects, because it promotes students' application of information to actual problems, promoting the growth of critical thinking and practical problem-solving skills (Barrows, 1996).

Arnold (2019) explores the integration of Problem-Based Learning (PBL) within higher education service learning, highlighting its potential to enhance theory-practice transfer. The study emphasizes that PBL deeply immerses students to solve real-world challenges, promoting critical thinking and practical application of theoretical knowledge. By aligning service learning with PBL, students can better address community needs while developing problem-solving skills. Similarly, (Bielefeldt et al., 2009) examine the impacts of project-based service learning on students' development. Their research shows that this approach not only improves technical and professional skills but also enhances students' understanding of societal issues and their ability to contribute positively to communities. The study emphasizes how crucial experiential learning is for developing civic engagement and a sense of social responsibility. In PBL courses focused on social innovation or service learning, students collaborate in teams to identify, analyze, and propose solutions to community challenges. This approach not only enhances their academic learning but also develops their sense of social responsibility and civic engagement (Hmelo-Silver, 2004). The collaborative nature of PBL necessitates effective communication, teamwork, and the integration of diverse perspectives, making it an ideal pedagogical approach for addressing complex social issues (Savery, 2015).

C. SRL in PBL Pedagogy

Integrating SRL into PBL pedagogy is essential for maximizing the benefits of this instructional approach. PBL requires students to engage in independent research, critical analysis, and iterative problem-solving, all of which are facilitated by strong SRL skills (Hmelo-Silver, 2004). (English & Kitsantas, 2013) highlight how PBL settings help SRL by empowering students to establish objectives, track their progress, and evaluate their results, all of which improve learning and memory. Similarly, (Paraskeva et al., 2017) explore the integration of PBL and SRL in blended learning environments, highlighting how these approaches improve student learning strategies and collaboration. They argue that combining PBL and SRL empowers students to become more autonomous and effective learners. (Stefanou et al., 2013) further discusses the role of SRL in promoting autonomy within PBL settings, noting that these pedagogies enable students to take charge of their learning through self-regulated inquiry and problem-solving.

SRL enables students to manage the demands of PBL by setting clear goals, employing strategic learning techniques, and continuously monitoring their progress (Pintrich, 2004). It also develops a sense of ownership, as students must often revise their approaches based on feedback and evolving project requirements (Schunk & Zimmerman, 1998). The acquisition of SRL skills is critical for students to succeed in PBL environments, particularly in courses aimed at social innovation where problems are dynamic and multifaceted.

Several instruments have been developed to measure SRL in educational settings. One widely used tool is the Motivated Strategies for Learning Questionnaire (MSLQ), through which students' motivational orientations and learning methods are evaluated (Pintrich et al., 1993). Another is the Self-Regulated Learning Interview Schedule (SRLIS), designed to gather qualitative data on students' self-regulation (Zimmerman & Pons, 1986). In engineering education, the adaptation of such tools to measure SRL within PBL frameworks is vital, as it allows for a deeper understanding of how engineering students manage their learning in complex, real-world problem-solving tasks (English & Kitsantas, 2013). The use of technologically advanced technologies, including learning analytics, to offer real-time insights into SRL behaviors is another focus of more recent research., making SRL measurement more dynamic and context-sensitive (Jovanović et al., 2017).

III. RESEARCH QUESTION

This study was conducted in a design course titled "Design Thinking for Social Innovation" offered to first-year engineering undergraduate program at an Indian private university. The course followed the PBL pedagogy in which the students addressed societal problems. While the course majorly followed the PBL pedagogy, and adhered to four of the five principles of PBL pedagogy, it lacked student ownership of learning. Also, successful engagement in PBL requires students to own their learning and actively participate in community engagement. Therefore, this study aims to promote student ownership of learning and assess its effect on their ability to self-regulate their learning by developing content for students' self-study in the online mode. The intervention was evaluated through the following research question.

How does Self-Regulated Learning (SRL) differ in flipped and in-person delivery modes in a PBL course?

