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Early geometry teaching and learning: An analysis of early childhood student teachers' geometric reasoning through the van Hiele framework

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Abstract
Geometry is a foundational domain of mathematics, particularly in early childhood education, where it supports the development of spatial reasoning and conceptual understanding. Effective early geometry instruction requires teachers to possess well-developed geometric reasoning aligned with learners' developmental levels. This study examines the geometric reasoning levels of 30 early childhood student teachers enrolled in a Bachelor of Education program at a university in the United Arab Emirates, using the van Hiele theory of geometric thinking as the analytical framework. Data were collected through a 150-item early geometry terminology test assessing level 1-level 3 (visualization, analysis, and informal deduction). Descriptive statistics revealed that student teachers achieved the highest mean scores at level 1 (mean [M] = 65.2, standard deviation [SD] = 21.8), followed by level 2 (M = 62.9, SD = 14.1), with the lowest performance at level 3 (M = 54.9, SD = 11.2). Performance declined progressively across van Hiele levels, consistent with the hierarchical nature of geometric reasoning. No statistically significant differences were observed across years of study. The findings highlight persistent gaps in higher-order geometric reasoning among prospective early childhood teachers and emphasize the need for sustained, theory-driven instructional interventions in teacher education programs to strengthen early geometry teaching and learning. This study contributes to early geometry and teacher education research by demonstrating the diagnostic value of the van Hiele framework for identifying conceptual gaps that persist across years of study.

Keywords: van Hiele theory, geometric reasoning, early geometry, early childhood teacher education, pre-service teachers, spatial reasoning

INTRODUCTION

The National Council of Teachers of Mathematics (NCTM) emphasizes the integration of mathematics in early childhood education as a foundation for later learning and development (NCTM, 2022). Young children are viewed as naturally curious and capable of engaging with mathematical ideas when provided with rich, play-based, and inquiry-oriented learning environments. Such experiences not only support conceptual understanding but also foster positive dispositions toward mathematics, which are critical for sustained engagement across schooling. The early childhood mathematics education curriculum at the university where this study was conducted is aligned with NCTM (2022) principles and standards and aims to prepare student teachers with the knowledge, skills, and dispositions required for effective early mathematics teaching (UAEU, 2024).

This paper is originated from a larger study with undergraduate students in the early childhood Bachelor of Education program at the United Arab Emirates University as part of the Summer Undergraduate Research Experience PLUS initiative.

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Contribution to the literature

- This study provides a diagnostic analysis of early childhood student teachers' geometric reasoning using the van Hiele framework within a Middle Eastern teacher education context.
- It demonstrates the persistence of hierarchical declines in geometric reasoning across van Hiele levels, even across years of study, highlighting structural gaps in teacher preparation.
- The findings support the use of theory-aligned diagnostic assessments to inform the design of sustained, developmentally sequenced geometry instruction in early childhood teacher education programs.

Within the NCTM (2022) framework, geometry in early childhood education emphasizes three core dimensions:

(a) recognizing, naming, and classifying two- and three-dimensional shapes,

(b) describing and comparing geometric attributes and components, and

(c) developing spatial reasoning through the construction, transformation, and decomposition of shapes.

Together, these dimensions aim to cultivate early geometric understanding that supports spatial reasoning and problem-solving from an early age.

Despite the centrality of geometry in early mathematics, research consistently indicates that many teachers lack confidence and conceptual depth in teaching geometry, particularly in relation to naming shapes, describing properties, and reasoning about geometric relationships (Markovits & Patkin, 2021). Jones and Tzekaki (2016) further highlight the importance of visual reasoning and instructional design in supporting learners' transitions from arithmetic to geometric thinking, noting that this shift poses persistent challenges for both learners and teachers.

In alignment with NCTM (2000) geometry standards and the objectives of the Mathematics Education for Young Children (CURR 320) curriculum at a university in the United Arab Emirates (UAE), a broader study was designed to develop and evaluate an instructional framework informed by the van Hiele (1986) theory of geometric thinking.

The present paper reports specifically on the pre-test phase of this broader study. Its purpose is to examine early childhood student teachers' geometric reasoning across the first three van Hiele levels prior to the implementation of the instructional framework. The guiding research question is: How do student teachers' levels of understanding of early geometry concepts vary across the van Hiele levels of geometric reasoning and years of study?

