



Impact of Flipped Teaching on Academic Performance in Mathematics: A Comparative Study of Experimental and Control Groups

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Abstract

School mathematics achievement helps students to access higher education programs and STEM career opportunities. The traditional lecture-based teaching methods fail to create effective student engagement because they do not support deep comprehension of concept. The present situation requires educational institutions to investigate teaching methods which research has shown to be more effective. The research investigated how flipped teaching affected mathematics performance of XI Standard secondary school students by comparing their results with those students who learned through traditional teaching methods.

Researchers conducted a scholarly investigation using the implementation of a pre-test and post-test equivalent group experimental framework. Researchers selected 200 XI standard students through purposeful selection and assigned them equally to two groups which included experimental group of 100 students who experienced flipped teaching and a control group of 100 students who learned through conventional teaching methods during two units which covered set theory and relations and functions. Researchers used a Mathematics Achievement Test (MAT) which they developed to assess mathematic performance. The experimental group scored enhanced results in compared with the control group during their post-test assessment which showed statistically significant results ($t = 15.89$, $p < 0.01$; $d = 2.25$). The implementation of flipped classroom teaching methods produced both statistically significant results and major improvements in mathematics achievement which secondary students attained through their practices. The study demonstrates that flipped teaching enables students to grow comprehension of concepts while they acquire ability to think critically which provides important information for developing new teaching methods that will improve secondary mathematics education in India.

Keywords: *Flipped Teaching, Academic Performance, Secondary Education and Experimental Group.*

1. Introduction

Mathematics serves as the fundamental subject for developing intellectual abilities and academic skills in secondary school students. Secondary-level students who possess strong mathematical abilities establish their academic achievement in board examinations and their future education possibilities in STEM fields because mathematics functions as the base for scientific reasoning and numerical assessment and logical thought processes. International assessments, including PISA and TIMSS, consistently show that secondary-level mathematics achievement is a strong predictor of workforce readiness and participation in knowledge-driven economies (OECD, 2019). The Indian educational system considers XI Standard as the crucial point where students first encounter abstract mathematical concepts which include algebraic structures and functions and set theory. Students need to develop completely new mathematical thinking abilities to master these topics, but traditional teaching methods make it hard for them to reach this goal.

1.1 Challenges in Traditional Mathematics Teaching

The secondary education system still maintains its original mathematics teaching methods which have existed since past decades. The teach-practice-assess model which schools use today designates teachers as main knowledge providers who spend classroom time teaching through direct instruction and demonstration of worked examples. The students must complete their homework assignments which require them to demonstrate their understanding of the material yet they will face challenges because their peers and teachers cannot assist them during moments of confusion. This approach has several well-documented limitations. The first point restricts students to learn through active cognitive methods because they can only access expert assistance during their class time. The second point requires all students to receive the same educational material because their previous knowledge and learning speed have not been assessed. Third public demonstrations of new concepts create an environment which makes students feel more anxious about mathematics learning because they must face their first experience with new ideas in front of others. Fourth traditional lectures fail to develop critical thinking skills which need analysis, synthesis and evaluation because these skills develop through collaborative and exploratory learning activities (Hattie 2009 Bishop & Verleger 2013).

1.2 Need for Innovative Pedagogical Approaches

The well-documented limitations of traditional mathematics teaching, coupled with the increasing availability of digital learning technologies, have created both the need and the opportunity for innovative pedagogical approaches. Constructivist learning theories (Vygotsky, 1978; Piaget, 1970) explain that people create understanding through direct involvement with educational materials and their sociocultural environment and the learning atmosphere. Active learning frameworks put this principle into practice by designing classroom experiences where students process, apply, and evaluate information during class, rather than simply receiving it. Students who learn in active learning environments that focus on their needs achieve better mathematics results than those who study through passive methods that involve lectures (Boaler, 2002; Dewey, 1938; Johnson & Johnson, 1994). The execution of these methodologies in practical situations becomes difficult because educators must complete essential educational content within predetermined instructional time limits. The flipped classroom model enables educational institutions to achieve their objectives through its research-based approach which enables students to learn at a deeper level while maintaining needed educational content.

