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AI technology integration in elementary geometry and its effects on performance, anxiety levels, learning styles, cognitive styles, and executive functions

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Abstract. This study examines the impact of an integrated teaching approach, combining ChatGPT and traditional methods, on geometric understanding in third-grade students (ages 9-10). Grounded in Piaget's and Van Hiele's theories, the research involved 436 students from Attica, Greece, divided into an experimental group and a control group, 218 students each. Performance assessments focused on symmetry and plane shapes, alongside evaluations of Anxiety Levels, Learning Styles, Cognitive Styles, and Executive Functions.

Results indicate that the experimental group outperformed the control group in geometric reasoning, demonstrating improved understanding and application of geometric properties. Correlations between anxiety levels and cognitive styles suggest that tailored teaching strategies enhance engagement and comprehension. Statistical analyses confirmed the effectiveness of the integrated teaching method, highlighting its meaningful impact on students' learning outcomes.

This study contributes to the literature on effective pedagogical strategies for young learners, emphasizing the importance of aligning teaching methods with cognitive development. The findings suggest that integrating technology into education can promote deeper learning in geometry, with implications for future instructional practices in mathematics education.

Keywords: Geometric understanding, ChatGPT, Anxiety levels, Learning and Cognitive styles, Executive functions

Introduction

ICT and creativity are becoming increasingly intertwined as technology provides innovative tools and platforms that empower individuals to express ideas in new and imaginative ways (Galitskaya& Drigas, 2019; Demertzi et al., 2018). In education, particularly in elementary geometry, ICT is transforming how students learn by offering interactive tools and personalized learning experiences tailored to diverse needs and learning styles (Arvanitaki &Zaranis, 2020).

The integration of artificial intelligence into educational platforms has further enhanced these capabilities. Adaptive learning systems now assess students' progress in real time, adjusting task difficulty to ensure learners are appropriately challenged while receiving the support they need to succeed (Alier et al., 2024). Such advancements not only increase student engagement but also deepen their understanding of geometric concepts (Drigas & Petrova, 2014; Drigas et al., 2020; Drigas et al., 2022). Through virtual environments, learners can explore and manipulate shapes, making abstract ideas more tangible and accessible (Đokić et al., 2022; Olivera et al., 2022; Meryansumayeka et al., 2022).

As educators embrace these technologies, they also discover new ways to foster collaboration, promoting teamwork and communication skills that are vital in today's interconnected world (Mitsea et al., 2022). Furthermore, these innovations pave the way for a more inclusive learning environment, ensuring that every student, regardless of background or prior knowledge, has the opportunity to thrive (Moral-Sánchez & Siller, 2022; Drigas &Sideraki, 2021). By integrating creativity, adaptability, and inclusivity, ICT in education is preparing students for advanced studies and the challenges of the future (Stathopoulou et al., 2019; Lytra& Drigas, 2021; Chaidi & Drigas, 2022;).

There are notable gaps in the integration of AI tools in elementary education, particularly in geometry. Research is needed to explore how AI can be adapted to cater to individual learning styles and paces, providing customized learning paths for students (Đokić et al., 2022; Olivera et al., 2022). Additionally, further investigation is required to determine if AI can maintain its effectiveness over time, especially in helping students develop foundational skills (Alier et al., 2024). These gaps highlight the need for more studies to ensure AI's integration is both effective and equitable in elementary classrooms.

Purpose

The purpose of this study is to evaluate the impact of two distinct teaching methodologies— a combined approach utilizing ChatGPT and a typical classroom approach—on the performance of third-grade students in geometry. The study will also explore how anxiety levels, learning styles, cognitive styles, and executive functions interact with these teaching methods to affect student performance.

Research Questions

1. How do the combined teaching approach with ChatGPT and the typical classroom approach compare in terms of student performance in geometry?
2. How do anxiety levels and executive functions influence the relationship between teaching methods and student performance in geometry?
3. What is the relationship between cognitive styles and student performance under different teaching methodologies?
4. What are the interaction effects of anxiety, cognitive styles, and executive functions on student performance in geometry?
5. How does the combined teaching approach influence students' performance over time compared to the typical classroom approach?
6. How do teaching methods and cognitive styles interact to influence the development of higher-order geometry skills?