A. Context

The study was carried out in a first-year design course that followed a problem-based approach. This 16-week course offers an immersive experience in societal problem-solving to students who follow the design thinking process to articulate and address the problem. The course, taught by an interdisciplinary team of faculty members, empowered students to spot, frame, and address a societal problem, focusing on several themes like education, hygiene, agriculture, community connect, and so on. To give sufficient time for community engagement, the course adhered to a rigid plan that allowed for 9-12 hours of community engagement across the semester. Figure 1 shows the PBL approach followed for the course. The course was majorly redesigned in 2021-2022 with the PBL pedagogy. In this version of the course, students solve real-world societal problems through the design thinking process. Design thinking was followed in the course through modules such as empathy, define, ideate, prototype, and testing. Every session followed classroom teaching with different tools specific to each module to help students solve the problem. Feedback was part of the assessments. The flow depicted in Figure 1 is partially modeled after the course presented in its earlier version, as described by (Yelamali & Kotabagi, 2023) and augmented by the design in the current version.

Despite the aspirations of the course, the student's readiness to take on complete ownership of learning was limited, which often led to faculty teaching several concepts. Thus, of the five principles of PBL, the faculty observed that the students did not take complete ownership of learning. To address this, the content of three modules, as shown in table 1, was curated for online access to deliver the sessions in a flipped mode.

While the PBL pedagogy remained the same for the course, the redesigned course as a part of the PBL certification program for the academic year 2023-2024 had the elements of reflections and the online content. The semester-wide flow of the course,

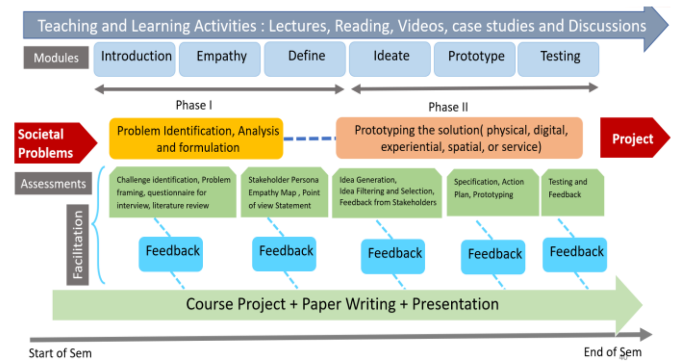

Fig. 1. PBL Pedagogy

as shown in Figure 2, comprised of in-person classroom sessions, community visits, and assessments. During phases I and II, the students visited the community 3 and 2 times, respectively. Each community visit (CV) was conducted with a clear set of expectations and deliverables from students, which were discussed during the post-CV and comprised of a written reflection. Each post-CV session was followed by an assessment.

TABLE I
ONLINE CONTENT

Module	Topics	Content-Type
1	Questionnaire Design	File
	1H5W Model	Video
	Post Interview Steps – Ampoule Case Study	File
2	Empathy Map	Video
	Problem Statement Formulation	Video
3	What is Ideation?	Video
	What is Brainstorming?	Video
	How is brainstorming done?	Video
	Brainstorming for Ampoule Case Study	File
	Idea Filtering for Ampoule Case Study	File
	Idea Evaluation for Ampoule Case Study	File

B. Participants

This online intervention of learning material was offered to 70 students while the remaining 70 students took up the in-person version of the course. Both groups solved societal problems with immersive community engagement. Out of 140 responses, 93 volunteered to participate in the survey, of which 40 belonged to the experimental group, and 53 belonged to the control group. The students' consent was sought via a Google form, and the objectives of the study were explained to them without revealing the measures used to study the effectiveness to prevent participant bias.

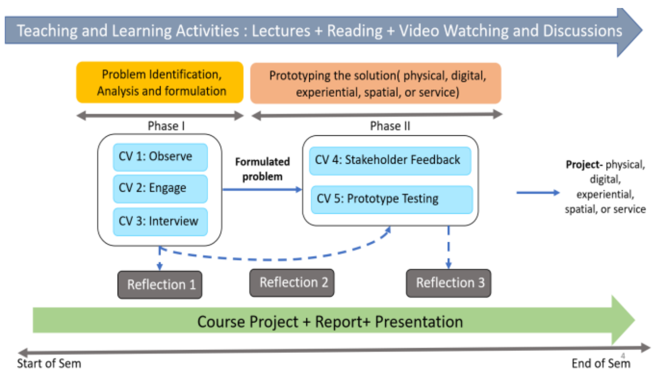

Fig. 2. Course flow, phases, and data collection

C. *Data Collection*

A two-group design was used to study the influence of the intervention. The difference in self-regulated learning was measured using the existing questionnaire by (Toering et al., 2012) given at the end of the semester in an online format. This questionnaire assessed self-regulated learning across six sub-scales: Planning, Self-monitoring, Evaluation, Reflection, Effort, and Self-efficacy, of which only the first three subscales were relevant for this study, comprising 25 items. Table II shows the instrument used for data collection. This data was supplemented with written reflections across empathy, ideation, and testing design phases. However, the results of the analysis of the qualitative strand will be included in future work.

