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Impact of ICT Integration on Students' Geometry Performance across Cognitive Domains

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Abstract

This study investigates the effects of Information and Communication Technology (ICT) integration on students' geometry performance across different cognitive levels. Using a pretest-posttest design, 157 students' geometry scores were analyzed across four cognitive domains: knowledge, understanding, application, and higher-order thinking abilities. Analysis of Variance (ANOVA) was employed to determine significant differences between groups before and after ICT integration. Results revealed statistically significant improvements in overall geometry scores after ICT implementation ($p < .001$). Specifically, knowledge-level tasks showed the most dramatic improvement ($p < .001$), followed by higher-order thinking abilities ($p = .007$). Understanding-level performance showed statistically significant but smaller improvements ($p = .011$), while application-level tasks showed no statistically significant change ($p = .332$). These findings suggest that ICT integration has differential effects across cognitive domains, with particular benefits for foundational knowledge acquisition and higher-order thinking skills. Implications for educational practice and future research are discussed, highlighting the importance of targeted ICT implementation strategies aligned with specific cognitive learning objectives.

Keyword: Cognitive domain, geometry, information communication technology

Introduction

Geometry education presents unique challenges for both educators and students. The abstract nature of geometric concepts, spatial reasoning requirements, and the need to connect visual representations with formal mathematical principles make geometry a particularly challenging subject for many students (Clements & Battista, 1992). In recent decades, Information and Communication Technology (ICT) has emerged as a potential solution to enhance mathematics education broadly, and geometry instruction specifically

(Gómez-Chacón et al., 2016). In the case of availability of ICT tools and internet facilities with teachers Ghimire, S. P., & Paudel, K. C. (2025) found that sixty percent of the teachers have an internet connection in their home in at least one of their devices.

The integration of ICT tools in geometry education offers numerous potential methods, including interactive visualizations, dynamic manipulations, and immediate feedback. Digital tools can transform static geometric figures into dynamic objects that students can manipulate, allowing them to explore geometric properties and relationships in ways impossible with traditional paper-and-pencil methods (Hohenwarter & Jones, 2007). This capability aligns well with constructivist learning theories, which emphasize the importance of active student engagement in building mathematical understanding (Duffy & Cunningham, 1996). Despite the theoretical promise of ICT integration, empirical evidence regarding its effectiveness remains mixed and often fails to differentiate impacts across cognitive domains (Drijvers et al., 2016). While some studies report significant positive effects (Zengin et al., 2012), others find minimal or contextually dependent impacts (Li & Ma, 2010). This inconsistency highlights the need for more nuanced research examining how ICT influences different aspects of geometric thinking and learning.

Process of Geometry Learning in Cognitive Levels

Bloom's revised taxonomy (Anderson et al., 2001) provides a useful framework for analyzing mathematics learning across cognitive levels. In the context of geometry education, these levels can be categorized as: Recalling geometric definitions, properties, theorems, and formulas falls under knowledge level, whereas comprehending the geometric concepts and relationships, interpretation of geometric diagram and explaining the concepts occurs in understanding level. Similarly, the application level in geometry is the use of geometric knowledge to solve routine problems in the similar context. Similarly, in the higher ability level students have to analyze the complex geometric situations, evaluating different approaches, and creating solutions to the problems. Research suggests these cognitive domains may be differentially affected by instructional interventions (Watson & De Geest, 2005). However, few studies have systematically examined how ICT integration specifically impacts performance across these different cognitive levels in geometry education.

Objectives of the Study

The present study aims to address this gap by investigating the following objectives:

- To determine the overall impact of ICT integration on students' geometry performance
- To analyze the differential effects of ICT integration across four cognitive domains: knowledge, understanding, application, and higher ability.

Limitations

Due to different constraints of the research, this study was concentrated in the usual classroom instruction with ICT integration. It is one of the quasi-experimental research designs. As this was a study on social sciences research, this research was conducted at the 95% confidence level. All the confounding variables, such as teachers' effects, prior technology experience, or specific ICT tools used, were minimized completely. This study was conducted over the duration of 45 periods, including different tests and covering all the geometry lessons prescribed by the curriculum. The long-term effects of the use of ICT were not controlled.