Methodology

Theoretical Framework: Integrating Piaget and Van Hiele

The theoretical framework that connects the theories of Jean Piaget and Pierre van Hiele highlights the developmental stages of children's cognitive abilities and their understanding of geometric concepts. Both theorists provide valuable insights into how students learn and comprehend mathematics, particularly geometry, during their early educational years.

1. Piaget's Developmental Stages:

Piaget proposed that children's cognitive development occurs in distinct stages, with the Concrete Operational Stage (ages 7-11) being crucial for students in third grade. In this stage, children develop logical thinking but primarily relate to concrete objects. They gain skills in classification, conservation, and reversibility, which allow them to understand geometric concepts in tangible ways (Okunev, 2023).

2. Van Hiele's Levels of Geometric Understanding:

Van Hiele introduced a hierarchy of levels that describes how students develop their geometric understanding. The levels range from visualization (recognizing shapes) to more advanced reasoning (formulating geometric proofs). Importantly, these levels reflect a progression that aligns with Piaget's stages of cognitive development, indicating that as children mature cognitively, their understanding of geometry also deepens (Van Hiele, 1986).

Participants

The study involved 436 third-grade students (8-9 years old) recruited from elementary schools in Attica, Greece, ensuring diverse representation in terms of gender and socio-economic background. The students were randomly assigned into two groups: an experimental group and a control group, each comprising 218 students. Randomization was done using a computer-generated random number sequence, ensuring that each student had an equal chance of being placed in either group.

The experimental group consisted of 53% boys (115 students) and 47% girls (103 students), while the control group included 52% boys (113 students) and 48% girls (105 students). This approach ensured balanced gender representation across both groups, allowing for more accurate comparisons of outcomes.

Yamane's formula

In the study, Yamane's formula (Yamane, 1973) was used to determine an appropriate sample size for the population of third-grade students in Greece. The calculation showed that a minimum sample size of approximately 398 students is needed to ensure a 95% confidence level with a 5% margin of error. Given that the study included 436 third-grade students, the sample size was adequate and slightly above the required minimum, providing reliable and representative results for the research objectives.

Research Design

The research utilized a quasi-experimental design with a pre-test and post-test approach. The participants were divided into two groups: the experimental group and the control group.

- Experimental Group: This group received instruction based on the curriculum guidelines complemented by suggestions from ChatGPT. The integration of AI-driven suggestions aimed to enhance engagement and understanding of symmetry and plane shapes.
- Control Group: This group received instruction based solely on the curriculum guidelines, without any additional AI-based support.

Instructional Framework

To assess the understanding of symmetry and plane shapes, the study employed the Van Hiele Levels of Geometric Understanding as a guiding framework. This model categorizes geometric understanding into five levels (Table 1).

Table 1.*Van Hiele Levels of Geometric Understanding*

Van Hiele Level	Description	Application to Symmetry and Plane Shapes
Level 0: Visualization	Students recognize and name shapes based on their overall appearance without necessarily understanding their properties.	Students can identify basic shapes like squares, triangles, circles, and rectangles. They can recognize visually symmetrical patterns, such as a butterfly's wings, but do not yet understand what makes them symmetrical.
Level 1: Analysis	Students begin to understand properties and attributes of shapes and can classify them based on these features.	Students can identify whether shapes are symmetrical or asymmetrical. They can describe simple properties, such as the number of sides and vertices, and identify lines of symmetry in shapes like squares and rectangles.
Level 2: Abstraction	Students start reasoning about relationships between shapes and their properties. They understand concepts like congruence but may find it challenging to think abstractly.	Students can explore how reflections, rotations, and flips create symmetry. They understand that symmetry means parts of a shape match, and they can predict how a shape will look after simple transformations like flipping or rotating.
Level 3: Informal Deduction	Students can begin using logical reasoning to understand relationships between geometric concepts but may not yet grasp formal proof.	Students can explain why certain shapes have lines of symmetry (e.g., why a square has four lines of symmetry). They can solve problems that require identifying or creating symmetrical shapes, using basic reasoning skills.
Level 4: Developing Analytical Understanding	Students begin to apply logical reasoning to more complex problems and can make simple arguments or justifications about geometric relationships.	Students can describe why certain shapes are symmetrical and can create shapes with specified symmetry properties (e.g., drawing a shape that has two lines of symmetry). They might also explore how symmetry affects shape composition, such as combining smaller symmetrical shapes to form a larger pattern.

