

Innovative Pedagogy for Engineering Mathematics: A Mixed-Methods Study of Flipped Classroom, Computational Tools, And Project-Based Learning

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Abstract

Engineering mathematics is a foundational discipline for all engineering branches, yet traditional lecture-based instruction consistently fails to engage students or develop their ability to apply mathematical reasoning to real-world engineering problems. This paper presents and evaluates an innovative pedagogical framework for engineering mathematics that integrates three evidence-based strategies: flipped classrooms, computational tools (MAT-LAB and Python), and project-based learning (PBL). A mixed-methods quasi-experimental study was conducted with 120 second-year engineering students over a 14-week semester. The experimental group ($n=62$) received the innovative pedagogy, while the control group ($n=58$) received traditional lecture-based instruction. Quantitative data included pre-test and post-test measures of conceptual understanding, student engagement, and mathematics anxiety. Qualitative data were collected through semi-structured interviews (10 students per group). Results showed that the experimental group scored significantly higher on the post-test (72.4 ± 7.6 vs. 58.7 ± 9.1 ; $t=8.14$, $p<0.001$, Cohen's $d=1.65$), reported higher engagement (4.3 ± 0.7 vs. 3.1 ± 0.9 ; $t=7.92$, $p<0.001$, $d=1.52$), and lower mathematics anxiety (4.1 ± 0.8 vs. 2.9 ± 1.0 ; $t=6.89$, $p<0.001$, $d=1.36$). Thematic analysis of interviews revealed three major themes: enhanced conceptual understanding, increased motivation and reduced anxiety, and appreciation for real-world connections. The paper concludes with practical recommendations for implementing innovative pedagogies in engineering mathematics courses. If reference is required in abstract then use this form (R. Kumar, Math. J. Interdiscip. Sci. Vol.7, p-112, 2019).

Keywords: Engineering mathematics, innovative pedagogy, flipped classroom, project-based learning, computational thinking, active learning

1 INTRODUCTION

Engineering mathematics—encompassing calculus, linear algebra, differential equations, Fourier analysis, and transform methods—constitutes the analytical foundation of virtually all engineering disciplines (12). From electrical circuit analysis to structural mechanics, from control systems to signal processing, mathematical tools are indispensable for modelling, analysis, and design. Consequently,

proficiency in engineering mathematics is a strong predictor of success in subsequent engineering courses and in professional engineering practice (11).

Despite this central importance, engineering mathematics education faces a persistent crisis. Across the globe, first-year engineering mathematics courses report disproportionately high failure and dropout rates (14). In the Indian context, where the present study is situated, annual failure rates in mandatory engineering mathematics courses range from 25% to 40% in many institutions (9). Even among students who pass, a troubling pattern emerges: they can perform procedural calculations but cannot apply mathematical reasoning to unfamiliar, real-world engineering problems.

The term "innovative pedagogy" in the context of mathematics education refers to teaching strategies that move beyond passive, transmission-based instruction to include active, collaborative, technology-enhanced, and context-rich approaches (10). Recent decades have seen the emergence of several such approaches: flipped classrooms, where direct instruction moves outside class time via video lectures (2); active and collaborative learning methods, including peer instruction and small-group problem solving (5); integration of computational tools such as MATLAB and Python for visualisation and simulation (9); and project-based learning (PBL), which engages students in extended, authentic engineering tasks (4). However, most existing studies examine these strategies in isolation. Relatively few have investigated their **combined** effect within a single coherent pedagogical framework, particularly in the context of engineering mathematics in Indian technical institutions. This gap motivates the present study.

This paper addresses the following research questions:

1. How does an innovative pedagogical model (combining flipped classroom, computational tools, and project-based learning) affect engineering students' conceptual understanding of mathematics compared to traditional instruction?
2. What are students' perceptions of the innovative pedagogical model in terms of engagement, mathematics anxiety, and perceived relevance?

2 LITERATURE REVIEW

2.1 A. Challenges in Traditional Engineering Mathematics Instruction

Traditional mathematics instruction in engineering programmes predominantly follows a lecture-tutorial-examination model. The instructor presents definitions, theorems, and worked examples on the blackboard; students passively listen and take notes; tutorials involve solving standardised problems; and examinations assess procedural fluency under time pressure (1).

This approach has been extensively critiqued on several grounds. First, it emphasises **procedural fluency**—the ability to execute algorithms correctly—at the expense of **conceptual understanding**—the ability to explain why those algorithms work and when they are applicable (7). Second, it does not prepare students to transfer mathematical knowledge to engineering contexts. Students who can solve textbook differential equations often cannot model a physical system or interpret the solution meaningfully (6). Third, these pedagogical shortcomings translate into measurable outcomes: high failure rates, low retention, and widespread mathematics anxiety among engineering students (14).

2.2 B. Active and Collaborative Learning

Active learning is broadly defined as instructional methods that engage students in the learning process through meaningful activities, discussion, and reflection, rather than passive listening (3). Common active learning techniques include think-pair-share, peer instruction, concept questions (clicker

questions), small-group problem solving, and structured debates.

