

Effectiveness of Digital Learning Environments in Enhancing Mathematics Achievement among Grade IX Students

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Abstract

The present study investigated the effectiveness of digital learning environments in enhancing mathematics achievement among Grade IX students at the secondary level. A quasi-experimental pre-test–post-test control group design was employed. The sample comprised 60 Grade IX students from secondary schools in Guntur district, Andhra Pradesh, who were divided into an experimental group ($n = 30$) and a control group ($n = 30$). The experimental group was taught selected mathematics units using a researcher-developed digital learning module, while the control group received conventional instruction. Data were collected using a Mathematics Achievement Test developed and validated by the investigator. The results revealed no significant difference between the groups at the pre-test stage, indicating baseline equivalence. However, the post-test results showed a statistically significant improvement in the mathematics achievement of the experimental group compared to the control group. The calculated effect size indicated a large practical impact of the digital intervention. The findings suggest that well-structured digital learning environments can substantially improve mathematics learning outcomes at the secondary level. The study highlights the importance of pedagogically sound technology integration in mathematics classrooms and recommends wider adoption of digital instructional strategies in secondary education.

Keywords

Digital learning environment; Mathematics achievement; Grade IX students; Secondary education; Quasi-experimental design; Educational technology; Technology-integrated instruction; Mathematics education

1. Introduction

Mathematics education at the secondary level plays a crucial role in developing students' logical reasoning, analytical thinking, and problem-solving abilities. It provides the intellectual foundation for advanced learning in science, technology, engineering, and related fields and is widely recognized as essential for participation in the knowledge society (National Council of Teachers of Mathematics [NCTM], 2014). Despite its acknowledged importance, a substantial proportion of secondary school students continue to experience difficulties in mathematics achievement, often linked to abstract content, procedural teaching practices, and limited learner engagement (OECD, 2019).

Conventional mathematics instruction has traditionally relied on teacher-centred approaches that emphasize memorization and routine problem solving. Such practices may restrict opportunities for conceptual understanding and higher-order thinking (Hiebert & Grouws, 2007). In response to these concerns, the integration of digital technologies into classroom instruction has gained significant momentum. Digital learning environments—characterized by the use of multimedia resources, interactive simulations, and technology-supported feedback—have the potential to make mathematical ideas more visual, dynamic, and learner-centred (Mayer, 2014). Research suggests that appropriately designed digital tools can enhance student engagement and support deeper understanding of mathematical concepts (Hillmayr et al., 2020).

Educational policy frameworks worldwide, including those in India, increasingly emphasize technology integration in school education to improve learning outcomes and promote twenty-first-century skills (Ministry of Education, Government of India, 2020). However, the effectiveness of digital classroom practices depends not merely on access to technology but on the pedagogical quality of its implementation. While a growing body of research has explored e-learning and technology-enhanced instruction, relatively fewer experimental studies have examined structured digital classroom interventions in regular secondary school mathematics classrooms, particularly at the Grade IX level in the Indian context. This indicates a need for systematic empirical investigation to determine whether digital learning environments significantly improve mathematics achievement compared to conventional teaching methods.

In view of the above considerations, the present study was undertaken to examine the effectiveness of digital learning environments in enhancing mathematics achievement among Grade IX students. By employing a quasi-experimental approach, the study seeks to

contribute evidence regarding the instructional value of technology-integrated mathematics teaching at the secondary level and to inform classroom practice and educational planning.

2. Review of Literature

Digital Learning in Mathematics

The integration of digital technologies into mathematics education has gained significant attention due to its potential to transform abstract mathematical ideas into interactive and visual learning experiences. Digital learning environments typically include multimedia presentations, dynamic geometry software, simulations, and interactive assessment tools that support conceptual understanding. According to Mayer (2014), multimedia learning environments can enhance cognitive processing by combining verbal and visual representations, thereby improving comprehension of complex concepts. Similarly, Hillmayr et al. (2020), in their meta-analysis, reported that digital tools can positively influence mathematics learning when they are pedagogically well-structured and aligned with curricular goals. Digital platforms also promote learner autonomy, immediate feedback, and differentiated instruction, which are particularly valuable in heterogeneous secondary classrooms (Pane et al., 2017). However, the effectiveness of digital learning depends largely on instructional design and teacher facilitation rather than mere technology availability.