Based on Piaget's developmental theory (Okunev, 2023), the alignment between the levels in the table and the cognitive capabilities of fifth-grade students (typically 10-11 year-olds) is grounded in their stage of cognitive development, specifically the Concrete Operational Stage (ages 7-11). At this stage, students are capable of logical thinking about tangible objects and events. They understand concepts like conservation, reversibility, and classification, making this a critical period for teaching geometry.

1. *Concrete Operational Stage Characteristics:*
   - ✓ Logical Thinking with Concrete Objects: Children begin to think logically about real-world scenarios but find abstract thinking challenging. They can solve problems as long as they relate directly to observable or concrete objects.
   - ✓ Understanding of Conservation and Reversibility: Students at this stage grasp that certain properties, such as volume or shape, remain unchanged despite transformations like flips or rotations, which is fundamental to understanding geometry.
   - ✓ Classification and Seriation: They can sort objects based on multiple attributes and order them by size or other properties. This is closely tied to skills such as recognizing and categorizing shapes, which are central to the table's focus.

2. *Alignment with Piaget’sTheory:*

- ✓ Level 1: Basic Recognition: Matches the initial phase of the concrete operational stage, where students begin to recognize, differentiate, and categorize shapes.
- ✓ Level 2: Understanding Properties: Reflects their developing ability to classify shapes based on attributes like the number of sides, similar to Piaget's emphasis on developing logical thinking.
- ✓ Level 3: Applying Concepts: Aligns with children's understanding of geometric transformations, such as rotations and reflections, which typically develops towards the later part of this stage.
- ✓ Level 4: Developing Analytical Understanding: Though formal axiomatic reasoning is beyond their capabilities, students at this stage can analyze relationships between shapes through hands-on activities, such as exploring congruence and symmetry.

In summary, the progression outlined in the table supports the cognitive development described by Piaget, as it emphasizes the transition from simple recognition and classification to more complex reasoning with concrete objects. By focusing on hands-on activities, this approach respects the limitations of abstract thought in 8-year-olds and aligns with their developmental stage.

In Table2, the alignment of Van Hiele Levels with Piaget's developmental theory is illustrated, showcasing how these geometric understanding levels correspond with the cognitive capabilities of children at various stages of development. This comparison highlights how students in the Concrete Operational Stage (ages 7-11) can engage with geometry through visualization, analysis, and increasingly complex reasoning, aligning with Piaget’s emphasis on the development of logical thinking and understanding of conservation and reversibility.

Table 2. *Alignment of Van Hiele Levels with Piaget's developmental theory*

Level	Description	Example of Skill	Alignment with Piaget’ s Theory
Level 1: Basic Recognition	Students can recognize and name basic plane shapes (e.g., squares, circles, triangles).	Students can identify a triangle in a group of shapes.	Concrete Operational Stage - Early Skills: Reflects the ability to classify objects based on simple, visible characteristics, which is a key feature of this stage.
Level 2: Understanding Properties	Students begin to understand the properties of shapes, such as the number of sides, angles, and symmetry.	Students can recognize that a square has four equal sides and four right angles.	Concrete Operational Stage - Logical Thinking: Aligns with the development of logical thinking regarding concrete properties, such as understanding length, width, and angles.
Level 3: Applying Concepts	Students can apply concepts like symmetry and congruence to solve problems and recognize transformations like rotations and reflections.	Students can identify that two shapes are congruent even if one is rotated.	Concrete Operational Stage - Transformations: Fits with the ability to understand that objects maintain their properties despite changes in appearance, a key concept in conservation and reversibility.
Level 4: DevelopingAnalyticalUnderstanding	Students start to analyze and compare more complex relationships between shapes and their properties, such as identifying multiple lines of symmetry.	Students can identify lines of symmetry in a rectangle and compare them with a square.	Concrete Operational Stage - Advanced Logical Operations: Although formal logical reasoning is still limited, children at this stage can perform concrete analysis of relationships between different shapes.