TABLE II
SRL INSTRUMENT

ITEMS
(P1) I determine how to solve a problem before I begin.
(P2) I think through in my mind the steps of a plan I have to follow.
(P3)I try to understand the goal of a task before I attempt to answer.
(P4) I ask myself questions about what a problem requires me to do to solve it, before I do it.
(P5) I imagine the parts of a problem I still have to complete.
(P6) I carefully plan my course of action to solve a problem.
(P7) I figure out my goals and what I need to do to accomplish them.
(P8) I clearly plan my course of action to solve a problem.
(P9) I develop a plan for the solution of a problem.
(M1)While doing a task, I ask myself questions to stay on track.
(M2)I check how well I am doing when I solve a task.
(M3) I check my work while doing it.
(M4) While doing a task, I ask myself, how well I am doing
(M5) I know how much of a task I have to complete.
(M6) I correct my errors.
(M7) I check my accuracy as I progress through a task.
(M8)I judge the correctness of my work.
(E1) I look back and check if what I did was right.
(E2) I double-check to make sure I did it right.
(E3) I check to see if my calculations are correct.
(E4) I check my work all the way through the problem.
(E5)I look back at the problem to see if my answer makes sense.
(E6) I stop and rethink a step I have already done.
(E7) I make sure I complete each step.
(E8) I look back at the problem to see if my answer makes sense.

D. *Data Analysis*

Tests for normality revealed that the data was not normally distributed. Thus, Mann Whitney test was applied to study the effect of the intervention. The analysis was conducted on the Google Colab environment using Python programming. The data was processed to eliminate outliers, and a few of the null values were replaced with the average score of the item.

IV. RESULTS AND DISCUSSION

The data distribution is displayed in Table III. The Mann Whitney Test findings are displayed in Table IV. To determine whether the data was normal, skewness and kurtosis were measured. The skewness of all items ranged from -1.48 to -0.54, with 3 items falling outside the acceptable threshold of -1 to 1. Similarly, the kurtosis of all items ranged from -0.79 to 1.87, with 2 items exceeding the acceptable threshold of -1 to 1.

The data is moderately skewed, particularly in the Planning and Evaluation constructs, where skewness approaches or exceeds -1 in some items. While the kurtosis for most constructs is close to 0, the skewness suggests that the data may not be perfectly normally distributed.

The Mann-Whitney U test was applied to compare self-regulated learning (SRL) between the flipped and in-person groups. The test was conducted on constructs representing different aspects of SRL: Planning (P), Monitoring (M), and Evaluation (E).

TABLE III
DISTRIBUTION OF DATA

Constructs	Skewness	Skewness Range	Kurtosis	Kurtosis Range
Planning	-0.90	-1.48 to -0.61	0.38	-0.79 to 1.87
Monitoring	-0.80	-1.01 to -0.54	-0.18	-0.68 to 0.46
Evaluation	-0.84	-1.01 to -0.54	0.12	-0.63 to 1.06

TABLE IV
MANN-WHITNEY TEST

Mode	Median	U-Statistics	p-value
	PLANNING: P1 TO P9		
In-Person	31.00	1101.0	0.054
Flipped	30.00		
	MONITORING: M1 TO M8		
In-Person	27.00	1065.0	0.031
Flipped	25.00		
	EVALUATION: E1 TO E8		
In-Person	28.00	1043.5	0.021
Flipped	26.00		

The Mann-Whitney U test results show that the p-value of 0.054 is indicating that there is no statistically significant difference in the planning scores between the in-person and flipped classroom modes. Although the result is close to significance, it does not provide enough evidence to conclude that one mode is superior to the other in terms of planning construct scores.