This study contributes to mathematics teacher education research by offering a diagnostic and foundational analysis of early childhood student teachers' geometric reasoning through the van Hiele framework. Rather than merely reporting performance levels, the findings inform the design of theory-driven instructional interventions aimed at strengthening early geometry teaching and learning within teacher education programs.

The Importance of Mathematics in Early Years

Mathematics plays a critical role in children's cognitive development during the early years, supporting the development of problem-solving, reasoning, and conceptual understanding (Wang, 2021). Through everyday activities such as counting, patterning, and shape recognition, young children engage informally with mathematical ideas that form the foundation for later learning (Clements & Sarama, 2021; Ginsburg et al., 2014). These early experiences are particularly important for the development of geometric and spatial reasoning, which underpin later success in mathematics and related disciplines.

The Importance of Geometry in Early Years

Geometry plays a critical role in early childhood development, forming the foundation for children's mathematical understanding, spatial reasoning, and cognitive growth (Clements & Sarama, 2016; Clement et al., 2022). From an early age, children engage intuitively with shapes, space, and patterns in their environment, gradually developing spatial awareness and shape recognition that support both mathematical learning and everyday problem-solving (Elia et al., 2018; Zambrzycka et al., 2017). Research consistently demonstrates that early geometric experiences are predictive of later achievement in mathematics and science, underscoring the long-term importance of early exposure to geometry (Clements et al., 2018; Novita et al., 2018).

Within early childhood education, the NCTM (2022) identifies geometry as a core content domain, emphasizing shape recognition and classification, description of geometric attributes, and the development of spatial reasoning through exploration and transformation of shapes. In alignment with these standards, the CURR 320 course at the selected university focuses on foundational geometric concepts—including lines, triangles, quadrilaterals, circles, similarity, and congruency—which are central to the development of spatial reasoning and logical deduction (Halas et al., 2019; Molina-Ayuso et al., 2023). These content areas provide an appropriate and theoretically grounded basis for examining prospective early childhood teachers' geometric reasoning.

The UAE Context of Early Childhood Education

The early childhood educational sector in the UAE is a multifaceted and diverse system, and it has nuances to it. This can be attributed to the country's demography, as its expatriates form the majority of the population (Baroudi & Haidar, 2025). In the UAE, early childhood education is greatly influenced by the combination of indigenous customs rooted in Islamic principles and contemporary educational methodologies adopted from international practices, creating an exclusive educational environment (Al-Yateem et al., 2023). The UAE's commitment to educational reform, particularly since its founding in 1971, has placed a high priority on the development of human capital, thereby leading to significant investments in both K-12 and higher education to meet the challenges of global competition (Yahya, 2022). This commitment extends to early childhood, where reforms have focused on improving curricula and teacher preparation programs to meet international standards while respecting local cultural contexts (Al Aleeli, 2022).

The UAE Context of Early Childhood Teacher Education

The early childhood teacher education programs in the UAE operate in an era of rapid national educational transformation (Al Aleeli, 2022). The field is undergoing a fast pace of curriculum development (reform), in the effort to enhance quality and strive towards international benchmarks and local cultural values (Dillon, 2019). One of the hardest challenges is training a highly qualified professional workforce to support the needs of this type of education, and this is a core part of the UAE's wider innovation strategy in early childhood education (Dillon, 2019).

The early childhood geometry teacher education landscape in the UAE faces several challenges (Dillon, 2019). One of the main issues is the lack of specialized training programs that focus on geometry education for early childhood teachers (Kesicioğlu, & Mart, 2022). This gap in professional development opportunities hampers teachers' ability to effectively introduce geometric concepts to young learners. In addition, there is a dearth of contextually relevant resources and teaching materials that align with the cultural and educational context of the UAE. To address these problems, it is crucial to develop comprehensive training programs and culturally appropriate educational resources. In line with NCTM (2000) geometry standards and the objectives of the curriculum for CURR 320, this study tried to develop and evaluate the effectiveness of an instructional framework based on two prominent theories, van Hiele (1986) theory and mathematical knowledge for teaching Ball et al. (2008). The geometric content for the pre- and post-tests was selected from concepts fundamental to primary education, as commonly outlined in widely used mathematics textbooks. This paper reports on the pre-test written by the early childhood student teachers on the early geometric concepts. Six geometric concepts were chosen from those that are common to widely used primary school mathematics textbooks were used as the content for the geometry teaching and learning. They are lines (parallel and perpendicular); triangles (right triangles, isosceles triangles); quadrilaterals (rectangles, squares, parallelograms, trapezium, and kites); circles similarity, and congruency.

