

Applications of Artificial Intelligence (AI) among Active Learning Strategies to Enhance Geometrical Thinking Competencies among Secondary Students

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Abstract

This research evaluates the development of Geometric thinking competencies of secondary students for (85) students in the Education Directorate of "Baghdad/ Karkh – III" for the academic year (2024/2025). This was achieved by training them on an educational unit based on active learning strategies and artificial intelligence (AI) applications, as well as preparing a test for geometric thinking competencies according to the skills of (visualization, analysis, inference, understanding relationships, and creativity and innovation) and monitoring their responses to a test in geometric thinking competencies, The test was constructed by the researcher based on "Van Hiele's hierarchical framework" of Geometric thinking, in addition to verifying its psychometric properties. The results classified students within the defined geometric thinking competencies, and also showed that applying the educational unit according to active learning strategies and artificial intelligence (AI) applications had an impact. The researcher recommended redesigning Geometry units in light of the teaching and learning model proposed by "Van Hiele Framework" including its descriptive and inferential skills, and studying the impact on the development of geometric thinking levels among students.

Keywords: Active Learning Strategies, Artificial Intelligence Applications, Geometric Thinking, Secondary School Students.

Introduction

Mathematics has played an important role in scientific thought as a model of truth, precision, and rational thinking, providing the tools and foundation for other sciences, in addition to its abstract nature that has prompted educational policies to examine and scrutinize further; in order to keep pace with the natural methodology of mathematical truth, and to unify the branches of mathematics into a cohesive entity, which has led to a high level of inspiration in technical development and the design of models and patterns that deepen mathematical thinking and relational understanding. As one of the mathematical structures that require further abstraction and generalization, and the development of logical inferential capacities in fields of mathematical thinking; geometric thinking; with its conceptual, analytical, and inferential levels and understanding of logical relationships.

Khoh (1992) pointed out that geometric thinking requires teaching practices by teachers to guide educational planning in a way that makes classroom activities effective for learning. Determining the level of thinking for a particular student or group is not important in itself, but what matters is the teacher's ability to select and use appropriate activities for students based on their level of thinking. Geometry can be meaningful for the student and allow progression from one level to another, and ignoring this leads to conceptual errors and reliance on rote memorization and mechanical application of rules.

Clements, Swaminathan, Hannibal, and Sarama (1999) discussed the question "Is Geometric thinking visual or non-visual?" and whether images are limited to fixed visual patterns or encompass flexible, dynamic, abstract, and transformable pictorial knowledge. They emphasized that cultivating the appropriate abstract understanding—one that integrates active and reflective visualization, including the capacity to deliberately manipulate mental images rather than relying solely on drawings—is an achievable objective across all levels of thinking. Moreover, building a clear and robust comprehension of the elements and properties of geometric shapes necessitates exposure to a variety of contexts.

According to Van de Walle (2001), Geometry instruction in the K- 8 curriculum should focus on core elements like points and lines while remaining sensitive to student understanding, he argued that instructional activities must be carefully calibrated so they do not exceed a students comprehension level. This approach allows teachers to implement a variety of tasks that are specially designed to elevate a students Geometric thinking from their current baseline.

Jones (2002) discussed Geometric thinking as a subject that provides a rich cultural and historical context through which mathematics can be practiced and stimulated students' desire to learn more and understand the reasons behind it. Presenting Geometry in a way that inspires curiosity and encourages exploration can enhance student learning and attitudes by encouraging them to discuss problems in Geometry, express their ideas, and develop clearly organized arguments to support their perceptions, thus improving connecting skills and acknowledging the importance of proof, he added that planning methods for teaching Geometric thinking must ensure that learning fosters enthusiasm by providing opportunities to explore spatial ideas and solve real -life problems. Furthermore, there is a necessity to ensure a solid understanding of fundamental concepts and the language of Geometric to establish a foundation for future work and empower students at levels of Geometric thinking.

Yin (2003) also highlighted the importance of the teacher's role in attending to students' levels of geometric thinking from the moment they enter the classroom. Teachers should begin by observing and documenting evidence of each student's level, then design instruction that aligns with these levels in order to support progression to more advanced thinking. Additionally, teachers are encouraged to engage in interviews with students to gain deeper insight into their geometric understanding, rather than relying solely on written assignments and tests.

