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Pre Service Mathematics Teachers Mastery of GeoGebra in the Topic of Polygons

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Abstract

This study explores how pre-service mathematics teachers develop skills, confidence, and face challenges in using GeoGebra, with a particular focus on the topic of polygons. While previous research has shown that GeoGebra supports effective mathematics teaching and learning, limited attention has been given to how future teachers experience and apply it during their training. The study aims to assess teachers' hands-on experience with GeoGebra, evaluate their confidence levels, and identify the main difficulties they encounter. A quantitative approach was employed using a performance test and a four-point Likert-scale questionnaire. The data were analyzed through descriptive and inferential statistics. Results revealed that the participants demonstrated good technical ability, especially in constructing simple geometric figures and using sliders, yet their conceptual and pedagogical understanding was only moderate. The main issues reported include limited pedagogical guidance, insufficient practice opportunities, and difficulty integrating GeoGebra effectively in classroom contexts. These findings suggest a need to strengthen TPACK-oriented pedagogical preparation to improve technology integration in teacher education. Future studies are encouraged to adopt mixed-methods or qualitative designs to gain deeper insight into teaching strategies and the long-term effects of GeoGebra use in mathematics classrooms.

Keywords: GeoGebra, Pre-service mathematics teachers, Polygons, Technological Pedagogical Content Knowledge (TPACK)

Introduction

The integration of technology into mathematics education has become essential in today's digital learning environment. To help students grasp abstract mathematical ideas more effectively, teachers are encouraged to adopt approaches that are dynamic, visual, and technology driven. Geometry, particularly the study of polygons, requires teaching methods that clearly illustrate the relationships among sides, angles, and symmetry. Researchers have emphasized that interactive and technology-supported tools can make such abstract topics more meaningful and engaging for learners (Wahyuni & Etfita, 2020).

Among the various digital tools available, GeoGebra stands out as an interactive platform that combines geometry, algebra, and statistics to enhance mathematical understanding through visual exploration (Muslim, Zakaria & Fang, 2023). However, the extent to which pre-service teachers can use GeoGebra effectively depends on their mastery of both technical and pedagogical skills. Many still struggle to integrate technology meaningfully into classroom instruction (Koesnandar, 2020). Therefore, this study aims to explore pre-service mathematics teachers' mastery, confidence, and challenges in applying GeoGebra to the topic of polygons. The findings are expected to contribute valuable insights into teachers' technological readiness and guide improvements in digital pedagogy for mathematics education.

Literature Review

This chapter discusses how pre-service mathematics teachers understand, use, and feel about GeoGebra, especially when teaching the topic of polygons. The discussion is guided by the Technological Pedagogical Content Knowledge (TPACK) framework by Mishra and Koehler (2006), which emphasizes how effective teaching requires the integration of three main types of knowledge, content, pedagogy, and technology. Content knowledge (CK) refers to a teacher's understanding of polygon concepts such as angles, sides, and symmetry. Pedagogical knowledge (PK) relates to how teachers design interactive lessons to make learning meaningful. Technological knowledge (TK) involves using GeoGebra to create dynamic visualizations that help students see geometric relationships clearly. When combined, these areas form the TPACK model a useful guide for integrating technology effectively in mathematics education.

Previous research has shown that GeoGebra can enhance students' conceptual understanding, visualization skills, and problem-solving abilities. However, the lack of structured training and sufficient infrastructure often limits its full potential. For instance, Osypova and Tatochenko (2021) found that while GeoGebra AR improved understanding of geometric concepts, teachers still faced challenges due to limited training. Similarly, Assadi and Hibi (2020) reported that integrated pedagogy courses significantly improved teachers' TPACK elements through systematic GeoGebra-based learning. Studies by Hernández et al. (2020) revealed that weak technical and pedagogical application reduces the effectiveness of GeoGebra in real classroom settings.