1.3 Concept of Flipped Classroom

Bergmann and Sams (2012) introduced their modern version of the flipped classroom model which creates a new educational framework because it switches the sequence between teaching and student learning activities. The method requires students to study through pre-recorded video lectures and digital materials which they must complete before their classroom time. The class period which formerly focused on lectures now serves as a time for students to collectively work on solving questions and participating in peer discussions and teacher-led analysis and advanced learning experiences. Pre-class activities enable students to develop basic cognitive skills while interactive classroom sessions deliver higher-level learning through active participation (Anderson & Krathwohl, 2001). The Flipped Learning

Network (2014) studied this approach as- “the FLIP framework that emphasizes four components of learning: flexible learning environments, learning culture shifts, intentional content design, and professional educator roles”. The flipped teaching increases academic achievement, learner motivation and classroom participation according to research findings from meta-analyses and systematic reviews (Akçayır & Akçayır, 2018; Zheng et al., 2020).

2. Review of Related Literature

The theoretical foundation of flipped teaching is grounded in constructivist learning. Lev Vygotsky's (1978) sociocultural theory demonstrates that people develop advanced thinking abilities through social interactions which occur within their zone of proximal development (ZPD). The flipped teaching uses this method because it needs learners to gain knowledge independently prior to the class session while students work together in class to receive help and learn from their peers. According to Piaget (1970) constructivism shows that people develop knowledge through assimilation and accommodation which hands-on problem-solving activities, not listening activities, most effectively develop. Dewey's (1938) experiential learning theory establishes that people achieve meaningful learning through purposeful experience and reflection which flipped classroom activities implement during their activity centred in-class time.

2.1.1 Interactive Learning Principles

Interactive learning, defined as pedagogical approach that encourages active student involvement in meaningful tasks while prompting reflection on their thinking (Prince, 2004), is strongly supported by research. Hattie (2009) conducted meta-analyses which showed that interactive learning environments with comprehensive feedback systems lead to greater academic achievement than traditional passive teaching methods. Research on cooperative learning has shown through multiple studies that structured peer interaction helps students understand complex concepts more effectively (Johnson & Johnson, 1994). The Flipped Classroom combines active learning methods with digital content delivery by dedicating class time to collaborative activities that research shows most effectively promote deep learning.

2.1.2 Flipped Teaching

The flipped teaching establishes a new pedagogy which creates different learning experiences for students at home and their classroom time. The learning process consists of two stages which begin with students studying instructional materials through independent activities that use video content and continue with their in-class activities which need them to use those materials for their collaborative learning tasks. Hamdan, McKnight, McKnight, and Arfstrom (2013) described the four essential components of flipped learning: “The four components are flexible environment, learning culture, intentional content and professional educators”, through which they demonstrated that study results depend on designing both educational components, not just the process of reversing homework and lecture delivery. The true effect of the method creates active knowledge building through student partnerships which replace traditional methods of receiving information in classroom environments according to Tucker (2012).

The flipped teaching depends on pre-class video as its main educational element. Effective videos which create learning content need to last between eight to twelve minutes and to present specific learning goals and to use a conversational style while displaying built-in assessment points and supporting classroom work. The design of videos requires Cognitive Load Theory which Sweller established in 1988 and Mayer and Moreno proved in 2003 to demonstrate its most effective design methods which consist of showing content in sections and using visual and audio elements together while preventing unnecessary information from entering the viewer's awareness. The class period becomes available for advanced learning tasks which include collaborative problem-solving and peer teaching and Socratic discussion and Think-Pair-Share and jigsaw activities and guided inquiry because content delivery no longer requires classroom time.

2.1.3 Flipped Teaching in Mathematics

The Flipped Classroom model demonstrates effective results through research conducted at secondary educational institutions. Bhagat and Chang (2016) discovered that Taiwanese secondary school students that received instruction through a flipped classroom method achieved better results in trigonometry while developing more favourable attitudes towards mathematics. Olakanmi (2017) documented those South African secondary students who studied chemistry

experienced both achievement improvements and attitude changes. Muir and Geiger (2016) conducted their research in Australia and discovered that flipping a Grade 10 mathematics classroom increased student participation while students developed a better understanding of algebraic concepts. The Indian educational system uses Birundha and Manoharan (2020) research which shows that students in the XI standard chemistry program achieved better results through flipped instruction methods that directly apply to existing Indian secondary educational programs.