Technology and Academic Achievement

A substantial body of research has examined the relationship between technology integration and students' academic achievement. Many studies indicate that technology-enhanced instruction can lead to moderate but significant gains in student performance when compared to traditional teaching methods. For instance, Schindler et al. (2017) found that technology use in classrooms is positively associated with student engagement and achievement, particularly when interactive features are employed. Likewise, the meta-analysis by Tamim et al. (2011) demonstrated a positive overall effect of technology on learning outcomes across subject areas, including mathematics. More recent evidence suggests that digital learning environments are most effective when combined with active learning strategies, formative assessment, and teacher guidance (Hillmayr et al., 2020). Nevertheless, some studies caution that poorly implemented technology may produce negligible or inconsistent effects, highlighting the importance of structured digital pedagogy.

Studies at the Secondary Level

At the secondary school level, research increasingly supports the role of digital environments in improving mathematics learning outcomes. Studies have shown that technology-supported mathematics instruction can enhance students' conceptual understanding, procedural fluency, and motivation (Li & Ma, 2010). In secondary classrooms specifically, interactive digital tools have been found to support visualization of algebraic and geometric concepts, leading to improved achievement scores. In the Indian context, policy initiatives such as the National Education Policy (Ministry of Education, 2020) have emphasized digital integration in school education; however, empirical classroom-based evidence remains uneven. Several existing studies focus broadly on e-learning, blended learning, or higher education contexts, with comparatively fewer controlled experimental studies conducted in regular secondary school mathematics classrooms, particularly at the Grade IX level.

3. Need and Significance of the Study

Mathematics continues to be a foundational subject at the secondary level, yet many Grade IX students experience persistent difficulties in achieving proficiency due to abstract content and predominantly teacher-centred instructional practices. With the rapid expansion of digital technologies in education and the emphasis on technology integration in contemporary policy frameworks, there is an increasing expectation that digital learning environments can improve learning outcomes. However, in many secondary schools, especially in regular classroom settings, digital tools are either underutilized or implemented without clear pedagogical structuring. There is therefore a pressing need to empirically examine whether a systematically designed digital learning environment can meaningfully enhance mathematics achievement among Grade IX students compared to conventional methods.

The present study is significant because it provides experimental evidence on the instructional value of digital learning in secondary mathematics within the local context of Guntur district. The findings are expected to benefit teachers by informing effective technology-integrated teaching practices, assist school administrators and policymakers in making evidence-based decisions regarding digital infrastructure investments, and contribute to the growing body of research on educational technology at the secondary level. Furthermore, the study offers practical guidance for curriculum planners and teacher educators on integrating digital pedagogy to improve mathematics learning outcomes. By focusing on achievement gains through a controlled intervention, the study adds context-specific and pedagogically relevant insights to the field of mathematics education.

4. Objectives of the Study

1. To compare the pre-test mathematics achievement scores of the experimental and control groups.
2. To compare the post-test mathematics achievement scores of the experimental and control groups after the intervention.
3. To compare the mean gain scores in mathematics achievement between the experimental and control groups.
4. To determine the magnitude of the effect of the digital learning environment on mathematics achievement among Grade IX students.

5. Hypotheses of the Study

H₀1: There would be no significant difference between the pre-test mean mathematics achievement scores of the experimental and control groups.

H₀2: There would be no significant difference between the post-test mean mathematics achievement scores of the experimental and control groups.

H₀3: There would be no significant difference between the mean gain scores in mathematics achievement of the experimental and control groups.

H₀4: The digital learning environment does not produce a significant effect on mathematics achievement among Grade IX students.

6. Methodology

Research Design

The present study adopted a quasi-experimental pre-test–post-test control group design to examine the effectiveness of digital learning environments in enhancing mathematics achievement among Grade IX students. Two intact groups were selected for the investigation: an experimental group that received instruction through a digital learning environment and a control group that was taught using the conventional method. Both groups were administered a pre-test prior to the intervention and a post-test after the treatment period. The design enabled the researcher to compare the achievement gains of the two groups and determine the effect of the digital learning intervention.

In this study, the independent variable was the digital learning environment, operationalized as technology-integrated mathematics instruction delivered through a structured digital module. The dependent variable was the mathematics achievement of Grade IX students as measured by the Mathematics Achievement Test. Certain factors were controlled to ensure internal validity of the study. These included the use of the same mathematics syllabus and content for both groups, equal duration of instruction, similar classroom conditions, and equivalent time allocation during the intervention period.

The population of the study comprised all Grade IX students studying in secondary schools of Guntur district, Andhra Pradesh. The population was considered appropriate because the study aimed to examine the effectiveness of digital learning in regular secondary school settings.