Teacher confidence is another key factor. Research by Zutaah Puotier et al. (2021) and Hamzah and Hidayat (2022) showed that limited training and negative attitudes toward technology lower teachers' confidence in using digital tools. Despite these benefits, several challenges still exist. Studies by Mazengera (2023), Schmid and Korenova (2022), and Bogdanova et al. (2023) highlighted issues such as limited institutional support, weak technical infrastructure, and lack of hands-on guidance. These findings suggest that structured, practical training and continuous support are essential for improving teachers' competence and confidence.

In conclusion, the literature shows that while GeoGebra holds great potential to enhance mathematical learning, its success depends on how well technology, pedagogy, and content are integrated. Strengthening these areas through well-planned training and support will help pre-service teachers design more interactive, creative, and effective mathematics lessons.

Research objectives

1. To identify the level of mastery in using GeoGebra among pre-service mathematics teachers focusing on the topic of polygons.
2. To identify the level of confidence in using GeoGebra among pre-service mathematics teachers focusing on the topic of polygons.
3. To identify the challenges in using GeoGebra among pre-service mathematics teachers focusing on the topic of polygons.

Methodology

Data for this study were gathered through two main methods. A GeoGebra performance task was completed, and the submitted files were examined to evaluate technical skills, conceptual understanding of mathematical ideas and the ability to apply pedagogical strategies when planning teaching activities. An online questionnaire distributed through Google Forms was also used to obtain information related to confidence, perceptions and challenges in using GeoGebra for teaching.

The results were analyzed using descriptive statistics such as mean, standard deviation, median, skewness and kurtosis to identify overall patterns and levels of mastery. A paired sample t test was then conducted to determine whether a significant difference existed between technical mastery and the combined conceptual and pedagogical mastery.

Tables and Figures

This section presents the demographic profile of the respondents, covering gender, current academic achievement, experience with GeoGebra, learning resources, and usage purposes. Data was analyzed using frequency and percentage, with results displayed in tables for clarity.

Table 1
Distribution of Respondents by Gender

Gender	Frequency	Percentage (%)
Male	9	31.0
Female	20	69.0
Total	29	100

Table 2
Distribution of Respondents by CGPA

CGPA	Frequency	Percentage (%)
3.75 – 4.00	14	48.3
3.50 – 3.74	11	37.9
3.00 – 3.49	4	13.8
2.50 – 2.99	0	0
2.00 – 2.49	0	0
≤1.99	0	0
Total	29	100

Table 3
Distribution of Respondents by CGPA

Experience Duration	Frequency	Percentage (%)
Less than 1 year	9	31.0
1 – 3 years	17	58.6
More than 3 years	3	10.3
Total	29	100

Table 4
Distribution of Respondents by GeoGebra Learning Resources

Learning Resource	Frequency	Percentage (%)
University courses	10	34.5
YouTube	26	89.7
Books/Modules	4	13.8
Lecturer/Teacher guidance	26	89.7
ChatGPT	19	65.5

Table 5
Distribution of Respondents by Purpose of Using GeoGebra

Purpose	Frequency	Percentage (%)
Academic assignments	27	93.1
Teaching and learning	24	82.8
Self-directed learning	11	37.9

The tables illustrate that most respondents are female, academically high-achieving, and have moderate experience with GeoGebra. Digital and interactive resources such as YouTube and lecturer guidance are preferred, and usage is primarily linked to formal academic tasks rather than self-directed learning.

Before comparing the mean scores for the two constructs, the normality of the data was assessed using skewness and kurtosis. For moderate sample sizes, skewness within ±2 and kurtosis within ±3 is considered acceptable for normal distribution. Analyses were conducted in SPSS v27 and supported visually with histograms.

Table 6
Skewness and Kurtosis for Technical and Concept-Pedagogy Mastery

Proficiency Dimension	Skewness	Kurtosis
Technical	-1.767	1.840
Conceptual & Pedagogical	-0.957	0.765

Both constructs fall within acceptable limits, indicating that the data are approximately normally distributed.

