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The Effects of Blended Learning on the Performance of Engineering Students in Mathematical Modeling

Saurabh Kalra*,
PhD Scholar, Department of Management, MRIIRS

Dr Nandini Srivastava,
Professor, Department of Management, MRIIRS

Dr. Vandana Gambhir,
Assistant Professor, Department of Psychology, University of Delhi

Abstract

This paper explores the implementation of blended learning, an active learning methodology, in an ordinary differential equations (ODE) course for engineering students. The study aims to evaluate the impact of blended learning on students' performance in mathematical modelling. The methodology involved a combination of synchronous and asynchronous activities, delivered both in-person and remotely, leveraging the experiences gained by students during the COVID-19 pandemic. The instructional design was guided by Bloom’s taxonomy of cognitive domains. The findings indicate that students progressed from basic knowledge and understanding to higher-order analysis and application, particularly in learning systems modelling using ODEs.

Keywords: blended learning, mathematical modelling, mathematics education, differential equations, STEM, engineering education

1. Introduction

Higher education institutions throughout the globe have a fundamental duty to prepare their pupils for university study, which is an important chance to help shape well-rounded people. Students majoring in science, technology, engineering, and mathematics (STEM) subjects must acquire specialized knowledge and abilities in order to be able to drive social and economic advancement in the 21st-century society. Dictionary research in the engineering field uses a variety of active learning approaches, bolstered by current digital technologies, to explore disciplinary fundamentals from multiple angles and improve students' theoretical and practical understanding in order to cultivate a well-defined university profile.

In mathematics education and engineering training, active learning techniques like gamification and the flipped classroom are often used, in addition to collaborative, problem-based, project-oriented, and competency-based learning approaches 【1–8†source】. Placing the student at the center of the learning process is a fundamental tenet shared by all approaches, notwithstanding their differences. For example, collaborative and problem-based learning methods foster cooperation by motivating students with varying skill sets to cooperate and share accountability for accomplishing a shared objective.

Blended learning, sometimes referred to as b-learning, is the process of combining in-person encounters with electronic material that is used both synchronously and asynchronously to encourage interactions amongst diverse views. B-learning forces students to adapt to a variety of activities and resources relevant to the subject matter, pushing them to interact with learning styles outside their typical inclinations.

The majority of STEM programs are traditionally created to function best in classroom environments, where the main components of the learning activities are laboratory procedures and analytical techniques. But the capacity to carry out these tasks was limited during the COVID-19 pandemic-related partial shutdown. However, digital tools like virtual labs and online software platforms were crucial in assisting students in swiftly adjusting to their new environment [11–18].

The B-Learning Approach

Blended learning (b-learning) is a pedagogical approach that integrates the best practices traditionally conducted in the classroom with various technological applications【19, 20 source】. This method requires creating an interaction-rich environment, enabling both direct and remote communication, allowing students to engage with different learning styles. In b-learning, a variety of virtual media are utilized to present interactive content that enhances the learning experience for STEM students. Examples include infographics, animations, videos, collaborative learning platforms, and virtual laboratories【9, 22 source】.

This approach offers multiple benefits for student performance, often surpassing those of a purely face-to-face learning environment. Since course content and activities are not confined to the classroom, students have the flexibility to study and complete practical tasks according to their schedules. Additionally, as noted by some researchers, diagnostic conversations or personalized feedback, which can be challenging in face-to-face settings, are often more effectively delivered in an online environment. Students tend to find online feedback more agreeable, which can increase their engagement and participation in learning activities.

The importance of adopting a b-learning approach became particularly clear during the COVID-19 lockdown, when most college students relied heavily on digital devices like cell phones, tablets, and computers for their academic activities. However, the rapid shift to virtual learning during the lockdown was often unplanned and implemented to mitigate the negative impacts on education. Now that the health crisis has eased, the lessons learned from this experience should be systematically applied to develop a more structured and meaningful b-learning environment that provides students with authentic active learning experiences. As a result, the teaching and learning processes currently used in mathematics training within university-level engineering programs must be reevaluated and restructured.