A landmark meta-analysis by (5) synthesized 225 studies comparing active learning to traditional lecturing in STEM (science, technology, engineering, and mathematics) courses. The results were striking: active learning reduced failure rates by 55% and increased examination scores by approximately half a standard deviation (effect size =0.47). These effects held across disciplines, class sizes, and institution types.

In mathematics specifically, collaborative learning has been shown to promote **reasoning** (the ability to construct logical justifications) and **metacognition** (the ability to monitor and regulate one’s own understanding) (15).

2.3 Technology Integration

The integration of digital technology into mathematics instruction has been a major theme in educational research for three decades (8). In engineering mathematics, two technological approaches are particularly relevant: computational tools and the flipped classroom.

2.3.1 Computational Tools: MATLAB and Python

MATLAB (Matrix Laboratory) and Python (with libraries such as NumPy, SciPy, and Matplotlib) are widely used in engineering practice for numerical computation, data analysis, simulation, and visualisation. (9) reported that engineering students who used MATLAB alongside traditional instruction scored significantly higher on applied problem-solving tasks than peers who received only traditional instruction (mean difference = 18.4%, $p < 0.01$).

2.3.2 Flipped Classroom

The flipped classroom model inverts the traditional lecture-homework sequence. Students watch short video lectures (typically 10–15 minutes) at home before class. Class time is then used for active learning activities: problem solving, discussion, peer instruction, and projects (2).

2.4 Project-Based Learning (PBL)

Project-based learning is an instructional approach in which students learn by actively engaging in real-world, meaningful projects over an extended period (13). In engineering mathematics, PBL typically involves teams of students working on authentic engineering problems that require the application of mathematical concepts.

(4) provide extensive evidence that PBL improves student engagement, retention of concepts, and ability to transfer knowledge to new contexts.

3 PROPOSED INNOVATIVE PEDAGOGICAL FRAMEWORK

3.1 A. Overall Structure

The proposed framework was designed for a 14-week semester course titled "Engineering Mathematics III" (covering ordinary differential equations, partial differential equations, Fourier series, and linear algebra). The course had three contact hours per week and two tutorial hours per week.

Table 1: Components of the Proposed Innovative Pedagogical Framework

Component	Description	Time Allocation (hours/week)
1. Pre-class (flipped)	Students watch 10–15 minute video lectures; complete online readiness quizzes	2 (outside class)

2. In-class active learning	Collaborative problem solving; peer instruction; clicker questions	3
3. Project-based module	One team project per major unit (4 projects total)	1 (in class) + 2–3 (outside)

4 METHODOLOGY

4.1 A. Research Design

A **mixed-methods quasi-experimental** design was employed. The study had two phases: (1) quantitative phase: pre-test/post-test comparison between experimental and control groups; (2) qualitative phase: semi-structured interviews to capture student perceptions.

4.2 B. Participants and Setting

The study was conducted at a private engineering institute in North India during the autumn semester of 2025. Participants were 120 second-year students enrolled in four sections of "Engineering Mathematics III" (common to electronics and computer science engineering streams).

Control group (two sections, n = 58): Received traditional lecture-tutorial instruction.

Experimental group (two sections, n = 62): Received the innovative pedagogy described in Section III.

5 RESULTS

5.1 Quantitative Findings

Table 2 presents the means, standard deviations, t-values, p-values, and effect sizes for all quantitative measures.

Table 2: Comparison of Control and Experimental Groups

Measure	Control (n=58) Mean ± SD	Experimental (n=62) Mean ± SD	t-value	p-value	Cohen's d
Pre-test (CUT)	42.3 ± 8.2	41.9 ± 8.5	0.26	0.79	0.05
Post-test (CUT)	58.7 ± 9.1	72.4 ± 7.6	8.14	<0.001	1.65
Engagement survey	3.1 ± 0.9	4.3 ± 0.7	7.92	<0.001	1.52
Math anxiety (reverse)	2.9 ± 1.0	4.1 ± 0.8	6.89	<0.001	1.36

6 DISCUSSION

The results of this study strongly support the efficacy of the proposed innovative pedagogy for engineering mathematics. The 23% higher post-test scores in the experimental group (d = 1.65) exceed the average effect size for active learning in STEM (d = 0.47, from (5)). This suggests that combining flipped classroom, computational tools, and PBL produces **synergistic effects** beyond what any single strategy achieves alone.

7 CONCLUSION

This paper presented and evaluated an innovative pedagogical framework for engineering mathematics that integrates flipped classrooms, computational tools (MATLAB/Python), and project-based learning. A mixed-methods study with 120 second-year engineering students demonstrated that the framework produced significantly higher conceptual understanding, greater engagement, and lower mathematics

anxiety compared to traditional lecture-based instruction. Effect sizes were very large ($d = 1.36$ – 1.65), and qualitative data revealed that students appreciated the real-world connections, felt more confident, and developed deeper understanding.

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