Review of Related Literature

The researcher reviewed the different literature based on the research findings on the impact of ICT use in learning geometry. The potential of ICT to transform mathematics education has been widely recognized. Drijvers et al. (2010) identified three primary functions of technology in mathematics learning: (1) performing routine procedures, (2) developing conceptual understanding, and (3) solving authentic problems. Each function may influence different cognitive aspects of mathematical proficiency (Kilpatrick et al., 2001). Meta-analyses by Li and Ma (2010) and Cheung and Slavin (2013) found moderate positive effect of technology integration on mathematics achievement, with effect sizes ranging from 0.28 to 0.45. However, these studies also revealed significant variability in outcomes based on implementation factors, student characteristics, and content domains. Geometry presents unique opportunities for technology integration due to its visual nature. Dynamic geometry environments (DGEs) such as GeoGebra, Cabri Geometry, and Geometer's Sketchpad allow students to create, manipulate, and transform geometric figures while observing invariant properties (Hollebrands, 2007). These environments can bridge the gap between empirical exploration and formal deduction, which is a central challenge in geometry education (Marrades & Gutiérrez, 2000). Research by Arzarello et al. (2002) and Laborde (2001) demonstrated how DGEs can support the transition from perceptual to theoretical understanding in geometry. By allowing students to test conjectures through dynamic manipulations, these tools create opportunities for developing both intuitive understanding and formal reasoning.

Research examining the cognitive impacts of technology integration has produced varied results. Chan and Leung (2014) conducted a meta-analysis focusing specifically on dynamic geometry software and found stronger effects for conceptual understanding ($d = 0.65$) than for procedural skills ($d = 0.48$). Similarly, Bray and Tangney (2017) reported that technology-based interventions showed larger effects for higher-order thinking than for basic computational skills. However, other studies have found more complex relationships. Kieran and Drijvers (2006) observed that technology use sometimes enhanced conceptual understanding but could also potentially diminish basic skills if not carefully implemented.

Olive and Makar (2010) argued that technology's impact depends on how it transforms the mathematical activity and whether it creates opportunities for meaningful mathematical thinking across cognitive levels.

While existing research provides valuable insights into the possible benefits of the use of ICT in mathematics education, several limitations exist in the current literature: Few studies systematically examine the differential impacts of ICT across specific cognitive domains within a single mathematical content area. Many studies focus on either basic skills or problem-solving, without considering the cognitive levels. There were sufficient researches on the effect of ICT in mathematics learning and teaching but limited research exists on how ICT integration might differentially affect various cognitive aspects of geometry learning specifically, the present study addresses these gaps by examining how ICT integration influences geometry performance across four distinct cognitive domains, providing a deep understanding of concept where and how technology can most effectively support geometry learning.

Methods and Materials

This section deals with the details of methods and procedures for the analysis of numerical data collected from the pretest and posttest of the students of grade IX in four purposively selected schools of Kathmandu district. This chapter also contains the research design, research tools, sampling procedures, and analysis procedures.

This study employed a quasi-experimental pretest-posttest design to investigate the effects of ICT integration on students' geometry performance across different cognitive levels. The research was conducted in a natural classroom setting, with measurements taken before and after the implementation of ICT-enhanced geometry instruction. In this study**,** there were 157 students (N = 157) enrolled in the mathematics classes of selected four schools of Kathmandu district. Researcher has conducted the experiment in geometry lessons of compulsory mathematics as prescribed by the existing curriculum of grade IX of Nepal (MoE,2015) of Nepal. The recommended lessons in geometry were preliminary concept of geometry, triangle and its properties, parallelogram and its properties, similarity, and the relations between the areas of plane figures were included in the geometry part of compulsory mathematics course. Out of selected four schools of Kathmandu district, taken as sample of the study including two community and two institutional schools. Further, these schools were divided in two schools (one community, one institutional) were selected for experiment where as other two schools were selected for control group. All the students of grade IX of respective schools were selected for sample by census method. Participants drawn from different schools of grade IX is presented in the descriptive statistics table to ensure adequate sample size and representation.