According to some perspectives, achieving better learning outcomes is possible if teachers can overcome their resistance to digital technology and move beyond a preference for face-to-face interaction, recognizing the potential benefits of online learning or a hybrid approach. Teachers should embrace the responsibility to redesign their courses, incorporating content and activities that utilize b-learning, thereby offering students a richer and more diverse learning experience than what is available solely online or in the classroom.

1.1 Taxonomy of the Cognitive Domain

In their professional activity, engineers employ their skills, competences, knowledge, and methodologies to tackle challenges that are special to their subject. Bloom's taxonomy offers a helpful framework to test and evaluate how these traits are gained, developed, or enhanced throughout the college teaching and learning process. Six stages are identified by this taxonomy to categorize educational objectives: knowledge, comprehension, application, analysis, synthesis, and assessment (refer to Figure 1).

According to Bloom, knowledge represents the most basic achievement level. At this stage, students recognize or recall ideas, content, or phenomena, with their responses to test situations expected to mirror their initial learning experiences. Moving up to the understanding level, students are expected to comprehend and interpret oral, written, verbal, or symbolic communication, applying the concepts and ideas conveyed. At the application level, students must use appropriate abstractions to solve problems, especially in situations where no specific solution is provided.

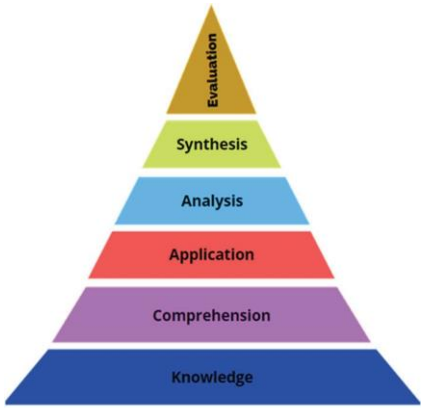

Fig 1: Six stages of Educational Objectives

Students deconstruct material into its basic parts at the analysis level of Bloom's taxonomy, understanding the connections, correlations, and interactions among them as well as their underlying structure. In order to address issues within a theoretical or methodological framework, students must use their creativity at the synthesis level. They must pull from a variety of sources to create a new scheme or pattern that was previously unclear. In order to evaluate information, techniques, or solutions, students must use particular criteria and parameters to produce either quantitative or qualitative value judgments. This is the highest level of the cognitive domain.

Creating arithmetic learning exercises for engineering students is a particularly good use for Bloom's taxonomy. In order to analyze the dynamics or phenomena of a system using first-order ordinary differential equations (ODEs), for example, students must have a thorough grasp of the crucial features and features of ODEs. This is best accomplished in a blended learning (b-learning) environment, which successfully combines online and in-person learning. Finding the best and most suitable tactics and exercises to meet the learning goals in any circumstance is the main problem.

1.1. Application of ODEs to Mathematical Modelling

Through a process of mathematical modeling, learners go through several stages of the cognitive domain. This progression specifically includes understanding the relevant parameters and variables, performing dimensional analysis, understanding the meaning of each term within the ODE, applying techniques to obtain analytical solutions and performing error analysis, and finally, interpreting the obtained solutions in the context of ordinary differential equations (ODEs). Students' involvement with these intricate cognitive processes may be greatly increased by using strategies like blended learning (b-learning), which improves understanding and application of mathematical topics.

Engineering students participate in a profoundly meaningful learning process when they take on the challenge of modeling real-world systems, whether they are drawn from ordinary life or their professional sector. In this procedure, mediators are essential in establishing a setting that encourages the development and exchange of novel ideas [33, 34]. Students actively control their own learning in such a setting, and they also gain from in-person interactions between teachers and students. These exchanges might include project supervision and one-on-one counseling utilizing the board, both of which are essential components in the context of engineering education.