Experimental Studies

Flipped Classroom instruction shows strong evidence of its effectiveness through comparative experimental studies and quasi-experimental studies. Jensen, Kummer, and Godoy (2015) demonstrated that university biology students achieved greater learning outcomes in flipped classrooms because of active learning activities, which created better educational opportunities than using unstructured classroom time with homework and lectures. Ryan and Reid (2016) showed that university students who learned general chemistry through a flipped classroom model experienced both better academic results and improved knowledge retention. Kang (2015) showed that flipped instruction helped Korean EFL students achieve better academic results, which demonstrates its effectiveness across all academic fields. The researchers Kim, Khara, and Getman (2014) discovered core design elements that urban universities should use to build their flipped classroom model and found that their design needs structured classroom activities, which lead to specific educational performance outcomes.

Effects on Achievement

The strongest evidence for flipped classroom model effectiveness comes from systematic reviews and meta-analyses. Akçayır and Akçayır (2018) examined 71 studies which showed that academic achievement increased most frequently as academic gain, while mathematics and STEM fields displayed the most reliable improvements. Zheng, Bhagat, Zhen, and Zhang (2020) performed a comprehensive meta-analysis of 45 researches, which demonstrated that flipped learning had a constructive on student performance ($g = 0.52$) and student motivation. Wei et al. (2020) discovered that Chinese middle school students showed exceptional progress in mathematics achievement across different mathematics topics. Lo and Hew (2017) showed K-12 students consistent mathematics achievement improvement when studies included well-designed pre-class and in-class teaching elements. Goodwin and Miller (2013) determined that students in flipped teaching showed scholarly benefits, because most evidence supported this finding even though research remained ongoing at the time.

2.1.4 Research Gap

International research has produced substantial evidence yet core elements of knowledge remain unaddressed. First, rigorous experimental research focused on XI standard secondary school students in India is scarce because most studies conducted in India focus on higher education research or non-mathematics disciplines. Second, there exists a research gap concerning achievement outcomes which assesses different cognitive levels of Bloom's taxonomy because existing studies do not show whether flipped instruction benefits all levels or only specific levels which include knowledge understanding application and analysis. The Indian research field lacks equal group experimental designs which use pre-test and post-test methods that provides the strongest causal evidence. The present study is designed to address all three of these gaps.

3. Need of the Study

This study explores the impact of flipped classroom pedagogical method on mathematics performance of XI standard students studying in secondary level, with particularly focus on achievement gains in the units of sets and relations and functions, as well as across different levels of revised taxonomy of Bloom. The study uses a pre-test and post-test equivalent group experimental framework to analyse the results of flipped classroom instruction versus conventional pedagogical methods.

4. Statement of the Problem

Flipped classroom instruction has proven effective through international studies but its impact on mathematics achievement at XI standard level in Indian secondary schools needs more experimental research. Majority of studies carried in the context of India focussed on tertiary level education or non-mathematics subjects. Many studies use quasi-experimental or survey designs instead of pre-test and post-test comparable group experimental designs which limits their ability to establish causality. Researchers need to conduct methodologically sound studies that assess flipped classroom instruction's effectiveness in improving mathematics results for XI standard secondary students compared to traditional teaching methods.

4.1. Objectives of the Study

The study objectives framed for the investigation were:

- To compare the mean pre-test scores of class XI students of the experimental group and control group in mathematics and establish baseline equivalence.
- To compare the mean post-test scores of class XI students of the experimental group and control group after the learning of flipped teaching.
- To evaluate the gain scores of both groups and compare the magnitude of improvement.
- To analyse the effect of flipped teaching at cognitive level of Bloom's revised taxonomy ("Knowledge, understanding, application, and analysis") on mathematics achievement.
- To measure the magnitude of the effect of flipped teaching instruction on achievement in mathematics using Cohen's d.