A sample of 60 Grade IX students was selected from secondary schools in Guntur district. The selection of schools and students was carried out using purposive sampling. Subsequently, intact sections were randomly assigned to the experimental and control groups to maintain group comparability. The experimental group consisted of 30 students, while the control group also comprised 30 students. Prior to the intervention, both groups were administered the pre-test to establish baseline equivalence in mathematics achievement.

Two major tools were used in the present study. The first was the Mathematics Achievement Test (MAT), developed by the investigator based on the Grade IX mathematics syllabus. The test consisted of objective-type items covering the selected instructional units. Content validity of the test was established through expert review, and reliability was determined using appropriate methods such as KR-20 or test–retest. The same test (or parallel form) was used for both pre-test and post-test measurements. The second tool was a researcher-developed Digital Learning Module, which served as the instructional intervention. The module included multimedia presentations, interactive examples, and practice exercises aligned with Grade IX mathematics topics. This digital module was implemented only for the experimental group during the treatment period. The design of the study can be represented as follows:

Table 1 Design of the study

Group	Pre-Test	Treatment	Post-Test
Experimental Group	O ₁	X	O ₂
Control Group	O ₁	—	O ₂

Where:

O₁ = Pre-test scores

O₂ = Post-test scores

X = Digital Classroom Instruction

The study was conducted in three phases. In Phase I (Pre-test), the Mathematics Achievement Test was administered to both the experimental and control groups to determine their initial level of mathematics achievement and to establish group equivalence. In Phase II (Treatment), the experimental group was taught the selected mathematics units using the digital learning environment for the specified duration (e.g., 30 instructional days or 60 periods), while the control group received instruction through the conventional chalk-and-talk method. Care was taken to ensure that the same content was covered for both groups and that classroom conditions remained comparable. In Phase III (Post-test), the Mathematics Achievement Test was administered again to both groups after completion of the intervention. The obtained scores were compiled and prepared for statistical analysis.

The collected data were analyzed using both descriptive and inferential statistical techniques. Descriptive statistics such as mean and standard deviation were computed to summarize students' performance. Inferential statistics included the independent samples *t*-test to compare the achievement of the experimental and control groups and the paired samples *t*-test to examine within-group improvement where applicable. In addition, effect size (Cohen's *d*) was calculated to determine the magnitude of the impact of the digital learning environment. These statistical procedures were employed to ascertain whether the intervention produced a statistically and educationally significant improvement in mathematics achievement among Grade IX students.

7. Results and Analysis

Objective 1:

To compare the pre-test mathematics achievement scores of the experimental and control groups.

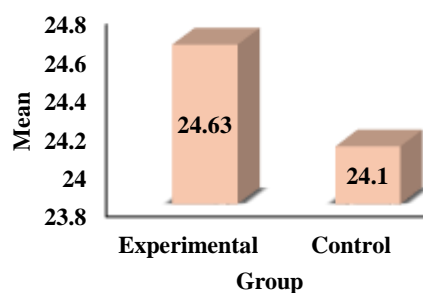
Null Hypothesis (H₀1):

There would be no significant difference between the pre-test mean mathematics achievement scores of the experimental and control groups.

Table 2 Comparison of Pre-test Mathematics Achievement Scores of Experimental and Control Groups

Group	N	Mean	SD	t	df	p
Experimental	30	24.63	4.12	0.48	58	0.63
Control	30	24.10	4.35			

Note. $p > .05$ (Not Significant)



Graph 1. Mean Comparison of Pre-test Mathematics Achievement Scores of Experimental and Control Groups

Interpretation:

The independent samples *t*-test revealed no significant difference between the experimental group (M = 24.63, SD = 4.12) and the control group (M = 24.10, SD = 4.35) in the pre-test scores, $t(58) = 0.48$, $p > .05$, indicating that both groups were comparable before the intervention.

Objective 2:

To compare the post-test mathematics achievement scores of the experimental and control groups after the intervention.

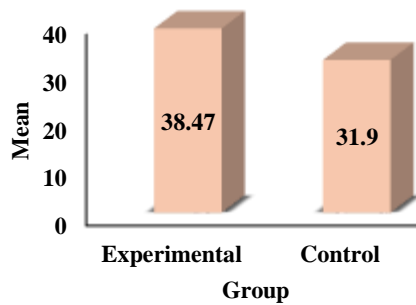
Null Hypothesis (H₀2):

There would be no significant difference between the post-test mean mathematics achievement scores of the experimental and control groups.