Table 1.
Descriptive Statistics of the Sampled School Type

Schools Types	No. of Students
Public Schools	53
Institutional Schools	104
Experiment Group	71
Control Group	86

Tools for Data Collection

For the collection of necessary data, different research tools were applied in systematic order. The construction of tools and its validation procedures are mentioned as:

Geometry Achievement Test (GAT)

A comprehensive geometry achievement test containing 40 items in each of the pretest and posttest were included in the GAT. The test items were parallel with correlation coefficient 0.97 (similar difficulty levels and same content areas) were constructed in the achievement test. The test items were validated with expert judgement and item analysis. The items with item difficulty level (P-value) 30% to 70% and item discrimination index (D-value) 0.30 to 0.70 were selected for the final test by using formula $P=\frac{U_R+L_R}{U_n+L_n}\times 100\%$ (Singh, 2006, p.47-55) and $D=\frac{U_R-L_R}{U_n \text{ or } L_n}$ (Ebel, 1979). The GAT was developed to measure student performance across different cognitive domains. The assessment included four sections specifically designed to evaluate: the items testing recall of geometric definitions properties and formulas (Knowledge level), items requiring interpretation of geometrical relationship and concepts (Understanding level), items involving the use of geometric principles to solve the similar problems (Application level), and the items requiring analysis, evaluation and creation new relations in geometric concept (higher ability level). The achievement test was administered to both groups: Experiment and control. A pretest (before using ICT integration) and a posttest (after using ICT integration). The Content validity was established through expert review, and reliability was assessed using Cronbach's alpha reliability coefficient with value 0.768.

Process of Intervention

To identify the effectiveness of students' performance in geometry, the intervention consisted of geometry instruction enhanced with appropriate ICT tools. The ICT integration included. Dynamic geometry software, such as GeoGebra, allows for interactive exploration of geometric concepts. Further, the digital visualization tools such as: animated geometric figures were used to enhance spatial understanding of students. Similarly, online assessment platforms such as GeoGebra classroom and Google Classroom were used for immediate feedback. The collaborative digital environments were used for supporting students to enhance their geometrical concept. The intervention was implemented for 45 periods including pre-test and posttest. This was the sufficient time period to cover the geometric content of grade IX as prescribed by curriculum of secondary level.

Methods and Materials

For the collection of data, researcher has prepared an achievement test items based on the four levels of cognitive domain as recommended by curriculum of secondary level of Nepal. The test items were validated with the expert judgements consulting 15 experts including university professors, school teachers, and curriculum designers. The suggestion and feedback provided by the experts were incorporated and finalize the test item. Further, to determine the items consistency of test item, item analysis has done with pilot test in one of the community school, which is not in sample. The items were finalized with the basis of items analysis indices. The final achievement test was used for pretest and posttest.

The scores of students obtained in the test pretest and posttest (i.e before using ICT and after using ICT) were analyzed . The Scores were calculated for overall performance and for each cognitive domain (knowledge, understanding, application, and higher ability level). The One-way Analysis of Variance (ANOVA) was employed to examine differences between groups. The researcher analyzes the overall geometry scores obtained in pretest and posttest Further, the data were analyzed based on the students' scores obtained by the students in four levels of cognitive domain such as knowledge, understanding, application and higher ability. The inferential statistics was used to determine the effect of ICT at 0.05 level of significance.

Results and Discussion

The following table represent the descriptive statistics of pretest scores. In the analysis of pretest data shows the initial status of students before interventions.

Table 2.

Descriptive Statistics of the Pretest scores in different cognitive levels

Level of cognitive domains	N	Minimum	Maximum	Mean	Std. Deviation
Score in Knowledge for Pretest	157	2	10	5.86	2.272
Score in Understanding for Pretest	157	1	10	5.03	2.066
Score in Application for Pretest	157	1	10	4.80	1.930
Score in Higher Ability for Pretest	157	0	9	4.36	2.044

From the above descriptive statistics table the highest performance of students were found in knowledge as (Mean = 5.86, SD.= 2.72) whereas the lowest mean score was found in higher ability (Mean 4.36 , SD = 2. 044). The inferential statistics based on the ANOVA were presented in the following table.

The following table represent the analysis of data based on overall scores and scores in different levels of cognitive levels. The following table 3 presents the complete analysis of variance (ANOVA) results for geometry scores across different cognitive levels before using ICT (Pretest) and after using ICT (Posttest).

Table 3.