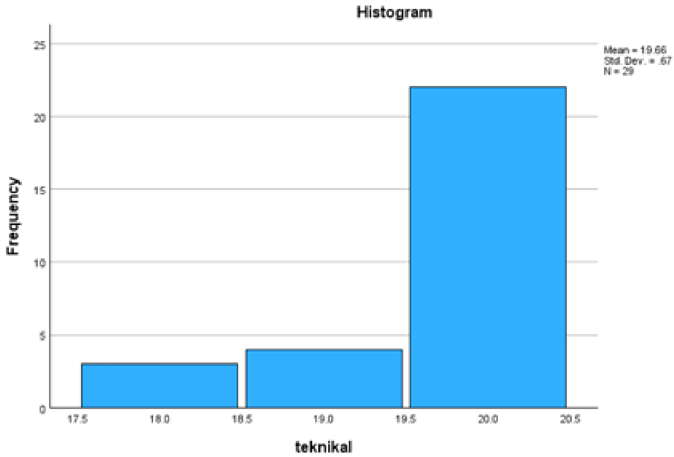

Figure 1: Histogram of Technical Proficiency Scores in GeoGebra

Most respondents scored near the maximum, resulting in a negatively skewed and tightly clustered distribution (SD = 0.67), indicating high and consistent technical mastery.

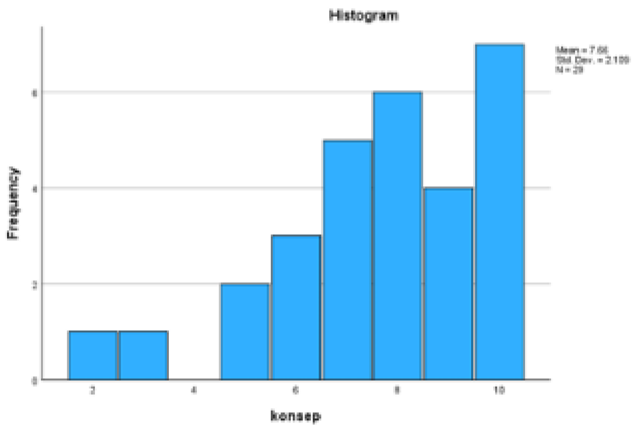

Figure 2: Histogram of Conceptual and Pedagogical Proficiency Scores in GeoGebra

Scores were more widely distributed, with a higher standard deviation (SD = 2.11), reflecting greater variability in respondents' conceptual and pedagogical mastery. Moderate skewness confirms the absence of extreme deviations. Overall, both constructs satisfy the normality assumption, supporting the use of a paired-samples t-test for inferential analysis.

Based on the previous normality assessment, both data sets technical mastery and concept-pedagogy mastery followed a normal distribution. Scores were converted into percentages to standardize scales before comparison. Since the same respondents provided scores for both constructs, a paired-samples t-test was used to examine mean differences.

Table 7
Mean and Standard Deviation for Technical and Concept-Pedagogy Mastery

Mastery Construct	Mean (%)	Standard Deviation
Technical	98.28	3.35
Conceptual & Pedagogical	76.55	21.09

Technical mastery scores are near perfect and tightly clustered, whereas concept-pedagogy scores show greater variability.

Table 8
Paired Samples t-Test Results

Mastery Construct	N	Mean (%)	SD	t	df	p-value
Technical	29	98.28	3.35			
Conceptual & Pedagogical	29	76.55	21.09	5.671	28	0.01

The paired-samples t-test shows a significant difference between technical and concept-pedagogy mastery ($t = 5.671$, $p = 0.01$). Technical mastery is significantly higher than concept-pedagogy mastery, confirming that respondents excel more in technical skills.