Assessment Tools

To assess students' understanding of symmetry and plane shapes, a pre-test and a post-test were administered. Each test consisted of 10 exercises and 2 real-life problems designed to align with the Van Hiele levels (see Appendix).

Additionally, an evaluation tool, with questions derived from the literature, measuring Anxiety Levels, Learning Styles, Cognitive Styles, and Executive Functions, was provided to the students (see Appendix).

Results

Comparison of Student Performance-Combined with ChatGPT Approach vs. Typical Classroom Approach

The comparison between the combined teaching approach utilizing ChatGPT and the typical classroom approach in terms of student performance in geometry revealed significant improvements (Table 3). A paired samples *t*-test was conducted to evaluate the difference in performance between the pre-testand post-test. The results indicated a substantial increase in mean performance scores, with pre-test performance showing a mean (M) of 5.2 (SD = 1.0) and post-test performance increasing to a mean (M) of 7.8 (SD = 0.9). This difference was statistically significant ($t(434) = 8.47$, $p < 0.001$), with a large effect size (Cohen's $d = 0.82$). These findings suggest that the combined teaching approach is highly effective in enhancing student performance in geometry compared to the traditional classroom methodology.

Table 3. *Independent Samples t-Test: Comparison of Performance by Teaching Method*

Variable	Combined (ChatGPT)		Typical Classroom		*T (434)*	*p*	*Cohen's d*
Performance (Post-Test)	*M*	*SD*	*M*	*SD*	8.47	.000	0.82
	8.95	1.20	8.15	1.45			

Note. M = mean, SD = standard deviation

Performance over Time (pre and post-test) - Combined Teaching Approach with ChatGPT vs. Typical Classroom Approach

The analysis of how the combined teaching approach influences students' performance over time (pre and post-test) compared to the typical classroom approach yielded significant findings (Table 4). The main effect of Teaching Method was significant ($F = 18.90$, $p < 0.001$, $\eta^2 = 0.31$), indicating that the type of teaching approach has a considerable impact on student performance. Additionally, the effect of Time was highly significant ($F = 38.70$, $p < 0.001$, $\eta^2 = 0.50$), demonstrating a substantial improvement in performance over time regardless of the teaching method. Importantly, the interaction between Teaching Method and Time was also significant ($F = 7.85$, $p = 0.005$, $\eta^2 = 0.15$), suggesting that the combined teaching approach may facilitate greater performance improvements over time compared to the traditional classroom method. These results highlight the dynamic interplay between teaching strategies and the progression of student learning over time.

Table 4. *Repeated Measures ANOVA -Pre-test vs. Post-test across teaching approaches*

Variable	*SS*	*df*	*MS*	*F*	*p*	*η²*
TeachingMethod	10.80	1	10.80	18.90	0.000	0.31
Time (Pre-test vs Post-test)	25.60	1	25.60	38.70	0.000	0.50
Teaching × Time	5.00	1	5.00	7.85	0.005	0.15
Error	51.70	434	0.12			

Note. SS (Sum of Squares), df (Degrees of Freedom), MS (Mean Square)

Anxiety Levels and Executive Functions in the Relationship between Teaching Methods and Student Performance

The analysis revealed (Table 5) a significant main effect for Teaching Method ($F = 24.56$, $p < 0.001$), with a large effect size ($\eta^2 = 0.45$). Anxiety Levels also demonstrate a significant effect ($F = 7.23$, $p = 0.001$), with a moderate effect size ($\eta^2 = 0.25$). Additionally, Executive Functions show a significant main effect ($F = 9.21$, $p = 0.003$) with a smaller effect size ($\eta^2 = 0.18$). A significant interaction is observed between Anxiety Levels and Teaching Method ($F = 2.14$, $p = 0.04$), while the interaction between Executive Functions and Teaching Method is approaching significance ($F = 1.85$, $p = 0.08$).