Analysis of Variance (ANOVA) of Geometry Scores Based on Cognitive Levels Before Using ICT (Pretest) and After Using ICT (Posttest)

Variable	Source	Sum of Squares	df	Mean Square	F	Sig.
Scores in Pretest	Between Groups	209.038	1	209.038	6.565	.011*
	Within Groups	4935.650	155	31.843		
	Total	5144.688	156			
Scores in Posttest	Between Groups	503.413	1	503.413	15.179	.000*
	Within Groups	5140.651	155	33.165		
	Total	5644.064	156			

Note. *Analyzed by Using SPSS 27 With 0.05 level of significance,*

** represent the significant in 0.-5 level of significance.*

From the Table 3, the overall geometry scores revealed the test of significance between the pretest and posttest performance of students before and after the use of ICT.

Better would be to describe the features (means) before going for ANOVA test or F-test.

Pretest Scores. The ANOVA results showed a significant difference between groups in pretest scores (F = 6.565, df = 1, p = .011). The between-groups sum of squares was 209.038, with a mean square of 209.038, while the within-groups sum of squares was 4935.650 (df = 155), with a mean square of 31.843. whereas the analysis of

Posttest Scores. Students in geometry between-groups difference increased substantially (F = 15.179, df = 1, p < .001). The between-groups sum of squares was 503.413, with a mean square of 503.413, compared to within-groups sum of squares of 5140.651 (df = 155) and a mean square of 33.165. The increase in the F-value from pretest (6.565) to posttest (15.179) indicates a more pronounced difference between groups after

ICT integration. This finding suggests that ICT-enhanced instruction had a substantial positive impact on overall geometry performance, aligning with previous research by Zengin et al. (2012) who found significant improvements in mathematics achievement following technology integration

Table 4.

Analysis of Variance (ANOVA) Based on Pretest and Posttest Scores Under Knowledge Level

Cognitive Level	Source	Sum of Scores	df	Mean Square	F	Sig.
Score in Knowledge for Pretest	Between Groups	0.401	1	0.401	0.077	.781
	Within Groups	804.516	155	5.190		
	Total	804.917	156			
Score in Knowledge for Posttest	Between Groups	86.003	1	86.003	29.578	.000*
	Within Groups	450.685	155	2.908		
	Total	536.688	156			

***Note*. Analyzed by using SPSS 27 with 0.05 level of significance**

From the above table, the analysis of students performance before and after the use of ICT is observed in the knowledge of students in Geometry.

Analysis of Pretest Knowledge Scores

There is no significant difference was observed between groups in knowledge-level performance before ICT integration (F = 0.077, df = 1, p = .781). The between-groups sum of squares was merely 0.401, with a mean square of 0.401, while the within-groups sum of squares was 804.516 (df = 155), with a mean square of 5.190.

Analysis of Posttest Knowledge Scores

From the analysis of above table ICT integration, a highly significant difference emerged between groups (F = 29.578, df = 1, p < .001). The between-groups sum of squares increased dramatically to 86.003, with a mean square of 86.003, compared to the within-groups sum of squares of 450.685 (df = 155) and a mean square of 2.908. This finding represents the most substantial improvement among all cognitive domains, with the F-value increasing from a non-significant 0.077 to a highly significant 29.578. This dramatic improvement suggests that ICT tools are particularly effective for enhancing basic knowledge acquisition in geometry. This may be attributed to the ability of digital tools to provide clear visualizations of geometric concepts, interactive demonstrations of properties, and immediate feedback on basic knowledge-level tasks, as suggested by Hohenwarter and Jones (2007).

Table 5.

Analysis of Variance (ANOVA) Based on Pretest and Posttest Scores Under Understanding Level

Cognitive Level	Source	Sum of Scores	df	Mean Square	F	Sig.
Score in Understanding for Pretest	Between Groups	63.791	1	63.791	16.422	.000*
	Within Groups	602.107	155	3.885		
	Total	665.898	156			
Score in Understanding for Posttest	Between Groups	23.774	1	23.774	6.546	.011*
	Within Groups	562.926	155	3.632		
	Total	586.701	156			

Note. *Analyzed by using SPSS 27, * represents significance in the 0.05 level of significance*

Pretest for Understanding Scores

From the analysis in Table 3, the significant differences existed between groups in understanding-level performance before ICT integration ($F = 16.422$, $df = 1$, $p < .001$). The scores between-groups sum of squares was 63.791, with a mean square of 63.791, while the within-groups sum of squares was 602.107 ($df = 155$), with a mean square of 3.885. Similarly, in the analysis of posttest scores the following Table gives the descriptive statistics of the posttest scores in cognitive levels.