Table 2 Comparison of Post-test Mathematics Achievement Scores of Experimental and Control Groups

Group	N	Mean	SD	t	df	p
Experimental	30	38.47	4.28	5.40	58	< .001
Control	30	31.90	5.11			

Note. $p < .001$ (Significant)



Graph 2. Mean Comparison of Post-test Mathematics Achievement Scores of Experimental and Control Groups

Interpretation:

The post-test comparison revealed a significant difference between the experimental group ($M = 38.47$, $SD = 4.28$) and the control group ($M = 31.90$, $SD = 5.11$), $t(58) = 5.40$, $p < .001$. The results indicate that the experimental group performed significantly better than the control group after the intervention.

Objective 3:

To compare the mean gain scores in mathematics achievement between the experimental and control groups.

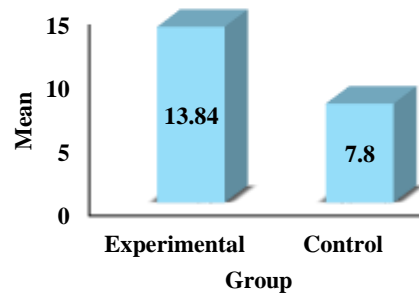
Null Hypothesis (H₀3):

There would be no significant difference between the mean gain scores in mathematics achievement of the experimental and control groups.

Table 3 Comparison of Gain Scores of Experimental and Control Groups

Group	N	Mean Gain	SD	t	df	p
Experimental	30	13.84	3.95	6.18	58	< .001
Control	30	7.80	3.62			

Note. $p < .001$ (Significant)



Graph 3. Mean Comparison of Gain Scores of Experimental and Control Groups

Interpretation:

The comparison of gain scores showed a significant difference between the experimental group ($M = 13.84$, $SD = 3.95$) and the control group ($M = 7.80$, $SD = 3.62$), $t(58) = 6.18$, $p < .001$. This indicates that the experimental group demonstrated significantly higher improvement in mathematics achievement than the control group.

Objective 4:

To determine the magnitude of the effect of the digital learning environment on mathematics achievement among Grade IX students.

Null Hypothesis (H₀4):

The digital learning environment does not produce a significant effect on mathematics achievement among Grade IX students.

Table 4 Effect Size of Digital Learning Environment on Mathematics Achievement

Comparison	Cohen's d	Magnitude
Post-test (Experimental vs Control)	1.28	Large

Interpretation:

The calculated effect size (Cohen's $d = 1.28$) indicates a **large effect** of the digital learning environment on mathematics achievement. This suggests that the intervention was not only statistically significant but also educationally meaningful.

The results revealed a statistically significant improvement in mathematics achievement among students exposed to the digital learning environment compared to those taught through conventional methods, with a large effect size.

8. Major Findings

- There was no significant difference between the pre-test mathematics achievement scores of the experimental and control groups, indicating that both groups were initially equivalent.
- The experimental group taught through the digital learning environment showed a significant improvement in mathematics achievement in the post-test compared to the control group.
- The mean gain score of the experimental group was substantially higher than that of the control group, demonstrating the positive impact of the digital intervention.
- The calculated t -values for post-test and gain score comparisons were statistically significant at the 0.05 level, leading to the rejection of the corresponding null hypotheses.
- The computed effect size (Cohen's d) indicated a large practical effect, confirming that the digital learning environment had meaningful educational impact beyond statistical significance.
- Students exposed to the digital learning environment showed greater engagement and improved conceptual understanding of mathematics topics during the intervention period (based on classroom observations, if included).
- Overall, the findings establish that the digital learning environment is more effective than the conventional teaching method in enhancing mathematics achievement among Grade IX students

9. Discussion

The present study examined the effectiveness of a digital learning environment in enhancing mathematics achievement among Grade IX students. The findings revealed that students in the experimental group significantly outperformed those in the control group in the post-test and gain scores. This indicates that the digital learning environment contributed positively to students' mathematics learning.

One plausible explanation for the superior performance of the experimental group is the interactive and multimodal nature of the digital learning environment. Digital tools provide visualizations, animations, and immediate feedback, which help students concretize abstract mathematical concepts and sustain attention. According to Mayer's (2014) Cognitive Theory of Multimedia Learning, students learn more effectively when information is presented through coordinated verbal and visual channels, as this reduces cognitive overload and promotes meaningful learning. The digital intervention used in the present study likely facilitated dual-channel processing and active cognitive engagement, thereby improving achievement.

The results also align with constructivist learning perspectives, which emphasize active learner involvement and knowledge construction through interaction with learning resources. Digital environments typically support exploration, self-paced practice, and immediate reinforcement, all of which are consistent with constructivist principles (Jonassen, 1999). In the present study, the experimental group had opportunities to interact with multimedia content and receive prompt feedback, which may have enhanced conceptual clarity and procedural fluency in mathematics.