4.2 Hypotheses of the Study

For the purpose of this study, the following null hypotheses (H_0) were formulated:

- H_{01} : There is no significant difference between the mean pre-test scores of the experimental group and the control group XI standard students in the mathematics achievement test.
- H_{02} : There is no significant difference between the mean post-test scores of the experimental group and the control group XI standard students in the mathematics achievement test.
- H_{03} : There is no significant difference between the mean gain scores of the experimental group and the control group XI standard students in the mathematics achievement test.
- H_{04} : There is no statistically significant difference in the mean pre-test and post-test scores of the experimental group.
- H_{05} : There is no statistically significant difference in the mean the pre-test and post-test scores of the control group.

5. Methodology

The present study used a pre-test and post-test parallel group experimental design, which educational research considers to be the most demanding quasi-experimental method. The design divides participants into two groups through either assignment or matching, which creates an experimental group (EG) that receives flipped teaching and a control group (CG) that receives conventional teaching methods. The assessment of both groups is conducted prior to and following the intervention through their pre-test and post-test evaluations. The pre-test functions to establish group baseline equivalence and permit analysis of intra-group advancement. The design's fundamental principle states that all post-test results between groups, which achieved pre-test equivalence, will show direct causal links to the instructional methods used.

5.1. Population and Sampling

The researchers selected XI Standard students from secondary schools throughout Bijnor as their research target population. The researchers selected 200 students from a secondary school to create a purposive sample that represented the standard teaching situation for which the flipped teaching had been developed. The students were assigned to two groups using a purposive sampling which created two groups of 100 students each.

Both groups had an equal gender distribution (50 boys and 50 girls per group), ensuring comparability across conditions. The t-tests which used independent samples showed that the mathematics achievement test mean pre-test scores of EG and CG students did not demonstrate any statistically significant differences between the two groups ($t = 0.88$, $p > 0.05$) which established that both groups had equal starting points.

5.2 Tools Used

The researcher-created mathematics achievement test (MAT) evaluated student performance through two intervention units which included unit I-Set theory and unit II-Relation and Functions. The MAT test consisted of 40 total marks which were divided into four cognitive levels according to Bloom's revised taxonomy. The study implemented a multi-level structure to investigate how Flipped Classroom instruction affected both overall achievement and specific cognitive processes.

A group of five Mathematics education experts conducted a systematic review to establish content validity for the Mathematics Achievement Test (MAT) by evaluating each test item according to its alignment with curriculum objectives and the corresponding Bloom's taxonomy level. Practicing secondary school mathematics teachers conducted a review that confirmed face validity. The study demonstrated a high level of inter item reliability because Cronbach's alpha method produced $\alpha = 0.87$ result which exceeded the 0.80 threshold used in achievement tests for experimental research according to Nunnally and Bernstein 1994. The test-retest reliability assessment which involved 40 students who were not part of the research sample exhibited a high correlation result of $r = 0.83$ with a p value of less than 0.01.

5.3 Procedure

Phase 1: Pre-test Administration

The two groups took the Mathematics Achievement Test (MAT) test which standardized test conditions. Pre-test scores were analysed through an independent samples t-test to confirm baseline equivalence between the groups. The pre-test was conducted one week before the intervention, which allowed enough time to reduce practice effects while maintaining the requirement that no new test content instruction could take place between the pre-test and the intervention start.

Phase 2: Intervention- Flipped Teaching (Experimental Group)

The experimental group underwent education through a structured flipped teaching plan developed specifically for this study, which included 19 lessons presented over eight weeks through Unit I: Sets (10 pre-class video lessons: L1–L10) and Unit II: Relations and Functions (9 pre-class video lessons: L1–L9). The students were given pre-class videos that lasted between 8 to 15 minutes for each lesson, which they had to watch together with a text document or power point presentation, and they needed to finish a self-assessment exercise before attending the following class. The 40-minute in-class sessions provided complete learning time provided for students to collaborate on the lesson through different activities, which consisted of peer teaching and group problem-solving and explanation exercises and peer evaluation and open-book tests and quizzes and worksheets. The in-class activities specifically targeted Bloom's Taxonomy application and analysis levels, while students completed knowledge and understanding tasks during their pre-class study time.

Phase 3: Conventional Teaching

The control group were provided instruction on the similar two units over the same eight-week period using the conventional teaching methods typically employed in the participating school. The teacher used direct instruction to teach new content which he demonstrated through worked examples on the board and assigned textbook exercises as

homework. Control Group students were not provided with video resources or pre-class preparation. The two groups received instruction from teachers who had identical qualifications and experience while both groups studied the same curriculum content through different teaching methods.