With a p-value of 0.031, which is below the 0.05 threshold, this result indicates a statistically significant difference in monitoring scores between the In-Person and Flipped classroom modes. The mean score for the flipped classroom (25.00) is slightly lower than that for the in-person classroom (27.00). This suggests that the in-person classroom mode may facilitate a higher level of self-reported monitoring than the flipped mode, as indicated by the significant U-statistic.

The p-value of 0.021, also below 0.05, indicates a statistically significant difference in evaluation scores between the in-person and flipped modes. The median score for the in-person classroom (28.00) is slightly higher than that for the flipped classroom (26.00). This suggests that students in the in-person classroom mode may report higher evaluation skills or engagement in evaluation-related activities than those in the flipped mode.

While the in-person mode of delivery shows a significant advantage in monitoring skills and evaluation skills, the flipped classroom demonstrates findings could be attributed to the incremental changes made in the course design, where only 3 modules were delivered online in the flipped classroom, suggesting that further refinement of the flipped PBL approach may be needed to optimize performance across all SRL constructs.

Also, qualitative experience of the authors of this study, who were the course instructors, suggested that students in the flipped classroom appeared to engage more actively during in-class discussions and demonstrated a higher level of ownership of their learning. This discrepancy between the quantitative and qualitative findings highlights the complexity of measuring SRL. It suggests that while students may not have self-reported significant differences, their behavior and engagement patterns indicate otherwise.

Furthermore, the faculty's reflections emphasize the critical role of instructor involvement in the success of PBL courses, particularly for first-year engineering students (Prince & Felder, 2006). The additional effort and time invested by faculty beyond scheduled class hours were noted as key factors in facilitating student engagement and ownership, regardless of the mode of delivery. This underscores the importance of supportive teaching practices and the need for faculty to adapt their strategies to create effective learning environments (Hmelo-Silver & Barrows, 2006). While the flipped classroom did not show a significant impact on SRL through the measured parameters, the qualitative analysis of students' reflections may derive useful insights that will be studied in the future.

V. CONCLUSION

This study explored the effect of flipped and in-person delivery modes on Self-Regulated Learning (SRL) within a PBL course for first year engineering students. The Mann-Whitney U test results revealed statistically significant differences in SRL between the two groups for specific constructs, notably in Monitoring and Evaluation, where the in-person classroom showed an advantage in monitoring and evaluation skills. Although the difference in Planning was not statistically significant, it suggests a trend toward better planning in the in-person group. These findings the traditional in-person setting still supports more effective planning and evaluation marginally.

Despite the statistically significant differences in monitoring and evaluation, faculty qualitative observations highlighted enhanced student ownership in the flipped classroom. This indicates that while students may not explicitly report improved self-regulation, their behaviors in the flipped environment reflect deeper engagement and active participation. This highlights the complexity of measuring SRL and suggests a potential disconnect between self-reported quantitative data and observed learning behaviors.

The findings emphasize the pivotal role of instructor support and adaptive teaching strategies in developing effective learning environments. Faculty involvement was crucial in promoting student engagement, regardless of delivery mode. While the quantitative outcomes were inconclusive, the qualitative data analysis of student`s reflections collected across empathy, ideation, and testing phases will be included in future work. This research study, while offering valuable insights into the integration of self-regulated learning within a first-year PBL course, encounters several limitations.

Despite providing insightful information about including self-regulated learning in a first-year PBL course, this pilot research study has several drawbacks. 140 first-year engineering students participated in the study. The results may be less applicable to larger populations and other educational contexts due to the small sample size and lack of variety in the participant pool. The existing instrument was used to measure self-regulated learning. Most of the items were used as is with a few changes related to tense or wordings. The existing sample size was not sufficient to examine the factor structure of the instrument, which is also a limitation of this study.

The study observes that in flipped classrooms, faculty members have a favorable opinion of student ownership. The complexities of peer interactions in both learning settings and students' experiences may not be adequately captured by a solitary focus on faculty observations. However, the same can be used for triangulation in the future.

The study's particular setting—a design thinking course for first-year engineering students that focused on societal issues—means that the conclusions might not apply directly to other fields of study, other year levels, or courses with distinct topic emphasis. In contrast to other educational environments, the potential and challenges of a design thinking course may have a different impact on the implementation and results of PBL and flipped classroom approaches.

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