2. Methodology

The purpose of this research was to assess how blended learning, or "b-learning," affected students' ability to create and solve first-order differential equation mathematical models. In order to do this, a sample consisting of 32 students enrolled in an ODE course within an engineering degree at a university was chosen. The selection method was not as random since the instructor was not involved in choosing the sample. As a result, pre-experimental design was used, which included evaluations for both the pre- and post-test. Because all of the participants were used to using digital technology, it was easier for them to participate in the research because the sample was thought of as time-dependent within the experimental design.

The sample size was in line with previous research, indicating that the b-learning strategy works better in smaller groups. The students in the group were paired with a particular teacher [23, 31]. The outcomes of this pilot project will provide insightful information for further implementations that could include a bigger sample size drawn from the wider study population.

2.1. Research Question

• Does implementing b-learning enhance student performance in mathematical modelling?

2.2. Hypothesis

To address the research question, this paper presents the following hypotheses:

•H0: B-learning has no impact on student performance in mathematical modelling.

• HA: B-learning positively impacts student performance in mathematical modelling.

2.3. Goal

This research set out to evaluate how engineering students performed while building and solving mathematical models utilizing first-order differential equations as a result of blended learning, or b-learning. In order to do this, we created a number of in-person and online learning exercises that focused on examining different systems or phenomena. Bloom's taxonomy of cognitive domain levels served as a design guide for these exercises, guaranteeing a planned development in the knowledge and comprehension of the pupils.

2.4. Implementation of the Didactic Proposal

The learning activities were designed to be completed both in-person and online (synchronously or asynchronously), in accordance with the b-learning method. Google Classroom was used to enable the asynchronous activities and provide access to instructional materials, exercises, videos, and tutorials. A virtual whiteboard served as assistance for Google Meet videoconferences, which were used to offer synchronous activities. During these sessions, alternative approaches to solving ordinary differential equations (ODEs) analytically were presented, and students were assisted in solving ODEs both symbolically and numerically via online tutorials on Matlab. In-person meetings were used to highlight important concepts, such the qualitative components of mathematical modeling, and to clear up any questions about the use of software or analytical methods.

Every activity was planned with the purpose of encouraging communication between students and between the teacher. The cognitive domain levels [25] were carefully arranged in a process that started with basic levels where students had to understand first-order ODE definitions, classifications, vocabulary, and symbols. The exercises then progressed to more difficult levels, concentrating on modeling itself, where students worked in groups to analyze, argue, develop relationships, debate, and discuss [37]. First-order ODEs were used to develop basic mathematical models for a variety of circumstances, including material mixing, exponential growth, temperature variations, and electrical circuits.

The series of didactic activities, as outlined in Table 1, were carried out both remotely and in-person, and were organized across several sessions as follows:

Session	**Type**	**Learning Activities**
1	Synchronous remote	Introduction to the subject, outlining objectives and providing support materials.
		Conducting a diagnostic evaluation.
		Formation of work teams.
2	Asynchronous remote	Engaging with readings, videos, and activities focused on the principles of ODEs.
		Completing Matlab R2022a tutorials covering algebra, graphs, calculus, and ODEs.
		Additional readings, videos, and exercises for solving ODEs analytically.
3	Synchronous remote	Guidance on analytical methods and procedures for solving ODEs.
4	Asynchronous remote	Administration of Questionnaire.
		Viewing readings and videos on modeling exponential growth systems.
5	Synchronous remote	Developing a mathematical model for a system and deriving its analytical solution.
		Numerical solution of the system's mathematical model using an online software platform.
6	Face-to-face	Comparison of analytical and numerical solutions related to the system's dynamics.
		Random assignment of exercises involving various scenarios to construct mathematical models using first-order ODEs.
7	Asynchronous remote	Construction of a mathematical model and derivation of its analytical solution.
		Obtaining the numerical solution.
8	Face-to-face	Drafting a written report.
		Presentation and discussion of results.
		Administration of the rubric.
9	Asynchronous remote	Administration of Questionnaire 2.
		Conducting the survey.