Phase 4: Post-test Administration

The mathematics achievement test (MAT) was conducted again to aforementioned two groups after they completed the eight-week intervention which included testing under standardized conditions. The post-test scores functioned as the main outcome assessment which researchers used to evaluate group differences. The two groups received identical time intervals between their pre-test and post-test evaluation to eliminate potential time-on-task effects.

6. Analysis of Data

6.1 Pre-test equivalence

Table 1 presents the descriptive statistics and t-test analysis for the pre-test scores of the experimental and control groups.

Table 1: Pre-test scores comparison

Group	N	Mean	SD	t-value	Result
Experimental	100	18.46	4.31	0.88	NS
Control	100	17.93	4.18	--	--

NS = Not Significant at $p < 0.05$

The result of independent samples t-test demonstrated no statistically significant difference between the pre-test means of the experimental group ($M = 18.46$, $SD = 4.31$) and the control group ($M = 17.93$, $SD = 4.18$), $t(198) = 0.88$. The two groups achieved equivalent mathematics performance before the intervention which verified the main requirement of the pre-test and post-test comparable group design. The differences seen in the post-test results demonstrate that H_{01} remains valid because it stems from the instructional method used.

6.2 Post-test Comparison

Table 2 represents the post-test scores comparison between the experimental group and control group following the intervention of flipped teaching.

Table 2: Post-test scores comparison

Group	N	Mean	SD	t-value	p-value	Cohen's d
Experimental	100	31.18	3.94	15.89	< 0.01	2.25
Control	100	21.84	4.96	--	--	--

The experimental group achieved a post-test mean score of 31.18 with a standard deviation of 3.94 which was higher than the control group's mean score of 21.84 and standard deviation of 4.96 according to $t(198) = 15.89$ and $p < 0.01$. The effect size $d = 2.25$ demonstrates a large effect of flipped classroom instruction. The result leads to the rejection of H_{02} .

6.3 Gain Score Analysis

Table 3 shows the gain score analysis which compares post-test results with pre-test results for both groups while providing paired t-test results that demonstrate improvements within each group.

Table 3: Gain Score and Within-Group Improvement Analysis

Group	Pre-test Mean	Post-test Mean	Mean Gain	Paired t	p-value	Cohen's d
Experimental	18.46	31.18	12.72	15.24	< 0.01	1.52
Control	17.93	21.84	3.91	5.47	< 0.01	0.55

The outcome of the within-group paired t-test demonstrated that both the experimental group and the control group showed substantial improvements from pre-test scores to post-test scores which resulted in the rejection of H_{04} and H_{05} . The Experimental Group showed an average improvement of 12.72 marks which equals 31.8 percent of the maximum score while the Control Group achieved an average improvement of 3.91 marks which equals 9.8 percent of the maximum score. The between-group comparison of gain scores confirmed this difference was highly significant $t(198) = 17.66$ $p < 0.01$ $d = 2.50$ which resulted in the rejection of H_{03} . The experimental group showed an effect size of $d = 1.52$ which exceeded three times the effect size of the control group that showed $d = 0.55$ thereby demonstrating that flipped classroom instruction produces much stronger learning gains.

6.4 Level wise Analysis

Table 4 provides a comparison among the achievement levels of the experimental and control groups for each cognitive level of Bloom's revised taxonomy.

Table 4: Post-test Performance Level wise

Cognitive Level	EG Mean	EG %	CG Mean	CG %	Max	% Diff.	t-value	Cohen's d
Knowledge	11.25	86.54%	8.79	67.61%	13	+18.93pp	7.44**	1.05
Understanding	6.42	80.25%	4.46	55.75%	8	+24.50pp	5.64**	0.80
Application	11.36	71.00%	7.42	46.38%	16	+24.62pp	13.43**	1.90
Analysis	2.15	71.67%	1.17	39.00%	3	+32.67pp	4.44**	0.63
Total (20 items, 40 marks)	31.18	77.95%	21.84	54.60%	40	+23.35pp	15.89**	2.25

The experimental group outperformed the control group at four levels of Bloom's revised taxonomy, with all differences significant at $p < 0.01$. The EG showed increased advantage at higher cognitive levels, starting from knowledge level, with 18.93 percentage points, and reaching 32.67 points at analysis level. The results demonstrate that flipped classroom instruction positively influences advanced cognitive abilities which require more effort to learn than standard lecture-based teaching methods.