This significant difference implies that teacher training programs should balance the development of technical skills with conceptual understanding and pedagogical abilities. Without integrating all three elements, GeoGebra usage in teaching risks remaining at a demonstrative level rather than producing deep learning outcomes.

This section summarizes results from the GeoGebra Problem-Solving Test, which comprised six questions with a maximum total score of 30 (5 marks per question). Questions 1–4 assessed technical mastery, such as creating sliders, constructing regular polygons, and observing dynamic changes in interior angles. Questions 5–6 assessed conceptual and pedagogical mastery, including explaining mathematical relationships and planning interactive teaching activities. Scores were analyzed using descriptive statistics (mean and standard deviation).

The overall mean score was 27.31/30 ($SD = 2.25$), indicating high performance among most respondents. Variation suggests some respondents struggled with conceptual or pedagogical aspects.

Table 9
Mean and Standard Deviation by Question

Q	Mastery Aspect	Task Description	Mean	SD
1	**Technical**	Build a slider (n = 3–12, increment 1)	4.90	0.31
2	**Technical**	Use slider to construct regular polygon	4.93	0.26
3	**Technical**	Determine interior angles of a dodecagon	4.93	0.26
4	**Technical**	Change number of sides and observe angles	4.83	0.47
5	**Conceptual & Pedagogical**	Design interactive GeoGebra activity for polygons	3.90	1.15
6	**Conceptual & Pedagogical**	Explain relationship between sides and interior angles	3.76	1.09

Technical scores are consistently high, indicating strong procedural skills. Conceptual and pedagogical scores are lower, showing room for improvement in reflective understanding and lesson design.

Table 10
Comparison of High-Performing Respondents

Respondent	Activity Title	Technical Mastery	Conceptual & Pedagogical Mastery	Strengths
R7	"Polygon in Traditional Art: Exploring Wau Bulan"	High (Polygon Tool & dynamic Slider)	High (Contextual cultural activity, clear objectives)	Integrates local culture with geometry
R9	"Polygon Architect: Build Your Dream Building!"	High (Regular Polygon & flexible Slider)	High (Strong conceptual justification, interactive experience)	Creative visual and mathematical design
R18	"Wind Turbine Blade Design"	High (Slider, Polygon, Angle Tool)	High (STEM approach, constructivist strategy)	Real-world applications, pedagogically reflective

These respondents demonstrated balanced technical, conceptual, and pedagogical mastery, integrating GeoGebra into meaningful, high-level learning experiences.

Table 11
Comparison of Low-Performing Respondents

Respondent	Activity Title	Technical Mastery	Conceptual & Pedagogical Mastery	Key Weakness
R5	Pattern Drawing (honeycomb/batik)	Low (Slider n=1, invalid polygon)	Low (No GeoGebra tools, poor conceptual understanding)	Misunderstanding basic geometry & poor TPACK integration
R8	Shape Tiling (square & hexagon)	Minimal (no construction or tools)	Very Low (one-sentence response)	Shallow content & pedagogy
R11	Mandala/batik pattern	Low (no dynamic tools, no polygons)	Low (no conceptual justification)	Lacking content knowledge & TPACK
R21	"Exploring Properties of Triangles"	Low (Slider increment 0.1, invalid polygon)	Low (narrow focus, formula not applied)	Narrow approach, objectives not met

These results indicate gaps in the ability to integrate technical skills, content knowledge, and pedagogy effectively. Low-performing respondents struggled with both conceptual understanding and the strategic use of GeoGebra, highlighting the need for structured TPACK-based training.

This section presents descriptive analyses of pre-service teachers' mastery, confidence, and challenges in using GeoGebra, specifically in teaching the topic of polygons. A total of 29 respondents participated, all enrolled in mathematics education programs at public higher education institutions. Data were collected via an online questionnaire, and responses were analyzed using median scores to indicate levels of mastery, confidence, and perceived challenges.