Khasawneh (2007) highlighted the importance of Geometric thinking at all school levels, aiming to

enhance students' ability to classify and model two-dimensional and three-dimensional Geometric shapes, analyze the characteristics and distinguishing features of those shapes, and improve their ability to select and use different representation systems such as coordinate geometry. It is crucial to understand the role of Geometric transformations and symmetry in analyzing mathematical situations, as well as to possess the ability using visual representations and spatial reasoning to solve problems within mathematics and beyond. In her study, she referred to the (NCTM, 2000) standards within the realm of geometry and spatial sense, which assumes that students from (9th - 12th) grades are ready to enter the stage of reasoning and proof capability. The preceding stages, comprising concepts, properties, and Geometric relationships, are foundational and prerequisites for teaching and learning geometry for students in these grades. It also includes developing students' ability to justify and think both inductively and deductively using examples, non-examples, and counter-examples to explore ideas and formulate and verify conjectures.

Luneta (2014) highlighted the role of geometric thinking in helping students understand shapes and their properties through visualization and physical representations, supported by structured and applied instruction. Geometric thinking may be described as the development and use of formal conceptual systems to explore shapes and space, enabling learners to solve geometric problems with deeper conceptual understanding. In this way, spatial reasoning is strengthened an essential component across all areas of mathematics which involves the ability to think and reason through comparison and the transformation of mental images."

Luneta (2015) confirmed that process worldwide cover four main outcomes in geometry that students should be able to achieve by the time they complete their studies: Exploring the properties and links between 2D and 3D shapes within Euclidean Geometry pinpointing locations and articulating spatial associations through coordinate systems; utilizing symmetry and Geometric transformations to evaluate mathematical scenarios; and leveraging spatial reasoning, visualization, and Geometric models for problem- solving.

Clements et al. (2019) supported the mechanism for improving Geometric thinking by transitioning from implicit sensory and concrete levels, where cognitive factors (building strong conceptual images) are involved, to clearer, more verbal generalizations and abstractions that distinguish the integrated concrete concepts (including rooted mental images and related verbal schemas that generate increasingly complex and robust processes and abstractions) by encouraging students to develop language through anticipating and accepting visual descriptions (model-based) and promoting responses related to attributes and characteristics.

Hohol (2020) defined Geometric thinking through its stages, which are: the perceptual stage, where students understand Geometric shapes as a whole visually, even considering the elements, parts, and Geometric properties; the descriptive or analytical stage, where integration with nature and the relationships between them is possible; the extract or the relational phase, characterized by the learners capacity to grasp the nested and hierarchical connections between various Geometric

concepts and their underlying properties, concerning necessary and sufficient conditions; formal inference, at this stage, students learn definitions, axioms, theorems, and proofs; the highest stage is the meta -mathematical level, which describes mathematicians who understand the relationships between Euclidean and non-Euclidean geometry.

Balasa, Mohammed, (2021) discussed that the hierarchical of Geometric cognition according to John A. Van de Walle can be understood as suggesting that, for students to learn school geometry in the traditional Euclidean manner, they need to interpret and translate axioms, definitions, and theorems into constructions they can actively build and visualize.

However, the thinking processes that students undergo while learning Geometry may not be the same for each of them at the same time. Due to their poor performance in the subject, researchers were inspired to explore the role that studied activities play in developing and understanding Geometric thinking among students by posing the question, 'Do the studied activities play any role in developing stages of Geometric thinking among students?'

Trimurtini, Waluya, Sukestiyarno, and Kharisudin (2022) discussed Geometric thinking through its interconnected levels, starting from the level characterized by recognizing Geometry through shape; the level characterized by recognizing the properties and relationships between Geometric shapes; the level identified by a meaningful definition of Geometry due to the relationship between the perceived Geometric shapes based on their properties and form; the level characterized by meaningful conclusions and the verification and understanding the rule of definitions and axioms, It also involves grasping the sufficient conditions and the reasoning processes required at each stage of a proof, as well as reaching a level characterized by an understanding of formal deductive reasoning where symbols are manipulated according to the rules of logic and recognizing the role and necessity of indirect evidence and counterexamples.