The Van Hiele Theory

The van Hiele (1986) theory provides a robust theoretical lens for understanding how learners develop geometric reasoning through qualitatively distinct and hierarchically ordered levels. Central to the theory is the premise that progression through the levels is not age-dependent but instruction-dependent, requiring carefully sequenced learning experiences that align with learners' current modes of reasoning (Arnal-Bailera & Manero, 2024; Vojkuvkova, 2012). This assumption is particularly critical in early geometry, where learners' thinking is grounded in perceptual and experiential encounters with shapes and space rather than formal definitions or deductive structures.

At level 1 (visualization), learners recognize shapes based on their overall appearance and visual prototypes rather than properties. In early childhood contexts, this level is characterized by naming shapes such as "triangle" or "square" based on familiar orientations or everyday objects, without attention to defining attributes (Clements & Sarama, 2020; Elia et al., 2018). Research consistently shows that both children and pre-service teachers often remain at this level when instructional experiences emphasize labeling over reasoning (Markovits & Patkin, 2021).

Level 2 (analysis) marks a shift from holistic recognition to an explicit focus on properties and attributes of shapes. Learners begin to identify characteristics such as parallel sides, equal angles, or symmetry, although these properties are not yet logically connected across shape classes (van Hiele, 1986). In early geometry education, this level is foundational for understanding classification and comparison of shapes, which are core components of NCTM (2022) early geometry standards. However, studies indicate that pre-service early childhood teachers often demonstrate fragmented analytical knowledge, particularly when distinguishing between related quadrilaterals or explaining why a shape belongs to a given category (Halas et al., 2019; Kesicioğlu & Mart, 2022).

Level 3 (informal deduction) involves reasoning about relationships between properties and across classes of shapes, allowing learners to form logical arguments and generalizations. Although formal proof is not expected at this level, learners can justify why all squares are rectangles or explain the conditions for similarity and congruence (van Hiele, 1986). In the context of early childhood teacher education, competence at this level is essential for meaningful instructional explanations, responsive questioning, and the design of learning trajectories that support children's progression beyond visual recognition (Clements et al., 2018; Eshetu et al., 2022).

The hierarchical and cumulative nature of the van Hiele levels implies that weaknesses at lower levels constrain reasoning at higher levels. Empirical studies across diverse contexts consistently report a decline in performance as tasks demand higher van Hiele reasoning, particularly among pre-service teachers (Arnal-Bailera & Manero, 2024; Vojkuvkova, 2012). This theoretical principle directly underpins the present study, as it provides a coherent explanation for variations in student teachers' performance across level 1-level 3 and highlights the necessity of targeted instructional interventions aligned with learners' current geometric reasoning levels.

MATERIALS AND METHODS

Research Design

This paper forms part of a broader study designed to develop and evaluate an instructional framework informed by the van Hiele theory of geometric thinking and mathematical knowledge for teaching. The broader study adopted a one-group pre-/post-test quasi-experimental design. However, the present paper reports only on the pre-test phase of the study.

Specifically, it examines early childhood student teachers' geometric reasoning levels based on their performance on the early geometry terminology test (EGTT) prior to the implementation of the instructional intervention. The focus of this analysis is therefore descriptive and diagnostic, aiming to establish a baseline profile of student teachers' geometric reasoning across the first three van Hiele levels.

Participants

Student teachers enrolled in the CURR 320 course were purposively selected as participants for this study. This course is part of the Bachelor of Education course in early childhood education. According to the university's regulations, a student can sign up for a course depending on his or her study plan and students from different years of study can enroll for a particular course.

Table 1. EGTT item description

Item description	Number
Total number of items	150
True/false items	49
Multiple choice questions items	101
van Hiele level 1 items	40
van Hiele level 2 items	70
van Hiele level 3 items	40

The CURR 320 a one-semester course taken once during the four-year program that the student teachers need to do during the four years of the program. A total of 30 female student teachers participated in the study, of which 10, 16, and 4 student teachers were from year 1, year 2, and year 3, respectively. The student teachers were predominantly Emirati student teachers aged between 18 and 24.