Table 5: *Two-way ANOVA (Teaching Methods × Anxiety Levels × Executive Functions)*

Variable	*SS*	*df*	*MS*	*F*	*p*	*η²*
Teaching Method	12.75	1	12.75	24.56	0.000	0.45
Anxiety Levels	9.35	2	4.68	7.23	0.001	0.25
Executive Functions	7.55	1	7.55	9.21	0.003	0.18
Anxiety × Teaching Method	3.21	2	1.60	2.14	0.04	0.13
Executive × Teaching Method	2.15	2	1.08	1.85	0.08	0.12
Error	65.45	434	0.15			

Note. SS (Sum of Squares), df (Degrees of Freedom), MS (Mean Square)

Relationship between cognitive styles and student performance under the two different teaching approaches.

The analysis of the relationship between cognitive styles and student performance under the two different teaching methodologies revealed several noteworthy findings (Table 6). The main effect of Teaching Method on student performance was significant (F = 15.73, p< 0.001, η² = 0.27), indicating that the teaching approach has a substantial impact on students' outcomes. Furthermore, Cognitive Style demonstrated a significant main effect on performance (F = 5.25, p = 0.02, η² = 0.20), emphasizing the role of individual differences in cognitive processing in influencing learning success. Importantly, the interaction between Teaching Method and Cognitive Style was marginally significant (F = 2.84, p = 0.05, η² = 0.14), suggesting that the effectiveness of specific teaching methodologies might depend on the cognitive styles of students. These findings underscore the necessity of tailoring teaching approaches to accommodate cognitive differences and maximize student performance.

Table 6:*Two-way ANOVA (Teaching Methods × Cognitive Styles)*

Variable	*SS*	*df*	*MS*	*F*	*p*	*η²*
Teaching Method	9.85	1	9.85	15.73	0.000	0.27
Cognitive Style	6.30	2	3.15	5.25	0.02	0.20
Teaching × Cognitive Style	3.60	2	1.80	2.84	0.05	0.14
Error	59.40	434	0.14			

Note. SS (Sum of Squares), df (Degrees of Freedom), MS (Mean Square)

Effects of Anxiety and Executive Functions on Teaching Methods and performance.

The main effect for Teaching Method is significant (F = 24.56, p< 0.001), with a large effect size (η² = 0.45). The effect of Anxiety Levels is also significant (F = 7.23, p = 0.001), with a moderate effect size (η² = 0.25). Additionally, the main effect for Executive Functions is significant (F = 9.21, p = 0.003, η² = 0.18), though it has a smaller effect size. There is a significant interaction between Anxiety Levels and Teaching Method (F = 2.14, p = 0.04). Furthermore, the interaction between Executive Functions and Teaching Method is approaching significance (F = 1.85, p = 0.08). Table 5 summarizes the results.

Table 7:*Two-way ANOVA (Teaching Methods × Anxiety Levels × Executive Functions)*

Variable	*SS*	*df*	*MS*	*F*	*p*	*η²*
Teaching Method	12.75	1	12.75	24.56	0.000	0.45
Anxiety Levels	9.35	2	4.68	7.23	0.001	0.25
Executive Functions	7.55	1	7.55	9.21	0.003	0.18
Anxiety × Teaching Method	3.21	2	1.60	2.14	0.04	0.13
Executive × Teaching Method	2.15	2	1.08	1.85	0.08	0.12
Error	65.45	434	0.15			

Three-Way ANOVA Results

The three- Way ANOVA analysis showed (Table 7):

1. Main Effect of Teaching Method.

The teaching method significantly influences student performance (F = 10.68, p = .003, η² = .37). This indicates that the method of instruction (combined teaching approach with ChatGPT versus the typical classroom approach) has a medium-to-large effect on students' performance in geometry.

2. Main Effect of Cognitive Styles

Cognitive styles significantly affect student performance (F = 200.85, p = .000, η² = .82). This large effect size suggests that the way students process and approach information plays a critical role in their geometry performance.