Saralar -Aras, Birgili (2022) discussed the commonalities of Geometric thinking levels with natural sciences are examined, where scientists utilize engineering knowledge and skills; despite the numerous In the context of Geometric education various determinants influence the learning process, these include individual human traits (such as cognitive aptitude and drive), societal influences (including gender dynamics and economic background), and institutional factors (such as academic policies and faculty quality) notably, the study emphasizes that educators remain the primary catalyst for academic achievement wielding the most significant impact through their instructional methods and classroom engagement.

Khalaf (2022) confirmed that artificial intelligence (AI) algorithms provide cognitive and skill-based activities that enhance students' knowledge and skills interactively, in addition to integrating the virtual environment with the real world, and employing augmented reality with AI software to achieve quality education based on problem-solving and future foresight, and to stimulate the latent potentials of students to transform theoretical knowledge into practical applications in the fields of engineering, science, and mathematics, and to gradually prepare students with innovative digital skills.

Faris (2024) mentioned the use of artificial intelligence in identifying students' learning styles and tailoring appropriate educational content for them, including providing suitable educational materials that match each student's level. AI can enhance students' understanding of mathematics and improve their mathematical abilities by designing interactive and innovative educational programs that help students grasp mathematical concepts better and strengthen their computational skills. It also involves analyzing the methods they use to solve mathematical problems and providing immediate feedback and guidance to help improve their problem-solving strategies and understand mathematical concepts more effectively.

In the same context, Wang Wei (2025) highlighted the importance of effectively integrating digital applications into educational practices related to Geometric thinking, while practical activities and group discussions can provide opportunities for hands-on application, enhance social interaction, and the need to design applications that are not only engaging but also educationally meaningful, incorporating adaptive educational interfaces and algorithms, the effectiveness of digital tools should be carefully balanced to support complex educational objectives such as abstraction and problem-solving, particularly in Geometric thinking, which requires spatial understanding.

As discussed by Dimitriadou and Lanitis (2025) Geometric thinking features a very strong visual and spatial component, which can therefore be analyzed very well through artificial intelligence (AI) models to train students and assist teachers driven by the revolutionary capabilities of AI, as the field of geometry is currently experiencing a noticeable transformation, with this advanced technology not only providing solutions to complex geometry problems but also leading to pioneering innovations in design.

Jones (2002) noted the complexity in learning demonstration and the abundance of evidence indicating how difficult this is for students, and that there are some studies showing that students can learn proof mathematically. Proof serves many functions including communication, discovery, intellectual challenge, verification, and organization, which must be conveyed effectively if proofs and assertions are to be meaningful activities.

Pusey (2003) argued that the poor performance of students in geometry reflects the challenge present in teaching geometry at all educational levels. In light of this challenge, a reasonable question to consider is the extent of exposure that teachers had to geometry as a subject, in addition to the amount of training they received in teaching geometry, given that teacher preparation programs can be designed to meet the needs for developing students' Geometric thinking, alongside practical ideas for teaching geometry, which closely align with the application of modern practical contexts.

Turgut, Yenilmez, Anapa (2014) confirmed that the weakness in performance at Geometric thinking levels is manifested in the teacher's lack of knowledge about student performance at an early stage of learning, by investigating how concepts such as rotation are represented. Students concentrated on equality and how parts correspond when reflected across a line of symmetry, as well as the symmetry observed when a shape is visually folded along that line, including the equality of side lengths and

angle measures in certain shapes. This underscores the urgent need to translate Geometric concepts using educational software that supports both conceptual and procedural understanding of these concepts.

In the same context, Luneta (2014) addressed the definition of misconceptions in Geometric thinking as 'cognitive difficulties that hinder students from mastering any area of knowledge', Misconceptions may arise from 'misapplication of a rule, excessive or insufficient generalization, or alternative conceptions of a situation'. He considered misconceptions to be a 'natural stage of conceptual development'. In order for students to confront the fundamental conceptual difficulties in geometry, it is essential to overcome misconceptions as they are 'simple symptoms of the difficulties faced by the student during the experience of learning.'

Regarding the studies that addressed the applications of artificial intelligence aimed at developing levels of Geometric thinking, we present the following in order from the most recent to the oldest:

Wang and Wei (2025) investigated two educational platforms featuring distinct interface styles, three-dimensional and horizontal. The study used a between-group experimental design to examine whether preschool children in China could develop geometric perception through these platforms and to compare how effectively knowledge was transferred across different interface styles. The findings indicate that well-designed educational applications can support students' cognitive development. They also show that the design of the learning interface plays a significant role in platform effectiveness, with three-dimensional interfaces yielding better performance in more complex tasks.