Instruments

The EGTT was developed to assess student teachers' geometric reasoning across the first three van Hiele levels: visualization (level 1), analysis (level 2), and informal deduction (level 3) (**Table 1**). Test items were systematically constructed and mapped a priori to van Hiele levels and to six core geometric content areas commonly addressed in primary mathematics curricula: lines (parallel and perpendicular), triangles (right and isosceles), quadrilaterals (rectangles, squares, parallelograms, trapeziums, and kites), circles, similarity, and congruency.

The EGTT comprised 150 items, including 49 true/false items and 101 multiple-choice items. The distribution of items across van Hiele levels was designed to reflect increasing cognitive demand, with 40 items at level 1, 70 items at level 2, and 40 items at level 3. The instrument was intended as a diagnostic, theory-aligned assessment tool rather than a standardized achievement test. While items were developed based on established theoretical and curricular principles. Formal psychometric validation (e.g., internal consistency indices) was not conducted; however, the internal content validity of the instrument was examined through expert review by two mathematics education lecturers involved in teaching the course, who evaluated item alignment with van Hiele levels and core geometric concepts.

Scoring and Van Hiele Level Coding

Each of the 150 EGTT items was mapped a priori to one of the first three van Hiele levels of geometric reasoning. Student teachers' responses were scored using an answer key, with each correct response awarded one point, yielding a maximum possible score of 150. Scores were aggregated by van Hiele level to examine patterns of geometric reasoning across increasing levels of cognitive demand.

Table 2. EGTT performance comparisons of van Hiele levels of geometric reasoning across years of study

Variable	Year of study	N	M	SD	Minimum	Maximum	Skewness	Kurtosis
Level 1	1	10	66.8	26.2	30	93	-0.58	-1.75
	2	16	66.0	20.4	25	93	-0.50	-0.79
	3	4	57.5	18.5	30	70	-1.90	1.71
Level 2	1	10	62.2	14.3	40	81	-0.16	-1.33
	2	16	64.7	15.2	34	86	-0.52	-0.39
	3	4	57.6	9.48	46	69	-0.29	1.36
Level 3	1	10	53.0	9.92	37	68	-0.51	-0.54
	2	16	55.1	13.2	28	75	-0.46	-0.18
	3	4	58.8	4.33	55	65	1.54	2.89

Ethical Considerations

Ethical approval was obtained from the university to conduct the study (ethics approval no: ERSC_2024_4786). Informed consent was obtained from all participants. Student teachers were assured of voluntary participation and the right to withdraw at any time without academic consequence. All responses were anonymized through coded identifiers, and results were reported in aggregate form to preserve confidentiality. Data were stored securely and accessible only to the research team. The study adhered to the ethical standards for educational research throughout all phases.

Data Collection Procedures

Data were collected during the regular delivery of the CURR 320 course. The EGTT was administered to participating student teachers prior to the implementation of the instructional framework as part of the broader study. Participation was voluntary, and all students completed the test under standardized conditions during scheduled course time.

Data Analysis

Quantitative data were analyzed using descriptive statistics to examine student teachers' performance across van Hiele levels and years of study. One-way analysis of variance (ANOVA) were conducted to explore differences in geometric reasoning across year groups. Effect sizes were reported using eta squared (η^2) to support interpretation of the results. Given the relatively small and uneven group sizes, statistical power was limited, and inferential findings are interpreted cautiously.

RESULTS AND ANALYSIS

Table 2 presents descriptive statistics for student teachers' geometric reasoning across the three van Hiele levels and years of study. Skewness and kurtosis values indicate no extreme departures from normality; however, given the relatively small sample size, these statistics are interpreted cautiously. Notable variability is observed, particularly at level 1, where the overall standard deviation (standard deviation [SD] = 21.8) reflects a wide range of proficiency among student teachers at this foundational level.

The findings in **Table 2** illustrate variations in the van Hiele levels of geometric reasoning among student teachers across different years of study for early geometry concepts. Overall, student teachers demonstrated the highest mean score at level 1 (visualization), with an average of 65.2 (SD = 21.8), suggesting stronger proficiency at this foundational level. Level 2 (analysis) showed a moderate level of understanding, with a mean score of 62.9 (SD = 14.1), slightly below level 1. The lowest mean score was observed at level 3 (informal deduction), with a score of 54.9 (SD = 11.2), reflecting weaker reasoning skills at this more advanced geometric reasoning stage.