While the teacher conducted the synchronous remote sessions via videoconferences, the students worked in both individual and group projects during the asynchronous distant sessions. In-person meetings were held using the Zone of Proximal Development (ZPD) methodology [35,36 source]. Sessions 5 and 6 were contextualized to represent the current situation by concentrating on the progression of the number of SARS-CoV-2 illnesses in the city where their institution is situated. This was done to engage and inspire students in the modeling exercises. The teams were given objectives related to growth and decay, carbon dating, Newton's rule of cooling and warming, and series circuits, all of which are important to engineering students.

As a component of the observation and assessment tools, questionnaires were used to evaluate the effectiveness of the educational activities. These resources are especially important in asynchronous online environments since they have a big impact on how well students learn. Online surveys have been proposed as a way to assist level and standardize the information that students learn in their first engineering courses, especially when combined with other resources. A survey and a rubric were used to collect additional data for the research (see Table 2). A written report of the finished task, a numerical solution, an analytical solution, a mathematical model, and a vocal presentation of the work were the five criteria that made up the rubric. A four-point Likert scale was used to grade the responses (null, regular, well, exceptional). The latter two criterion evaluated the growth of soft skills, while the first three criteria concentrated on the development of hard abilities.
Five questions and five activities were included in the pre-test for Questionnaire 1: (1) What is a differential equation (DE)? (2) What kinds of equations are differential? (3) What does a DE's order represent? (4) What does a non-linear DE's condition mean? (5) What kind of resolution is possible for a DE? Furthermore, two activities were designed to find the general or specific solution of a DE, and three tasks were offered to confirm the solutions of DEs. The purpose of the pre-test was to gauge students' familiarity with and comprehension of the core ideas of DEs. While the exercises examined their comprehension of DE structure and solution techniques, the five questions evaluated their knowledge of DE principles, categorization, and solution types. The pre-test was in accordance with Bloom's taxonomy levels 1 and 2.

Table 2. Observation and measurement instruments designed for the study.

Instrument	**Contents**	**Purpose**
Diagnostic Evaluation	Items/questions concerning the definition, domain, differentiation, and integration of one-variable functions.	To verify the homogeneity of prior knowledge within the sample using converging questions (multiple choice).
Questionnaire 1 (Pre-test)	Items related to ODE definitions, symbols, classification, usage, structure, and solution methods.	To measure the extent of ODE knowledge and understanding (cognitive domain levels 1 and 2).
Questionnaire 2 (Post-test)	Items related to the meaning of ODE terms, rules, and procedures for a mathematical model.	To assess the effectiveness of applying ODEs and analysing systems (cognitive domain levels 3 and 4).
Rubric	Five criteria with four levels	For qualitative analysis of hard and soft skill development.
Survey	Items with responses on a 6-point Likert scale	To quantitatively analyse student satisfaction with the b-learning approach used in the activities.

Six questions from Questionnaire 2 were included of the post-test to gauge how well the students understood and used differential equations (DEs). The following were the questions that were asked: (1) How is a DE put to use? (2) How can one fix a DE, in your opinion? (3) Were all of the terms in the DE clear to you? (4) What is a mathematical model, in your opinion? (5) What is the utility of a mathematical model? (6) What resources are available to you for mathematical model analysis? The purpose of the post-test was to evaluate the students' proficiency in using DEs to build fundamental mathematical models, using DE solution strategies, and interpreting DE concepts and modeled system behavior. This exam, which emphasizes application and analysis, is in line with Bloom's taxonomy levels 3 and 4.

Both quantitative and qualitative methodologies were used to examine the data and information obtained via the use of research devices. As part of the quantitative analysis, the pre- and post-test findings were analyzed using descriptive statistics, and a normality test was performed during the diagnostic assessment. Moreover, a hypothesis test was run using the Student's t-test in SPSS 2022 program to compare the means of matched data. A rubric was used in the qualitative study to assess how well students used DEs to model and examine a system's reaction. In addition, a survey and student reports were used to evaluate the growth of soft skills including cooperation, report writing, communication, and engagement in events.