Table 12
Respondent Distribution by Mastery of GeoGebra

Item	Task Description	STS f (%)	TS f (%)	S f (%)	SS f (%)	Median	Mastery Level
1	**Build a slider (name, min/max, increment)**	0 (0.0)	0 (0.0)	6 (20.7)	23 (79.3)	4	High
2	**Construct regular polygon from slider values**	0 (0.0)	0 (0.0)	4 (13.8)	25 (86.2)	4	High
3	**Determine interior angles of regular polygon**	0 (0.0)	0 (0.0)	7 (24.1)	22 (75.9)	4	High
4	**Use slider to change number of sides and observe angles**	0 (0.0)	0 (0.0)	5 (17.2)	24 (82.8)	4	High
5	**Plan interactive activities to teach polygons**	0 (0.0)	1 (3.4)	9 (31.0)	19 (65.5)	4	High
6	**Explain relationship between sides and angles**	0 (0.0)	1 (3.4)	8 (27.6)	20 (69.0)	4	High

Median scores of 4 across all items indicate high mastery of GeoGebra skills, particularly in technical tasks such as slider creation, polygon construction, and angle manipulation. Slightly lower percentages in pedagogical tasks (items 5 and 6) suggest that planning and explaining concepts interactively may require further development. Overall, respondents can handle GeoGebra technically and demonstrate readiness to integrate it into teaching.

Table 13
Respondent Distribution by Confidence in Using GeoGebra

Item	Task Description	STS f (%)	TS f (%)	S f (%)	SS f (%)	Median	Confidence Level
1	**Confident building slider**	0 (0.0)	0 (0.0)	8 (27.6)	21 (72.4)	4	High
2	**Confident constructing regular polygon**	0 (0.0)	0 (0.0)	4 (13.8)	25 (86.2)	4	High
3	**Confident determining interior angles**	0 (0.0)	1 (3.4)	6 (20.7)	22 (75.9)	4	High
4	**Confident manipulating slider and observing angles**	0 (0.0)	0 (0.0)	6 (20.7)	23 (79.3)	4	High
5	**Confident designing interactive activities**	0 (0.0)	1 (3.4)	7 (24.1)	21 (72.4)	4	High
6	**Confident explaining relationships between sides and angles**	0 (0.0)	1 (3.4)	4 (13.8)	24 (82.8)	4	High

Respondents show high confidence in technical tasks, consistent with the mastery results. Confidence in pedagogical integration (activities design and conceptual explanation) remains slightly lower, indicating that further hands-on training and reflective practice may strengthen teaching-related confidence. Overall, median scores of 4 reflect strong self-assurance in using GeoGebra for mathematics learning and teaching.

Table 14
Respondent Distribution by Challenges in Using GeoGebra

Item	Challenge	STS f (%)	TS f (%)	S f (%)	SS f (%)	Median	Level
1	**Lack of technical training**	1 (3.4)	3 (10.3)	9 (31.0)	16 (55.2)	4	High
2	**Difficulty using GeoGebra to teach polygons**	1 (3.4)	5 (17.2)	10 (34.5)	13 (44.8)	3	Moderate-High
3	**Low confidence in applying GeoGebra**	1 (3.4)	5 (17.2)	9 (31.0)	14 (48.3)	3	Moderate-High
4	**Limited access to technology**	1 (3.4)	2 (6.9)	5 (17.2)	21 (72.4)	4	High
5	**Difficulty linking math concepts to GeoGebra**	2 (6.9)	4 (13.8)	8 (27.6)	15 (51.7)	4	High
6	**Difficulty designing interactive activities**	0 (0.0)	3 (10.3)	10 (34.5)	16 (55.2)	4	High
7	**Limited time to master GeoGebra**	0 (0.0)	2 (6.9)	10 (34.5)	17 (58.6)	4	High

Five of seven items scored median 4, highlighting major challenges in training, infrastructure, pedagogical integration, interactive activity design, and time management. Items 2 and 3, concerning classroom application and self-confidence, scored median 3, indicating moderate-high challenges in transferring technical skills to real teaching scenarios. Despite high mastery and confidence, respondents face practical constraints that can limit effective use of GeoGebra in teaching.