Table 6.

Descriptive Statistics of the Posttest Scores in Different Cognitive Levels

Levels of Cognitive domain	N	Minimum	Maximum	Mean	Std. Deviation
Scores in Knowledge level	157	3	10	7.04	1.855
Scores in Understanding Level	157	1	10	6.12	1.939
Scores in Application level	157	0	10	6.24	2.274
Score in Higher Ability	157	0	10	5.38	2.249

Posttest Understanding Scores

From the above descriptive statistics table, the mean scores of the students in each of the cognitive domain were increases in the comparison of pretest. The highest mean scores were found in knowledge level (Mean 7.04 and SD 1.855) and the lowest mean scores were found in higher ability with (Mean 5.38 and SD 2.249). This shows that the interventions have more effective to change in knowledge and application level whereas intervention has low effect in higher ability level. Further, analysis is found in the following ANOVA table

After ICT integration, the difference between groups remained significant but decreased in magnitude (F = 6.546, df = 1, p = .011). The between-groups sum of squares decreased to 23.774, with a mean square of 23.774, compared to a within-groups sum of squares of 562.926 (df = 155) and a mean square of 3.632. The decrease in F-value from 16.422 to 6.546, while still maintaining statistical significance, presents an interesting pattern. This might suggest that while ICT integration continues to support understanding-level performance, its relative advantage compared to traditional methods may be less pronounced in this domain than in others. This aligns with research by Laborde (2001), who noted that conceptual understanding in geometry requires a complex integration of visual and theoretical thinking that may benefit from, but is not solely dependent on, technological support.

Table 7.

Analysis of Variance (ANOVA) Based on Pretest and Posttest Scores Under Application Level

Cognitive Level	Source	Sum of Scores	df	Mean Square	F	Sig.
Score in Application for Pretest	Between Groups	9.264	1	9.264	2.512	.115
	Within Groups	571.615	155	3.688		
	Total	580.879	156			
Score in Application for Posttest	Between Groups	4.908	1	4.908	0.949	.332
	Within Groups	801.895	155	5.174		
	Total	806.803	156			

Note. *Analyzed by using SPSS 27 with 0.05 level of significance*

Pretest Application Scores

In the analysis of above Table, there is no significant difference was observed between groups in application-level performance before ICT integration (F = 2.512, df = 1, p = .115). The between-groups sum of squares was 9.264, with a mean square of 9.264, while the within-groups sum of squares was 571.615 (df = 155), with a mean square of 3.688.

Posttest Application Scores

From the above table, following ICT integration, the difference between groups remained non-significant (F = 0.949, df = 1, p = .332). The between-groups sum of squares decreased to 4.908, with a mean square of 4.908, compared to within-groups sum of squares of 801.895 (df = 155) and a mean square of 5.174. The decrease in F-value from 2.512 to 0.949, both non-significant, suggests that ICT integration did not substantially impact students' ability to apply geometric knowledge to routine problems. This finding contrasts with the significant improvements observed in other domains and warrants further investigation. One possible explanation is that application-level tasks may require a combination of procedural fluency and conceptual understanding that develops over longer periods of practice and may not be as immediately responsive to technological intervention, as suggested by Kieran and Drijvers (2006).

Table 8.

Analysis of Variance (ANOVA) Based on Pretest and Posttest Scores Under Higher Ability Level

Cognitive Level	Source	Sum of Scores	df	Mean Square	F	Sig.
Score in Higher Ability for Pretest	Between Groups	16.491	1	16.491	4.022	.047
	Within Groups	635.535	155	4.100		
	Total	652.025	156			
Score in Higher Ability for Posttest	Between Groups	36.868	1	36.868	7.597	.007
	Within Groups	752.202	155	4.853		
	Total	789.070	156			

Note. *Analyzed by using SPSS 27 with 0.05 level of significance*

Pretest Higher Ability Scores

Marginal significant differences existed between groups in higher-order thinking performance before ICT integration (F = 4.022, df = 1, p = .047). The between-groups sum of squares was 16.491, with a mean square of 16.491, while within-groups sum of squares was 635.535 (df = 155), with a mean square of 4.100.