When comparing performance across years of study, first-year students at level 1 scored relatively high (mean [M] = 66.8), and second-year students scored similarly (M = 66.0), but third-year students had a noticeable decline in performance (M = 57.5). A similar trend was observed at level 2, where second-year students had the highest mean score (M = 64.7), followed by first-year students (M = 62.2), and again, third-year students scored the lowest (M = 57.6). At level 3, however, third-year students scored the highest (M = 58.8), while first-year and second-year students scored lower (M = 53.0 and M = 55.1, respectively). These results suggest that while student teachers' geometric reasoning tends to be strongest at level 1, it weakens at more advanced levels, particularly at level 3.

Furthermore, the progression across years of study is not necessarily associated with improved reasoning levels, with third-year students performing worse than their junior counterparts at level 1 and level 2. In other words, student teachers' understanding of early geometry concepts at the first three van Hiele levels does not vary significantly across years of study. The ANOVA results in **Table 3**, and the mean plots in **Figure 1** confirm that the differences observed across years of study are not statistically significant.

Performance declined progressively across van Hiele levels, which is consistent with the hierarchical nature of geometric reasoning proposed by van Hiele theory. When comparing performance across years of study, descriptive differences were observed across van Hiele

Table 3. ANOVA test results for EGTT

van Hiele level	Source of variation	Sum of squares	df	Mean square	F	p	η^2
Level 1	Between groups	273.7	2	136.9	0.275	.762	0.020
	Within groups	13,455.8	27	498.4			
	Total	13,729.6	29				
Level 2	Between groups	168.0	2	84.0	0.407	.670	0.029
	Within groups	5,572.9	27	206.4			
	Total	5,740.9	29				
Level 3	Between groups	96.0	2	48.0	0.365	.698	0.026
	Within groups	3,549.9	27	131.5			
	Total	3,645.8	29				

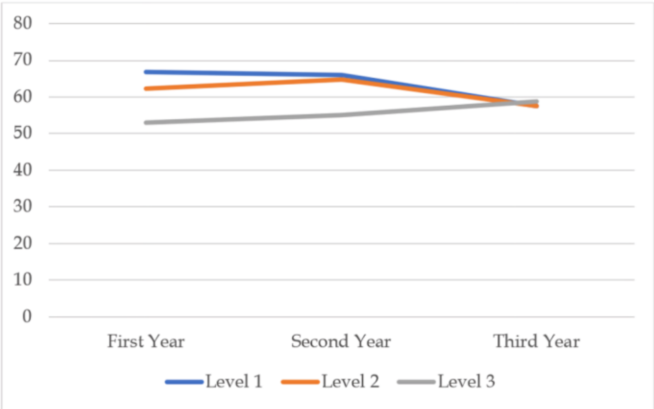

Figure 1. Mean plots across years of study (Source: Authors' own elaboration, based on EGTT data)

levels. However, these differences were not consistent across levels and did not follow a clear developmental pattern. Importantly, the ANOVA results presented in **Table 3** indicate that none of the observed differences across years of study were statistically significant. Given the small and uneven group sizes, these findings should be interpreted cautiously, and no definitive conclusions regarding progression across years of study can be drawn.

Based on the results in **Table 3**, none of the three van Hiele levels reflect any statistically significant differences among the three levels of study. Additionally, all the associated effect sizes (represented by η^2) were small and insignificant. Therefore, while the descriptive statistics in **Table 2** suggest trends in student teachers' geometric reasoning, the ANOVA results indicate that these trends are not statistically significant. These findings highlight potential gaps in developing geometric reasoning skills regardless of year of study. They could inform the design of interventions to improve early geometry teaching and learning among student teachers.

All associated effect sizes (η^2) were small, indicating that year of study accounted for only a minimal proportion of variance in geometric reasoning scores across van Hiele levels.

DISCUSSION

The findings of this study indicate that the participating early childhood student teachers demonstrated generally low to moderate levels of geometric reasoning, with an average performance of approximately 61% on the EGTT. This pattern suggests that most student teachers operated predominantly at van Hiele level 1 and level 2, with more limited evidence of reasoning at level 3. As the present analysis reports on the pre-test phase of a broader instructional study, these findings are interpreted diagnostically, offering insight into student teachers' baseline geometric reasoning prior to targeted instructional intervention.

These findings are consistent with a substantial body of research reporting that pre-service teachers often possess fragile conceptual understanding of geometry, particularly beyond visual recognition and basic property identification (Kesicioğlu & Mart, 2022; Markovits & Patkin, 2021).