The study reveals that participants demonstrate considerable technical competence and confidence in utilizing GeoGebra for mathematical tasks, including constructing sliders, polygons, and manipulating angles. However, gaps remain in lesson planning and instructional delivery. The primary challenges identified include insufficient training, limited access to technological resources, difficulty integrating conceptual understanding with digital tools, design engaging learning activities, and time constraints. These findings underscore the need for targeted professional development programs that integrate content knowledge, pedagogical strategies, and technology to enhance both teacher confidence and classroom effectiveness.

Discussion and Conclusion

This study highlights a clear gap between pre-service mathematics teachers' technical skills in GeoGebra and their ability to apply it effectively in conceptual and pedagogical contexts. While participants can confidently construct polygons, use sliders, and perform basic operations, their understanding of underlying mathematical concepts and ability to plan meaningful learning activities remains moderate. This suggests that technical proficiency alone is not enough for effective classroom application and underscores the importance of integrating technological knowledge (TK) with pedagogical knowledge (PK) and content knowledge (CK), consistent with the TPACK framework (Koehler et al., 2007; Mishra & Koehler, 2008).

Although participants expressed high confidence in performing technical tasks, this confidence did not always translate into their ability to design teaching activities or explain mathematical concepts effectively. This indicates that self-assurance in using technology can sometimes mask gaps in pedagogical reasoning and content understanding, supporting previous findings that confidence with tools does not guarantee instructional competence (Lotey et al., 2025). Many participants relied on informal learning sources, such as YouTube tutorials or guided tasks, rather than structured TPACK-based training, which may have contributed to this discrepancy.

Participants also reported a few challenges, including limited formal training, difficulty designing interactive activities, and issues related to resources or infrastructure. These findings point to systemic barriers that need to be addressed for technology to be used effectively in teaching. The observed difference between performance on procedural tasks and conceptual or pedagogical tasks further emphasizes the need for holistic training that develops all aspects of TPACK, preparing teachers to face real classroom challenges (Büşra Kartal & Cengiz Çınar, 2022). Overall, the study suggests that pre-service teachers can only use GeoGebra effectively in teaching polygons when technical skills are combined with reflective pedagogical planning and strong conceptual understanding. This underscores the importance of TPACK-focused training programs to turn technical ability into meaningful classroom practice.

In conclusion, the high technical skills demonstrated by pre-service teachers in GeoGebra are not enough for effective teaching. A balanced integration of technology, pedagogy, and content knowledge is essential for translating confidence into competence, particularly when teaching complex topics like polygons. From a theoretical perspective, this study reinforces the value of the TPACK framework as a guide for teacher preparation. It shows that technological mastery without corresponding pedagogical and content knowledge limits instructional effectiveness. By focusing on a specific topic such as polygons, the study demonstrates how TPACK can be applied in targeted ways, offering practical insights for curriculum design and teacher training.

Methodologically, the combination of surveys and performance-based assessments allowed for a richer understanding of participants' abilities and confidence, revealing gaps between perceived and actual competence that self-reports alone might have missed. Practically, the findings highlight the importance of structured professional development programs that integrate technical, pedagogical, and content knowledge. Such programs, supported by reflective practice and authentic classroom experience, can help pre-service teachers bridge the gap between confidence and effective teaching, enabling them to use GeoGebra meaningfully in mathematics instruction.

For future research, studies could explore other mathematics topics, include classroom observations during teaching practicum, and use qualitative methods to gain deeper insight into the challenges, strategies, and experiences of pre-service teachers. This would provide further guidance for improving TPACK development and ensuring that technology integration leads to high-quality teaching and learning in mathematics.

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