3. Results

The diagnostic evaluation's goal was to determine how homogeneous the sample was in terms of recalling earlier subjects, which included cognitive level 1 concepts including the definition, domain, differentiation, and integration of one-variable functions. In order to do this, the findings of the diagnostic examination were subjected to the Shapiro-Wilk normality test. Table 3 shows that the test produced a p-value larger than 0.05, which suggests that the sample data were normally distributed. This implies that the students' previous knowledge of these fundamental subjects was uniform at the beginning of the course.

Table 3. Shapiro–Wilk normality test on the results of a diagnostic evaluation

DF	Statistic	*p*-value	Decision at level (5%)
31	0.9500	0.0725	Normality cannot be rejected

With a sample size of 32 (DF = 31), the Shapiro-Wilk test statistic was 0.95000, and the corresponding p-value was 0.07250. Since the p-value is greater than the 5% significance level ($\alpha = 0.05$), we do not reject the null hypothesis of normality. Therefore, the data can be considered normally distributed for the purposes of this study.

The student sample participated in three synchronous and asynchronous remote sessions, after which Questionnaire 1 (pre-test) was administered to assess their knowledge and understanding of ODE fundamentals, covering cognitive levels 1 and 2. These fundamentals included definitions, symbols, classification, usage, structure, and solution methods of ODEs. The quantitative analysis of the pre-test results (see Table 4) revealed a mean score of 6.44, with a standard deviation of 1.66 and a variance of 2.77. This suggests that, by the end of the three sessions, the students had acquired a basic understanding of ODE concepts. However, this understanding was somewhat limited, likely because the topics were presented in an abstract manner without contextual application, which may have hindered the students' engagement and interest in fully grasping the concepts.

Following the learning activities, a post-test (Questionnaire 2) was conducted to evaluate any improvement in the students' knowledge and understanding. The post-test results showed a mean score of 8.81, with a standard deviation of 1.29 and a variance of 1.67, indicating a significant improvement in the students' comprehension of ODE concepts after the instructional sessions.

Table 4. Statistical results of the pre-test and post-test.

	N	Mean	Standard Deviation	Variance	Minimum	Median	Maximum
Pre-test	32	6.4375	1.6632	2.7662	3	6.5	9
Post-test	32	8.8125	1.2910	1.6657	6	9	10

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Five in-person and remote synchronous and asynchronous sessions were used to carry out team-based tasks. After these sessions, students were given Questionnaire 2 (the post-test) to gauge how well they used ODEs to build a mathematical model and assess the system's reaction, which correspond to cognitive levels 3 and 4, respectively. A rise in the mean score and a decrease in dispersion as compared to the pre-test results were found by the quantitative analysis utilizing descriptive statistics from the post-test findings (see Table 4), suggesting that the learning activities had a beneficial effect on students' learning.

In order to confirm these results even further, a matched sample the results of the pre- and post-tests were compared using the student's t-test (see Table 5). At a significance threshold of $\alpha = 0.05$, the alternative hypothesis (HA: $\mu1-\mu2 < 0$) and the null hypothesis (H0: $\mu1-\mu2 = 0$) were investigated. Based on the t-test findings, which had a test statistic of t0 = -3.69885 below the threshold value of -1.696 with 31 degrees of freedom, the null hypothesis had to be rejected. Furthermore, the rejection of the null hypothesis was further confirmed by the p-value (8.21435×10^{-4}) being smaller than α. The alternative hypothesis was therefore accepted, showing a statistically significant difference ($\mu2$) favouring the post-test in the means of the pre- and post-test. It was determined, at a 95% confidence level, that the b-learning strategy significantly improved student learning, especially when it came to using ODEs and analysing the reaction of the modelled system.