The observed decline in mean scores across successive van Hiele levels is consistent with the hierarchical progression of geometric reasoning proposed by van Hiele (1986). Student teachers performed strongest at level 1 (visualization), where tasks rely on perceptual recognition and familiar prototypes, and weakest at level 3 (informal deduction), which requires relational and justificatory reasoning. Similar patterns have been reported in studies involving both pre-service teachers and school learners, suggesting that advancement to higher van Hiele levels remains a persistent challenge across educational stages (Alex & Mammen, 2012; Eshetu et al., 2022; Vojkuvkova, 2012).

The particularly low performance at level 3 is of concern in the context of early childhood teacher education. Informal deductive reasoning is critical for teachers' ability to explain why shapes belong to particular categories, to respond meaningfully to children's misconceptions, and to design learning experiences that promote conceptual coherence rather than rote naming. Without adequate competence at this level, teachers may unintentionally reinforce superficial geometry instruction focused on labels rather than relationships (Clements & Sarama, 2020; Clements et al., 2018).

However, given the diagnostic nature of the assessment and the study's sample size, these findings should be interpreted as indicative rather than conclusive. Another noteworthy finding of the study is that no statistically significant differences in geometric reasoning were detected across years of study. While descriptive variations were observed, these did not follow a consistent developmental pattern and were not statistically significant. Given the small and uneven group sizes, the absence of detected differences should not be interpreted as evidence that progression does not occur. Rather, the findings suggest that, within the present sample, differences across years of study were not sufficiently pronounced to be identified through inferential analysis. Similar concerns have been raised in international research, which highlights that limited instructional time, isolated geometry courses, and insufficient emphasis on reasoning-based pedagogy may hinder conceptual growth among pre-service teachers (Jones & Tzekaki, 2016; Molina-Ayuso et al., 2024).

Within the UAE context, these findings highlight the importance of strengthening early childhood teacher education in geometry as the education system continues to align with international standards while remaining responsive to local curricular priorities. Developing teachers' geometric reasoning is particularly important for ensuring that early mathematics instruction extends beyond shape naming toward conceptually coherent and developmentally appropriate learning experiences.

Overall, the findings affirm the theoretical validity of the van Hiele framework for diagnosing and interpreting student teachers' geometric reasoning and provide a compelling rationale for the design of instructional interventions explicitly aligned with van Hiele levels. Such interventions have the potential to strengthen prospective teachers' conceptual understanding and, in turn, enhance the quality of early geometry learning experiences for young children.

Taken together, the findings not only illuminate student teachers' current geometric reasoning profiles but also point to structural and pedagogical gaps within early childhood teacher education. These gaps necessitate a reconsideration of how geometry is positioned, taught, and assessed within teacher preparation programs. The following section therefore outlines key implications for early childhood teacher education, grounded in the van Hiele theoretical framework and informed by the empirical evidence of this study.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the sample size was relatively small (n = 30), with uneven group sizes across years of study, which limited statistical power and reduced the likelihood of detecting statistically significant differences. Consequently, the findings should be interpreted cautiously and are not intended to be generalized beyond the study context.

Second, the EGTT was designed as a theory-aligned diagnostic instrument to examine geometric reasoning across the first three van Hiele levels rather than as a standardized achievement measure. While formal psychometric validation (e.g., internal consistency indices) was not conducted, the internal content validity of the EGTT was examined through expert review by two mathematics education lecturers, which partially supports the interpretability of the findings.

Finally, as this paper reports only on the pre-test phase of a broader instructional study, the findings reflect student teachers' baseline geometric reasoning prior to intervention. Future research incorporating larger samples and post-intervention analyses is needed to examine developmental change and instructional impact more robustly.

CONCLUSIONS AND RECOMMENDATIONS

This study contributes to research on early geometry and teacher education by providing a diagnostic analysis of early childhood student teachers' geometric reasoning through the lens of the van Hiele theory. The findings indicate that student teachers predominantly operated at the lower van Hiele levels, with performance declining as tasks required higher-order reasoning. This pattern is consistent with the hierarchical structure of geometric thinking proposed by van Hiele and highlights persistent challenges in developing informal deductive reasoning among prospective early childhood teachers.

Importantly, the absence of statistically significant differences across years of study suggests that, within the present sample, progression through the teacher education program was not associated with detectable differences in geometric reasoning levels. Given the diagnostic nature of the analysis, the relatively small sample size, and the limited statistical power, these findings should be interpreted cautiously and should not be taken as definitive evidence of a lack of developmental growth.