6.5 Content-wise Analysis

The achievements scores are tabulated with a breakdown, as per curriculum content, in Table 5.

Table 5: Content-wise Post-test Comparison

Topic	EG Mean	EG %	CG Mean	CG %	Max	% Diff.	t-value	Cohen's d
Set Theory (10 Qs,17 marks)	13.30	78.24%	9.00	52.94%	17	+25.29pp	8.69**	1.23
Relations & Functions (10 Qs, 23 marks)	17.88	77.74%	12.84	55.83%	23	+21.91pp	17.73**	2.51
Total MAT (20 Qs,40 marks)	31.18	77.95%	21.84	54.60%	40	+23.35pp	15.89**	2.25

The experimental group demonstrated higher performance than the control group in Unit I: Sets ($t = 8.69$, $p < 0.01$; $d = 1.23$) and Unit II: Relations and Functions ($t = 17.73$, $p < 0.01$; $d = 2.51$). The two units show almost identical percentage advantages which demonstrate that flipped classroom instruction created consistent educational gains throughout the XI standard mathematics curriculum.

7. Findings of the study

The study outcomes present clear and compelling evidence. The experimental group which underwent education through flipped teaching achieved superior results against the control group across all assessment methods. The observed effect sizes exceed Cohen's (1988) large effects threshold ($d \geq 0.80$) which makes these results one of the crucial findings in mathematics education research. The flipped teaching showed an outstanding effect on gain scores which proved that students achieved higher post-test scores while their learning progressed quicker from pre-test to post-test. The pedagogy effectively produces genuine learning progress which creates measurable results for students who start with different learning abilities.

7.1 Comparison with Previous Studies

The study results demonstrate broad agreement with existing international research while showing more substantial results than comparable studies. Bhagat et al. (2016) documented significant achievement gains for flipped instruction in high school mathematics in Taiwan; the present study replicates and extends these results within the Indian XI standard curriculum. The Bloom's taxonomy-level analysis, which showed the largest experimental group advantage at the analysis level, are consistent with the theoretical framework formulated by Bergmann and Sams (2012) and formalized by Hamdan et al. (2013) because flipped classroom pre-class assignment of lower-order tasks enables students to utilize class time on their most effective knowledge acquisition activities. The consistent unit-wise advantages across sets and relations and functions further demonstrate that the model's benefits are robust and generalizable across multiple mathematical content areas.

The study results show achievement gains because multiple linked mechanisms operate to explain these results. The pre-class video format enables students to control their content learning by deciding when they will study and which parts they will review because they can pause and rewind the video content without facing social pressure to ask for material repetition from their instructor. The approach enables students to start learning activities because it reduces two main obstacles which students with mathematics anxiety face when they try to engage with content. The first method enables students to practice their learning through collaborative problem-solving activities which create multiple opportunities to master content according to Bandura (1986) who identified this as the most effective way to develop self-efficacy. The second method enables students to gain vicarious learning experiences through peer teaching and collaborative activities because they observe classmates successfully solving problems which boosts their own confidence in their abilities. The third method enables students to receive instant feedback on their performance through formative assessments which include low-stakes evaluations of their class activities that include worksheets and quizzes

and peer feedback. The mechanisms work together to create an entire instructional system which provides support to all three aspects of mathematical learning through its cognitive and affective and social learning methods.

8. Educational Implications

8.1 Classroom instructional approach

The outcomes of the study have clear practical applications for secondary-level mathematics teachers. Educators should consider creating concise, focused pre-class videos (8–12 minutes) aligned with the knowledge and understanding levels of Bloom's taxonomy, accompanied by short self-check tasks to activate prior knowledge before class. Classroom time should be reimagined as a collaborative problem-solving environment rather than a lecture hall: peer teaching, group activities, and teacher-guided practice at the application and analysis levels should replace direct instruction as the primary mode of engagement. The consistent effectiveness observed across both sets and relations and functions indicates that the flipped classroom approach is broadly transferable across XI standard mathematics topics without requiring a complete redesign for each unit.