Polydoros et al. (2025) explored the synergy between ChatGPT and conventional teaching methods on the Geometric thinking of third-grade students, based on Piaget's and Van Hiele's theories. The sample included 436 students from Greece, divided equally into an experimental group and a control group, with 218 students in each. Their performance was assessed in areas such as symmetry and two-dimensional shapes, along with learning styles, thinking styles, and applied problem-solving tasks. The findings showed that the experimental group outperformed the control group in geometric reasoning, reflecting a stronger understanding and application of geometric properties. The data analyses affirmed the effectiveness of the integrated educational curriculum, highlighting its significant impact on Geometric thinking.

Tandililing, Sirampun, Kho, and Ruamba (2025) adopted a qualitative descriptive approach to explore the levels of Geometric thinking among (8th) grade students in Indonesia, using the Van Hiele Model to examine students' understanding of quadrilaterals. It addressed common misconceptions and limited comprehension by investigating how students classified, identified, and described the properties of these shapes. The sample consisted of 25 students selected through purposive sampling. Data were gathered using structured interviews, drawing tasks, and classification activities. The primary instrument included three tasks: drawing different quadrilaterals, identifying and defining their properties, and classifying them based on shared attributes.

The findings revealed that 50% of the students were at Level 0 (visualization), 36% were transitioning between Level 0 and Level 1 (analysis), and only 14% reached Level 1. Students tended to rely on visual appearance rather than formal geometric properties, which contributed to persistent misunderstandings about the relationships between different shapes. The results also underscored the need for instructional approaches that incorporate cultural relevance, utilize dynamic visual tools, and support learning to enhance geometric thinking.

Baez, Sanchez, Sandeep, and Pillana (2025) discussed the positive aspects of artificial intelligence in education through a high school Geometric project in the United States, which was part of an innovative initiative created by a mathematics teacher who utilized artificial intelligence to verify the effectiveness of a tool composed of two slides: the first slide provides solutions to problems and informal guides for Geometric examples, while the second slide contains a piece of art where students filling a drawing with triangles, removing the original template, transforming and coloring the triangles. Once the students complete the two slides, they write a paragraph reflecting their work on the second slide, and they upload their drawings to an artificial intelligence tool for redrawing, after which they review their designs based on reflective paragraph and writing another paragraph integrating insights gained from artificial intelligence to confirm the technology's constructive role in fostering critical thinking and creativity.

Mosia and Egara (2024) discussed how digital storytelling impacts the achievements and retention of secondary school learners in circular geometry using a quasi -experimental design with an unequal control group. The sample consisted of (132) final -year students in Nigeria, and a multi -step sampling procedure was employed, with the selected classes divided into experimental control groups. The Geometry Achievement Test (GAT), consisting of (30) multiple -choice questions aligned with core geometry theories, was administered. The results indicated that the experimental group performed significantly better in both achievement and information retention, highlighting the effectiveness of digital storytelling as an advanced instructional technique.

Obara, Nie (2023) conducted a case study with high school teachers who participated in a three-year professional development project in dynamic geometry in the United States, focusing on the effective use of dynamic geometry programs to improve student learning in geometry. Interviews were conducted with the teachers applying a task-based interview protocol regarding the relationship between triangles. The interviews were recorded, including the teachers' work on video, transcribed, and analyzed based on the three levels of Geometric thinking: recognition, analysis, and inference. It was found that the participating teachers demonstrated their skills and Geometric thinking in construction, exploration, and reasoning in a DG environment. The study indicates that the DG environment provides an effective platform for examining teachers' thinking in geometry.

Gao (2023) discussed the development of the first dynamic professional online mathematics Programme in China based on the super sketchpad, named Net Pad, primarily used to serve science education. A sample was selected from middle school students in Beijing as experimental subjects,

where research methods such as questionnaires and tests were applied to collect data for the research process. Two classes were randomly selected to participate in the teaching experiment. The research results show that teaching mathematics at the middle school level with the help of Net Pad in the topic of 'shapes and geometry' can better stimulate students' interest in mathematics, enhance their ability to understand plane geometry, develop their spatial imagination, exercise their thinking skills, and help them master good learning instructions.