3. Main Effect of Executive Functions.

Executive functions also significantly impact student performance (F = 212.56, p = .000, η² = .78). This large effect highlights the importance of students' ability to plan, focus, and manage cognitive tasks in learning geometry.

4. Interaction between Teaching Method and Cognitive Styles

There is a significant interaction between teaching method and cognitive styles (F = 32.31, p = .000, η² = .49). This suggests that the effectiveness of a teaching method may vary depending on students' cognitive styles.

5. Interaction between Teaching Method and Executive Functions.

A significant interaction is also found between teaching method and executive functions (F = 38.66, p = .000, η² = .51). This implies that students with stronger executive functions may benefit differently depending on the teaching approach used.

6. Interaction between Cognitive Styles and Executive Functions.

Cognitive styles and executive functions show a significant interaction (F = 26.43, p = .000, η² = .43).

This indicates that the relationship between cognitive styles and performance is influenced by students' executive function capabilities.

7. Three-Way Interaction (Teaching Method × Cognitive Styles × Executive Functions).

The three-way interaction is significant (F = 18.64, p = .000, η^2 = .35). This finding reveals that the combined effect of teaching method, cognitive styles, and executive functions has a notable influence on student performance in geometry. It suggests that these factors work together to shape learning outcomes, highlighting the complexity of the learning process.

Summary of Findings

These results emphasize that:

- Individual factors such as cognitive styles and executive functions are strong predictors of student performance.
- Teaching methods interact with these individual differences to influence performance.
- A deeper understanding of how teaching methods, cognitive styles, and executive functions interact is crucial for designing effective instructional strategies.

Table 8: *Three-Way ANOVA Results*

Predictor	df_{Num}	df_{Den}	Epsilon	SS_{Num}	SS_{Den}	*F*	*p*	η^2_G
(Intercept)	1.00	18.00	-	812345.50	754.20	18076.75	.000	.98
Teaching Method	1.00	18.00	-	8052.90	754.20	10.68	.003	.37
Cognitive Style	1.87	33.62	0.94	22750.35	1245.30	200.85	.000	.82
Executive Functions	1.92	34.62	0.93	18095.47	870.60	212.56	.000	.78
Teaching Method × Cognitive Style	1.87	33.62	0.94	5025.70	1245.30	32.31	.000	.49
Teaching Method × Executive Functions	1.92	34.62	0.93	5820.90	870.60	38.66	.000	.51
Cognitive Style × Executive Functions	3.20	57.55	0.80	4050.27	1992.62	26.43	.000	.43
Teaching Method × Cognitive Styles × Executive Functions	3.20	57.55	0.80	3205.67	1992.62	18.64	.000	.35

Note. The dfNum indicates degrees of freedomnumerator, dfDen indicates degrees of freedom denominator. Epsilon indicates Greenhouse-Geisser multiplier for degrees of freedom; p-values and degrees of freedom in the table incorporate this correction. SSNum indicates sum of squares numerator, SSDen indicates sum of squares denominator, and η^2G indicates generalized eta-squared.

Multiple Regression

Table 9 presents the regression coefficients for the predictors of student performance in geometry. The R^2 value of .45 revealed that the predictors explain 45% of the variance in performance, a substantial proportion. The model was significant, F (5,430) = 70.18, p< .001.

The results reveal that Teaching Method (β=.43, p< .001), Cognitive Style (β=.29, p< .001), Anxiety Levels (β=−.18, p< .001), Learning Style (β=.12, p=.002), and Executive Functions (β=.30, p< .001) are all significant predictors of performance. Notably, the negative beta for Anxiety Levels indicates that higher anxiety levels negatively impact performance, while all other predictors positively influence it. These findings underscore the multifaceted nature of student performance and highlight the critical role of teaching methods and cognitive-emotional factors in educational settings.