From an early childhood teacher education perspective, the findings highlight the need for geometry instruction that extends beyond shape recognition and basic property identification toward relational and justificatory reasoning aligned with higher van Hiele levels. Distributing geometry learning longitudinally across coursework and practicum experiences, rather than confining it to a single course, may better support conceptual progression. Explicit integration of the van Hiele framework as both a pedagogical and diagnostic tool can help student teachers recognize their own reasoning limitations while learning to scaffold children's geometric thinking effectively. In addition, the use of diagnostic assessments, such as the EGTT, may support formative decision-making in teacher preparation programs, particularly in contexts such as the UAE where early childhood education must align international standards with local curricular priorities.

From a teacher education perspective, the findings underscore the need for sustained and developmentally sequenced geometry instruction that explicitly supports progression across van Hiele levels. Integrating theory-informed instructional approaches, such as the van Hiele framework, across coursework and practicum experiences may better support student teachers in developing the conceptual depth required for effective early geometry instruction.

From a research perspective, this study highlights the value of theory-aligned diagnostic assessments for identifying foundational gaps in geometric reasoning among pre-service teachers. Future research should build on this work by employing larger samples, incorporating longitudinal or post-intervention data, and examining the impact of targeted instructional frameworks on the development of geometric reasoning over time. Strengthening prospective teachers' geometric reasoning has the potential to enhance the quality of early geometry learning experiences and to support children's long-term mathematical development.

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AI statement: The authors stated that they used generative AI tools for language editing and stylistic refinement only. No AI tools were used for data analysis, interpretation of results, or generation of research findings. All intellectual content, analysis, and conclusions remain the responsibility of the authors.

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REFERENCES

Al Aleeli, S. (2022). Empowering female pre-service teachers through culturally responsive teaching: Shared and divergent views of Arab and expatriate teacher educators in the United Arab Emirates. *Education 3-13, 50*(5), 592-611. https://doi.org/10.1080/03004279.2021.1876133

Alex, J. K., & Mammen, K. J. (2012). A survey of South African grade 10 learners' geometric thinking levels in terms of van Hiele theory. *The Anthropologist, 14*(2), 123-129. https://doi.org/10.1080/09720073.2012.11891229

Arnal-Bailera, A., & Manero, V. (2024). A characterization of van Hiele's level 5 of geometric thinking using the Delphi methodology. *International Journal of Science and Mathematics Education, 22*, 537-560. https://doi.org/10.1007/s10763-023-10380-z

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education, 59*(5), 389-407. https://doi.org/10.1177/0022487108324554

Baroudi, S., & Haidar, H. (2025). Sustainability in the United Arab Emirates secondary schools: A policy practice analysis. *Sustainability, 17*(7), Article 3129. https://doi.org/10.3390/su17073129

Clements, D. H., & Sarama, J. (2016). Math, science, and technology in the early grades. *The Future of Children, 26*(2), 75-94. https://doi.org/10.1353/foc.2016.0013

Clements, D. H., & Sarama, J. (2020). *Learning and teaching early math: The learning trajectories approach*. Routledge. https://doi.org/10.4324/9781003083528

Clements, D. H., Sarama, J., & Joswick, C. (2022). Learning and teaching geometry in early childhood. In A. Sharif-Rasslan, & D. Hassidov (Eds.), *Special issues in early childhood mathematics education research* (pp. 95-131). Brill. https://doi.org/10.1163/9789004510685_005

Clements, D. H., Sarama, J., Swaminathan, S., Weber, D., & Trawick-Smith, J. (2018). Teaching and learning geometry: Early foundations. *Quadrante, 27*(2), 7-31.

Dillon, A. (2019). Innovation and transformation in early childhood education in the UAE. In K. Gallagher (Ed.), *Education in the United Arab Emirates* (pp. 27-42). Springer. https://doi.org/10.1007/978-981-13-7736-5_2

Elia, I., van den Heuvel-Panhuizen, M., & Gagatsis, A. (2018). Geometry learning in the early years: Developing understanding of shapes and space with a focus on visualization. In V. Kinnear, M. Y. Lai, & T. Muir (Eds.), *Forging connections in early mathematics teaching and learning* (pp. 73-95). Springer. https://doi.org/10.1007/978-981-10-7153-9_5

Eshetu, D., Atnafu, M., & Woldemichael, M. (2022). The effectiveness of guided inquiry-based technology integration on pre-service mathematics teachers' understanding of plane geometry. *Journal of Pedagogical Research, 6*(4), 84-100. https://doi.org/10.33902/JPR.202215241

Ginsburg, H. P., Hyson, M., & Woods, T. A. (Eds.). (2014). *Preparing early childhood educators to teach math: Professional development that works*. Paul H. Brookes Publishing.