MdYunus, Ayub, and Hock (2019) identified levels of Geometric thinking according to van Hiele among learners in primary schools in Malaysia through the application of three different teaching strategies based on study units for (3) groups of students: the van Hiele Learning Stages Unit (VH-PL), which guides students through the learning process towards levels of Geometric thinking; the van Hiele theory integrated with the Google SketchUp Programme (VH-GSU); and the use of traditional teaching (NVH-CI). The study sample included 96 fifth-grade students, and data were collected using Geometry (WGT) and answer samples used; the results showed improved student performance across levels of Geometric thinking.

Rizki, Frentika, and Wijaya (2018) explored adaptive thinking among junior high school students and the level of Geometric thinking according to van Hiele in Indonesia, using a quasi-experimental methodology within an unequal control group, with a sample consisting of (34) 7th-grade students with (35) 8th-grade students in the experimental group, and (34) seventh-grade students and (34) eighth-grade students in the control group. The students in the experimental classes learned geometry using the Knisley model. The results of the data analysis showed an improvement in adaptive thinking skills in both seventh and eighth grades, and an improvement was also found in the level of Geometric thinking according to van Hiele. These results indicate the positive impact of the Knisley learning model on adaptive thinking skills and the level of Geometric thinking.

Kospentaris, Vosniadou, Kazi, and Thanou (2016) developed Visual Analytical Strategy Test (VAST) to investigate the use of spatial visual and analytical strategies in geometry with a sample consisting of thirty mathematics teachers and (134) eleventh -grade students in Greece. Students' performance on the VAST was compared to their performance on visual-spatial ability tests, abstract reasoning, and Geometric knowledge. The results showed high performance for all participants on the VAST items that could be solved using spatial visual strategies, and mathematics teachers demonstrated high performance on the VAST items that required the application of analytical Geometric strategies. There were also strong correlations between students' performance on visual-spatial ability tests and abstract reasoning.

A case study was conducted by Abd Wahab, et al., (2015) to assess spatial visual skills and the level of Geometric thinking among gifted students in India. The study sample consisted of (133) students, and a testing tool was applied to measure the performance of spatial visual skills. The test measured five spatial visual abilities, such as combining two-dimensional dimensions, rotation, and slicing. Spatial visual skills were tested using a standard test for mental spatial visualization, while the Van

Hiele Geometric thinking test (v HGT) was used to determine the level of Geometric thinking among the students. The results showed that the students' mental abilities in rotation and slicing were low, and the level of Geometric thinking among the study sample was at a concerning level, with the vast majority of students at the lowest level (level L1).

Meng (2009) investigated the learning of first-year Geometric students in a stage-based educational environment using Geometer's Sketchpad (GSP) according to Van Hiele's model in Malaysia, focusing on cubes and rectangular cuboids, and how their levels changed after stage-based education using GSP within a case study design with a sample of (6) participants. The results revealed that the initial levels of the students ranged from level (0) to level (2), and after the stage-based education using GSP, their levels increased.

Kotzé (2007) focused on providing activities for teachers and learners that assess basic skills in understanding Geometric concepts. The methodology included a case study investigating spatial awareness, with a sample consisting of (29) teachers and (290) students in South Africa. Evidence was gathered regarding the knowledge of mathematics teachers and their students in the concepts of space and shape. The challenges faced in forming and analyzing Geometric concepts were examined, and a description was provided of how teachers and learners responded to problems related to space and shape. Additionally, information on the athletic performance of a group of mathematics teachers and their students was organized, interpreted, and evaluated.

Study Problem

Numerous studies have been conducted on the difficulties of Geometric thinking, focusing on identifying the level of thinking. Geometric thinking difficulties are indicated through its hierarchical model, which students advance through to reach a higher level as their ideas about engineering concepts develop. Gaps were found in reliance on traditional methods of education and the provision of means to improve concentration and attention to students' thinking in engineering in order to reach the appropriate level for mastering the concepts in the basic stage successfully.

As identified by the researcher through their presence in the educational field, students exhibit weaknesses in thinking skills, which inspire difficulties for them; consequently, many students are unable to retrieve the necessary information from the provided data and face challenges in interpreting answers and drawing conclusions. Additionally, the difficulties in understanding geometry concepts and problem-solving are attributed to weak visual-spatial skills, and challenges in analyzing, interpreting, and understanding what students see and hear, considering that visual-spatial skills are part of the cognitive abilities necessary for learning geometry. There is also evidence that the educational difficulties students face in applying geometry are related to weakness and inconsistency in branches of Geometric thinking according to Van Hiele's Framework, which suggests that students have a poor understanding of Geometric concepts, as reflected in their performance in formal Geometric proofs, which scored poorly.