8.2 Curriculum Integration

Curriculum developers and textbook authors could enhance XI standard mathematics materials by embedding QR codes or hyperlinks that provide access to pre-class instructional videos which will create unified resources of the flipped teaching pre-class element together by the standard curriculum materials. Exercise sets should be explicitly scaffolded according to Bloom's taxonomy which enables teachers to assign students pre-class work of lower difficulty and students to perform at higher difficulty during in-class collaborative work with only minor extra work needed from teachers. The National curriculum framework and board syllabi should officially include technology-based pre-class learning as an essential part of educational planning because it allows teachers to implement flipped classroom methods while still following official curriculum requirements.

8.3 Teacher Training

Teachers need to acquire digital video production and editing and collaborative in-class activity design and student-centred learning environment facilitation skills because flipped classroom instruction implementation requires these competencies which conventional teacher education programs do not teach. Teacher training programs for pre-service and in-service teachers need to integrate organized modules that teach flipped classroom design and implementation together with guided practice sessions and peer feedback opportunities. School administrators should support teachers by providing the necessary technological infrastructure such as internet access, video production tools, and they need to provide scheduling flexibility which enables teachers to implement the model effectively.

9. Suggestions for Further Research

- The future research requires testing in different educational institutions which design their studies based on various geographic areas and language groups and economic backgrounds to determine whether the discovered results hold true in multiple settings.
- Researchers need to conduct longitudinal research which will study how students maintain achievement gains they obtained from flipped classroom instruction during six-month and one-year periods.
- The future study needs to examine how flipped classroom instruction affects students' mathematics self-efficacy and anxiety levels and motivation while measuring their academic achievement since these two elements determine how students develop their cognitive abilities and emotional responses.
- The future research needs to identify the best design elements for pre-class videos which include the video length and video format and interactive video components and storytelling method to enhance student engagement and their academic performance during class.

- The upcoming research needs to test how effective the flipped classroom method works with students who have distinct learning requirements which include students who face challenges in mathematics and students who excel academically and learners who are the first in their families to pursue higher education.
- The future research study needs to compare two different models of flipped classroom teaching which include fully flipped classrooms and partially flipped classrooms and individual student assessment methods and peer assessment methods of pre-class study activities to help teachers create their own teaching methods for their specific school environments.

10. Conclusion

The study demonstrates that flipped classroom instruction delivers both statistically significant and practically important benefits to mathematics academic performance of XI standard secondary school students. The experimental group underwent education through flipped teaching excelled over the control group acquiring conventional teaching on the overall Mathematics Achievement Test. The experimental group achieved a gain score of 12.72 marks while the control group attained 3.91 marks resulting in an effect size of $d = 2.50$ which represents an exceptionally large effect size. The students who achieved better results on sets and relations and functions maintained their advantage throughout all four levels of Bloom's revised taxonomy yet they reached peak performance at the analysis level.

The results provide theoretical consistency which matches the expected outcomes of constructivist learning theory, participatory learning approaches and the FLIP model of teaching. The flipped classroom model achieves its purpose by moving basic cognitive tasks to the time before class starts while using classroom time for group work that requires advanced thinking skills. The classroom practice of teaching students through teacher-led lectures results in students missing out on their most important resource because they should study at home but end up handling difficult tasks without proper help from teachers.

The flipped classroom model provides a valuable instructional strategy for secondary mathematics education in India with a practical solution to current challenges which include low student achievement and high examination demands and resistance against new teaching methods. The current research establishes strong support for using flipped classroom teaching methods in XI standard mathematics because it improves student academic performance and learning experience for secondary school students in India.

Acknowledgement: We sincerely express our heartfelt gratitude to the Government of Uttar Pradesh for their generous financial support for the project entitled "Effect of Flipped Teaching on Academic Performance and Self-Efficacy of Secondary Students in Mathematics" under the Research and Development Scheme during the year 2023–24. We also extend our sincere thanks to our project team for their cooperation, and contributions, which made the successful completion of this work possible.

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