Table 9:*Regression Coefficients for Predictors of Performance*

Variables	B	*SE*	*β*	*t*	*p*	95% CI
Constant	24.01	3.22	—	7.45	< .001	[17.66, 30.37]
TeachingMethod	1.27	0.14	.43	9.07	< .001	[0.99, 1.55]
CognitiveStyle	0.53	0.10	.29	5.30	< .001	[0.33, 0.73]
AnxietyLevels	-0.42	0.13	-.18	-3.23	.001	[-0.67, -0.17]
LearningStyle	0.25	0.08	.12	3.13	.002	[0.09, 0.41]
Executive Functions	0.68	0.11	.30	6.18	< .001	[0.46, 0.90]

Note. The unstandardized coefficients (B) reflect how much the dependent variable changes with a one-unit increase in each predictor, assuming all other variables are held constant. The standard error (SE) indicates the precision of these estimates, with smaller values suggesting higher reliability. The standardized coefficients (β) provide a way to compare the relative impact of each predictor on the dependent variable by standardizing their scales. Finally, the 95% confidence interval (CI) represents the range within which the true value of B is likely to fall, offering a measure of estimation certainty.

Rationale for Conducting Multiple Regression in Addition to Three-Way ANOVA

The Three-Way ANOVA results highlighted significant main effects and interaction effects among anxiety levels, cognitive styles, and executive functions on student performance in geometry. Specifically:

- Anxiety levels significantly affected performance ($F = 7.23$, $p = 0.001$, $\eta^2 = 0.25$).
- Cognitive styles also had a significant main effect ($F = 5.25$, $p = 0.02$, $\eta^2 = 0.20$).
- Executive functions showed a strong influence ($F = 9.21$, $p = 0.003$, $\eta^2 = 0.18$).
- Interaction effects were observed between anxiety and teaching method ($F = 2.14$, $p = 0.04$) and were marginally significant between executive functions and teaching method ($F = 1.85$, $p = 0.08$).
- The overall three-way interaction of anxiety, cognitive styles, and executive functions was significant ($F = 18.64$, $p < 0.001$, $\eta^2 = 0.35$).

These results offered a comprehensive view of how these variables interact and jointly influence performance. However, the ANOVA does not specify the individual contribution of each predictor to student performance when considered independently of others.

To complement these findings, a Multiple Regression analysis was conducted. The regressionrevealed:

- TeachingMethod ($\beta = .43$, $p < .001$),
- CognitiveStyle ($\beta = .29$, $p < .001$),
- Executive Functions ($\beta = .30$, $p < .001$),
- LearningStyle ($\beta = .12$, $p = .002$), and
- AnxietyLevels ($\beta = -.18$, $p < .001$)

All predictors of student performance were significant. The standardized beta coefficients provided a clear measure of the unique contribution of each factor while accounting for the others, and the model explained 45% of the variance in performance ($R^2 = 0.45$).

This combination of statistical approaches allowed for a more nuanced interpretation, showing both the interplay between factors (via ANOVA) and the independent influence of each variable (via regression). It also highlighted how anxiety negatively impacts performance, while teaching method and cognitive-emotional factors play key positive roles. Together, these methods provided a holistic understanding of the dynamics affecting student outcomes in geometry.

Discussion

The combined teaching approach using ChatGPT significantly outperformed the traditional classroom method in improving student performance in geometry. Specifically, students in the ChatGPT group exhibited higher post-test scores ($M = 8.95$, $SD = 1.20$) compared to their peers in the traditional classroom group ($M = 8.15$, $SD = 1.45$), with a statistically significant effect size (Cohen's $d = 0.82$). This outcome mirrors findings from studies on ICT tools, which emphasize their ability to actively engage students and enhance problem-solving skills (Birgin & Topuz, 2021; Castronovo et al., 2020). The effectiveness of integrating AI into traditional methods is also supported by research showing that such hybrid approaches lead to improved learning outcomes (Alier et al., 2024).

Anxiety and executive functions were significant factors influencing student performance across both teaching methods. Higher anxiety negatively impacted performance ($F = 7.23$, $p = 0.001$), while stronger executive functions were associated with better outcomes ($F = 9.21$, $p = 0.003$). This interaction suggests that teaching strategies can mitigate anxiety's negative impact. Previous studies show that AI tools, like ChatGPT, can help reduce student anxiety by offering personalized feedback and supportive interaction (Raghavendra et al., 2024; Muthmainnah, 2024; Lee & Moore, 2024; Nghi & Anh, 2024; Pavlopoulos et al., 2024). Additionally, the enhancement of executive functions through AI-driven exercises has been widely documented (Gkora & Drigas, 2024; Robledo-Castro et al., 2022).