Table 5: Hypothesis Test of the Pre-test and Post-test

t_0 statistic	DF	t_0.05,31	p-value
-3.69885	31	-1.696	8.21435×10^{-4}

Qualitative Evaluation

Regarding the qualitative evaluation, the results from the rubric indicated that the activity design effectively promoted student interaction and enabled the successful application of ODEs to model the assigned systems within each team. The students were able to adequately perform both the analytical and numerical solutions of the systems. Additionally, notable improvements were observed in the development of soft skills, including teamwork, report writing, organizational abilities, and verbal communication for presenting information to the group.

Feedback collected through the survey revealed that students felt comfortable with the activities and the work dynamics that were implemented. Table 6 highlights some of the student responses, which provide valuable insights for refining and improving the design of this didactic proposal in future iterations.

Table 6. Survey responses.

Items	Sample Response
Describe the interaction or collaboration in your team when carrying out these activities.	"Collaboration was very good; each person did their part, and there was great chemistry since my partner and I have known each other for a long time, which made everything go smoothly."
	"There was adequate cooperation and collaboration during the tasks; we agreed on ideas and made everyone’s work easier."
	"The communication with my partner was very good; we both contributed equally to the task."
What do you think about the material (text, software, etc.) you used to solve your task?	"The materials were very useful in solving the problem and provided the right tools to better understand the subject."
	"After researching different sources, we were able to completely satisfy our doubts and resolve any issues that arose."

	"The problem was clearly defined, and we relied on the book and had full support from Matlab's resources."
Describe the difficulties you had during this activity.	"In my opinion, the most difficult part was fully understanding the difference between the numerical and analytical solutions."
	"Better understanding the relationship between the variables was challenging."
	"Implementing the script in Matlab to obtain a numerical solution was a bit tricky."

Finally, this research has several limitations. First, the sample consisted solely of students from a single educational program, which limits the generalizability of the findings. Expanding the sample to include students from diverse educational programs would provide a more comprehensive understanding and broader applicability of the results. Second, the observation and measurement instruments used in the study need further validation to enhance their internal consistency and the accuracy of the evaluation outcomes. Future research should involve the participation of additional teachers and institutions, and incorporate advanced statistical techniques, such as factor analysis, to gain deeper insights into the data collected by these instruments.

4. Conclusions

In this study, we implemented a didactic proposal for mathematical learning using a blended learning (b-learning) approach, leading to several key observations. The findings from Questionnaire 1 highlight the need to diversify the activities early on, incorporating practical applications of ordinary differential equations (ODEs) to foster greater student interest in understanding foundational concepts. The descriptive statistics and hypothesis tests from Questionnaire 2 indicate that the b-learning approach significantly enhanced student learning, particularly in applying ODEs and analyzing modeled systems. However, the qualitative evaluation revealed the necessity of expanding the rubric and survey questions to better assess the development of soft skills.

Students' performance on problems requiring ODEs for mathematical modelling and systems analysis was generally improved by the b-learning technique. Active approaches are essential for developing research in mathematical education, refining educational procedures, and greatly increasing engineering students' acquisition of knowledge. Examples of these approaches include blended learning and the integration of information and communication technologies (ICTs). Using a strong experimental design that formalizes the analysis and observation of interactions in both virtual and classroom contexts is essential to studying this process in depth.

The use of Bloom's cognitive domain levels in the creation of educational activities has shown efficacy in organizing material and adjusting the degree of difficulty of those activities. For the purpose of creating synchronous and asynchronous activities, the experiences of educators and students throughout the COVID-19 epidemic, especially the change to remote learning, offered a good basis. These experiences need to be taken advantage of once educational institutions resume regular operations. By using the advantages of blended learning and carefully planning activities and resources to strike a balance between online and in-person interactions, educators may improve their courses. By doing this, students may interact with a range of learning styles while making use of the many digital technology and multimedia resources that are offered in blended learning programs. Institutions of higher learning should constantly assess how integrating technology has affected the promotion of active learning.