Posttest Higher Ability Scores

After ICT integration, the difference between groups became more pronounced (F = 7.597, df = 1, p = .007). The between-groups sum of squares increased to 36.868, with a mean square of 36.868, compared to within-groups sum of squares of 752.202 (df = 155) and a mean square of 4.853. The increase in F-value from 4.022 to 7.597, with p-value improving from .047 to .007, indicates that ICT integration had a substantial positive impact on higher-order geometric thinking abilities. This finding is particularly noteworthy as it suggests that technological tools can enhance not only basic knowledge acquisition but also complex cognitive processes such as analysis, evaluation, and creation. This aligns with research by Bray and Tangney (2017), who found that technology-based interventions showed stronger effects for higher-order thinking than for basic skills.

Comparative Analysis across Cognitive Domains

The obtained scores were analyzed on the basis of four levels of cognitive domain. Since, the F-value is increasing significantly from 0.077 to highly significant with F-value 29.578 in knowledge level. Similarly, the F-value is increasing from 4.022 (p= 0.047) to 7.597 (p = 0.007) which is also the significant change. The performance in understanding level performance is significantly difference between group but it is decreasing from 16.422 to 6.546). In same manner, there is no significant difference in application level as F-2.512 to a less significant 0,949. In the analysis of the result obtained from F-test it was found that there was U shape change (i.e significant change in Knowledge and higher ability but less change in understanding and application level) was found. These findings suggest a U-shaped relationship (significantly increase in both ends knowledge and higher ability and not increase in understanding and application levels). The benefits of ICT integration, with the greatest impacts observed at both the lower end (knowledge) and higher ability) of the cognitive domain. This pattern may reflect the dual capabilities of digital tools to both existing clear representations of basic concepts and facilitate complex exploration and problem-solving, while potentially having less distinct advantages for intermediate cognitive activities.

Implication of the Study

This study investigated the impact of ICT integration on students' geometry performance across different cognitive domains. The findings have different implication in the teaching and learning geometry. ICT integration significantly improved overall geometry performance, with the difference between groups becoming more noticeable after implementation. The effects of ICT varied substantially across cognitive domains: knowledge acquisition showed the most dramatic improvement, higher ability showed significant enhancement , understanding-level performance maintained significant differences but with reduced magnitude, application-level performance showed no significant improvement. A U-shaped relationship was observed between cognitive complexity and ICT benefits, with strongest effects at both ends of the cognitive domain. The implication of this study in geometry learning is divided into theoretical, and practical aspects. The theoretical implication of the findings of study can contribute to our understanding of how technology influences mathematical cognition across in different levels of cognitive domain. The U-shaped pattern of benefits suggests that ICT may serve dual cognitive functions: At the knowledge level, technology may function as an enhanced representational tool, making geometric concepts more accessible through visualization and interaction, thus supporting initial concept formation. At higher-order thinking level, technology may function as a cognitive speaker, extending students' capacity to explore complex relationships, test conjectures, and engage in mathematical creativity. This dual functionality aligns with Pea's (1987) distinction between technology as speaker and reorganizer of mental activity, suggesting that different cognitive processes may be differentially enhanced by technological tools.

The findings also have several important implications for educational practice: educators should consider implementing ICT tools with specific cognitive objectives in mind, recognizing that technology may be particularly effective for enhancing knowledge acquisition and higher-order thinking in geometry. While ICT showed strong benefits for certain cognitive domains, the lack of significant improvement in application-level performance suggests that traditional practice and problem-solving experiences remain important components of geometry education. In the teacher training program, there should be emphasis how to use technology effectively to achieve different cognitive objectives by supporting the educators for the enhancement of knowledge and skills on ICT tools for geometric thinking. Assessment practices should be aligned with the cognitive domains where ICT integration shows the greatest benefits, ensuring that educational evaluations capture the full range of impacts.

Conclusion

This study provides important evidence regarding the differential effects of ICT integration across cognitive domains in geometry learning. The findings suggest that technology can serve as both a foundational support for basic knowledge acquisition and a substantial knowledge for higher ability level, while having less pronounced effects on intermediate cognitive processes. These insights can inform more nuanced and targeted approaches to technology integration in mathematics education, ultimately enhancing the effectiveness of geometry instruction across the cognitive levels.

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