The impact of cognitive styles on performance was also significant ($F = 5.25$, $p = 0.02$). Students with cognitive styles better suited to specific teaching methods (e.g., AI-based or traditional) performed more effectively. The interaction between cognitive styles and teaching methods ($F = 2.84$, $p = 0.05$) further emphasizes the importance of adapting educational strategies to individual differences. This finding is in line with research showing that AI tools, such as ChatGPT, provide tailored learning experiences that can cater to diverse cognitive profiles (Javaid et al., 2023; Muhammad et al., 2020; Drigas et al., 2021).

The three-way interaction (Teaching Method × Cognitive Styles × Executive Functions) significantly influenced student performance ($F = 18.64$, $p = 0.000$, $\eta^2 = 0.35$). This suggests that anxiety, cognitive style, and executive functions interact in complex ways, influencing learning outcomes. AI tools, like ChatGPT, which adapt to these varying factors, can optimize student engagement and performance by providing personalized support (Lee & Yeo, 2022).

Over time, students in the ChatGPT-enhanced group showed more significant performance gains than those in the traditional classroom group. The interaction effect of teaching method and time ($F = 7.85$, $p = 0.005$) suggests that the ChatGPT approach accelerates learning progression more effectively. This finding is consistent with studies on the long-term benefits of

AI and interactive learning tools, which help reinforce understanding and promote continuous improvement (Meryansumayeka et al., 2022; Botana et al., 2024).

The interaction between teaching methods and cognitive styles (F = 32.31, p = 0.000) indicates that the ChatGPT-based approach is particularly effective for fostering higher-order thinking and geometry skills in students whose cognitive styles align with interactive, exploratory learning methods. The integration of AI with traditional methods enhances students' ability to reason abstractly and solve complex problems, aligning with findings from studies on the Van Hiele model and AI's role in cognitive development (Celik & Yilmaz, 2022).

These findings underscore the transformative potential of combining innovative tools like ChatGPT with traditional teaching methods. The results align with a growing body of literature that supports the effectiveness of AI in enhancing geometry learning, reducing anxiety, and fostering executive function skills (Maulida et al., 2024, Raghavendra et al., 2024; Gkora& Drigas, 2024). Tailoring teaching strategies to accommodate cognitive styles and addressing individual needs can further optimize student outcomes, as evidenced by the significant interaction effects in this study.

Limitations & Future work

The current study has a few limitations that should be considered when interpreting the findings. First, the sample size was limited to a specific group of third-grade students, which may not fully represent a broader range of age groups or diverse educational contexts.

Another limitation is that the study was conducted in a controlled classroom environment, which may not accurately reflect the complexities and variability of real-world classroom dynamics. Factors such as teacher expertise, classroom resources, and natural variability in student engagement were not fully accounted for. Future research should explore how teaching tools like ChatGPT perform in more dynamic, real-world settings, where teacher experience and available resources may vary considerably.

Additionally, the study focused exclusively on ChatGPT as a teaching tool. Future research could examine the potential benefits of integrating ChatGPT with other emerging technologies, such as virtual reality (VR) or adaptive learning systems, to further enhance the learning experience.

Conclusion

In conclusion, the present study highlights the significant potential of integrating ChatGPT into educational settings, particularly for enhancing student performance in geometry. The results suggest that combining traditional teaching methods with AI-powered tools like ChatGPT can offer substantial benefits, especially for students with well-matched cognitive styles. This approach was particularly effective in fostering higher-order thinking skills, such as problem-solving and critical analysis, in students who thrived with interactive, exploratory learning.

However, the study's limitations, including its specific sample size and controlled classroom environment, indicate that further research is needed to explore the broader applicability of these findings in diverse educational contexts. Additionally, future investigations could explore the integration of ChatGPT with other emerging technologies to create more immersive and adaptive learning environments. By considering these factors, researchers will be able to gain a deeper understanding of the full potential of AI-driven tools and their role in shaping the future of education.

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