Halas, Z., Robová, J., Moravcová, V., & Hromadová, J. (2019). Students' concepts of the trapezoid at the end of lower secondary level education. *Open Education Studies, 1*(1), 184-197. https://doi.org/10.1515/edu-2019-0013

Jeremiah, S., & Bosede, E. F. (2021). Effect of constructivist instructional strategy on students' achievement in secondary school mathematics curriculum in Rivers State. *Journal of Education, Society and Behavioural Science, 34*(10), 47-56. https://doi.org/10.9734/jesbs/2021/v34i1030362

Jones, K., & Tzekaki, M. (2016). Research on the teaching and learning of geometry. In A. Gutiérrez, G. Leder, & P. Boero (Eds.), *The second handbook of research on the psychology of mathematics education: The journey continues* (pp. 109-149). Sense Publishers. https://doi.org/10.1007/978-94-6300-561-6_4

Kesicioğlu, O. S., & Mart, M. (2022). Preschool teachers' opinions on teaching geometry. *Southeast Asia Early Childhood Journal, 11*(2), 21-36. https://doi.org/10.37134/saecj.vol11.2.2.2022

Leavy, A., Pope, J., & Breatnach, D. (2018). From cradle to classroom: Exploring opportunities to support the development of shape and space concepts in very young children. In V. Kinnear, M. Y. Lai, & T. Muir (Eds.), *Forging connections in early mathematics teaching and learning* (pp. 115-138). Springer. https://doi.org/10.1007/978-981-10-7153-9_7

Markovits, Z., & Patkin, D. (2021). Preschool in-service teachers and geometry: Attitudes, beliefs, and knowledge. *International Electronic Journal of Mathematics Education, 16*(1), Article em0619. https://doi.org/10.29333/iejme/9303

Molina-Ayuso, Á., Adamuz-Povedano, N., Bracho-López, R., & Torralbo-Rodríguez, M. (2024). Computational thinking with Scratch: A tool to work on geometry in the fifth grade of primary education. *Sustainability, 16*(1), Article 110. https://doi.org/10.3390/su16010110

NCTM. (2000). Principles and standards for school mathematics. *National Council of Teachers of Mathematics*. https://www.nctm.org/standards-and-positions/principles-and-standards

NCTM. (2022). Mathematics in early childhood learning: A position of the National Council of Teachers of Mathematics. *National Council of Teachers of Mathematics*. https://www.nctm.org/earlychildhoodmath/

Novita, R., Putra, M., Rosayanti, E., & Fitriati, F. (2018). Design learning in mathematics education: Engaging early childhood students in geometrical activities to enhance geometry and spatial reasoning. *Journal of Physics: Conference Series, 1088*, Article 012016. https://doi.org/10.1088/1742-6596/1088/1/012016

United Arab Emirates University (UAEU). (2024). Bachelor of education in early childhood education. *United Arab Emirates University*. https://www.uaeu.ac.ae/en/catalog/undergraduate/programs/bachelor-of-education-in-early-childhood-education.shtml

van Hiele, P. M. (1986). *Structure and insight: A theory of mathematics education*. Academic Press.

Vojkuvkova, I. (2012). The van Hiele model of geometric reasoning. In *Proceedings of the WDS'12* (pp. 72-75). MATFYZPRESS.

Wang, W. (2021). The characteristics of preschool mathematics education in the United Kingdom and its inspiration. In *Proceedings of the 6th Annual International Conference on Social Science and Contemporary Humanity Development* (pp. 321-325). Atlantis Press. https://doi.org/10.2991/assehr.k.210121.068

Yahya, K. (2022). Female Emirati teachers' perceptions of postgraduate degree attainment in the UAE. *Gulf Education and Social Policy Review, 2*(2), 144-170. https://doi.org/10.18502/gespr.v2i1.10046

Zambrzycka, J., Kotsopoulos, D., Lee, J., & Makosz, S. (2017). In any way, shape, or form? Toddlers' understanding of shapes. *Infant Behavior and Development, 46*, 144-157. https://doi.org/10.1016/j.infbeh.2016.12.002