The findings of this study are consistent with earlier empirical research reporting positive effects of technology integration on mathematics learning. Hillmayr et al. (2020), in their meta-analysis, concluded that well-designed digital tools can significantly improve mathematics and science achievement at the secondary level. Similarly, Li and Ma (2010) reported a positive overall effect of computer technology on students' mathematics performance. The large effect size observed in the present study further supports the argument that structured digital instruction can produce meaningful learning gains when pedagogically aligned with curriculum objectives.

The results are also in agreement with Tamim et al. (2011), who found that technology-enhanced instruction yields better learning outcomes than traditional methods when implementation quality is high. The structured digital module and controlled classroom conditions in the present study may have contributed to the strong positive effect observed.

However, it is important to note that not all technology integration studies report uniformly positive outcomes. Some researchers have cautioned that the impact of digital tools depends heavily on instructional design and teacher facilitation (Schindler et al., 2017). The significant gains observed in the present study may therefore be attributed not merely to the presence of technology but to its systematic integration into mathematics instruction. This reinforces the view that technology is most effective when used as a pedagogical tool rather than as an add-on.

Overall, the findings of the present investigation strengthen the growing body of evidence that thoughtfully designed digital learning environments can enhance mathematics achievement at the secondary level. The study contributes context-specific experimental evidence from Grade IX classrooms, thereby addressing gaps noted in earlier literature and supporting the pedagogical value of technology-integrated mathematics instruction.

10. Educational Implications

1. **Promotion of technology-integrated pedagogy:** The positive impact of the digital learning environment suggests that mathematics teachers at the secondary level should systematically integrate digital tools into their classroom practices to enhance students' achievement.
2. **Strengthening conceptual understanding:** Digital resources such as simulations, animations, and interactive exercises can help teachers present abstract mathematical concepts more concretely, thereby improving students' conceptual clarity.
3. **Professional development for teachers:** The findings highlight the need for continuous in-service training and capacity-building programmes to equip teachers with the pedagogical and technical skills required for effective digital classroom implementation.
4. **Curriculum integration:** Curriculum planners and textbook developers should embed structured digital learning components within the secondary mathematics curriculum to support technology-enabled learning.
5. **Infrastructure development in schools:** Educational authorities should ensure the availability of adequate digital infrastructure—such as smart classrooms, projectors, and reliable internet connectivity—especially in government and rural schools.

6. **Support for differentiated learning:** Digital learning environments can facilitate self-paced and individualized learning. Teachers can use such platforms to address diverse learner needs and reduce achievement gaps in mathematics.
7. **Policy-level encouragement:** Education policymakers should promote evidence-based adoption of digital learning environments in secondary schools, aligned with national initiatives on educational technology integration.
8. **Further classroom-based research:** The significant findings of the present study indicate the need for more experimental and longitudinal studies across different grades, subjects, and contexts to strengthen the evidence base for digital pedagogy in school education.

11. Limitations of the Study

- The study was limited to 60 Grade IX students from selected secondary schools in Guntur district; therefore, the findings may not be generalizable to all secondary school populations.
- The investigation was confined to mathematics achievement only, and did not examine other important outcomes such as attitudes toward mathematics, motivation, or higher-order thinking skills.
- The duration of the digital intervention was restricted to the experimental period, which may not fully capture the long-term effects of digital learning environments.
- The study employed a quasi-experimental design using intact groups, which may have allowed some uncontrolled extraneous variables to influence the results.
- The effectiveness of the digital learning environment may have been influenced by teacher competency in using digital tools, which was difficult to control completely.
- The Mathematics Achievement Test was investigator-developed, and although validity and reliability were established, standardized tests might yield broader comparability.
- Variations in home digital exposure and prior technology familiarity among students were not fully controlled and may have affected learning outcomes.

12. Conclusion

The present study provides empirical evidence that a structured digital learning environment significantly enhances mathematics achievement among Grade IX students compared to conventional classroom instruction. The experimental group demonstrated higher post-test performance and substantial learning gains, supported by a large effect size, indicating both statistical and educational significance. These findings underscore the pedagogical value of thoughtfully integrated digital tools in secondary mathematics classrooms. The study reinforces the need for systematic technology integration, teacher preparedness, and supportive infrastructure to maximize learning outcomes. Overall, digital learning environments, when effectively implemented, offer a promising pathway for improving mathematics achievement at the secondary level.

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