Research indicates key factors in the effectiveness of artificial intelligence-based interventions for learning mathematics, where the educational design should be based on pedagogical considerations rather than being directed by the constraints of artificial intelligence.

Teacher must organize learning by integrating results from technology-rich activities and the educational context, which includes attending to important aspects such as student motivation and interaction. In light of this, this study aims to identify the skills of Geometric thinking (mental visualization, analysis, deduction, understanding relationships, creativity, and innovation) among first-year secondary students in the Directorate of Education in Baghdad/Karkh 3^d. Thus, the research problem is defined by answering the following questions:

- Can AI applications improve Geometric thinking based on skills (mental visualization, analysis, inference, understanding relationships, creativity and innovation) according to active learning strategies?
- What is the level of Geometric thinking based on skills (mental visualization, analysis, inference, understanding relationships, creativity and innovation) among tenth-grade students?

Hence, the following hypothesis arises: "There are no statistically significant differences at the significance level $\alpha < 0.05$ in the skills of Geometric thinking among first-year secondary students (mental visualization, analysis, inference, understanding relationships, creativity and innovation) attributed to the teaching method according to active learning strategies."

Objectives of the Study

The fields of research in geometry have diversified in general; among them are research and studies that addressed the effectiveness of using artificial intelligence in teaching geometry through the impact of multiple programming languages on learning geometry, computer-aided design programs, and the use of the Geometer's Sketchpad and other programs developed in light of artificial intelligence programs. Other studies have addressed the use of activities and practical applications in teaching geometry, and Geometric thinking is considered one of the central pillars in school mathematics curricula across all educational stages, encompassing the study of plane, analytical, and spatial (three-dimensional) geometry in various grade levels. The current study aims to understand the physical world surrounding the student, comprehend Geometric models, develop analytical skills and solve Geometric problems, understand abstract and symbolic representations of Geometric concepts, recognize Geometric shapes and their properties as well as the relationships between those properties, and enhance spatial ability through drawing, creating, measuring, visualizing, comparing, and classifying Geometric shapes. A student who develops an understanding of spatial relationships and is aware of Geometric concepts will be better prepared to learn numerical ideas, measurement, and advanced mathematical topics.

Importance of the Study

This study presented a theoretical framework and previous studies addressing the applications of artificial intelligence and Geometric thinking skills, and provided a theoretical framework for teachers to undertake real and practical actions to improve engineering thinking skills. The study also gains importance through the general framework of mathematics curricula adopted by educational institutions, which aims to equip learners with future skills and incorporate those skills, especially concerning the applications of artificial intelligence in curricula. The study includes measuring the extent to which these concepts and applications are integrated into mathematics curricula to enhance Geometric thinking. Its importance from a practical standpoint lies in the novelty of the study and its ability to provide the Iraqi Ministry of Education with indicators regarding the degree of incorporation of artificial intelligence concepts and applications into mathematics curricula, thereby contributing to the development of educational programs. The study also offers an educational model that can be utilized to enhance Geometric thinking skills among secondary school students within active learning strategies.

Study Methodology

The researcher used an experimental method with a quasi-experimental design for a single group to investigate the impact of the application of artificial intelligence according to active learning strategies aimed at improving Geometric thinking skills. A Geometric thinking test (pretest – posttest) was prepared based on skills (mental visualization, analysis, inference, understanding relationships, creativity and innovation), and the educational unit was implemented according to active learning strategies.

Participants

The sample consisted of secondary students affiliated with the Baghdad Education Directorate /Karkh (III) for the second semester of the academic year (2024/2025). The sample of the study comprised (85) students, selected through convenience sampling. The group underwent a pretest for Geometric thinking, followed by the implementation of an educational unit that included applying artificial intelligence tools based on active learning strategies, and then a posttest for Geometric thinking was conducted.

Study Tools

The Guidance:

In order to achieve the study's objectives and answer its questions, an educational unit was prepared that includes Geometric concepts integrated according to the matrix of range and sequence. The unit included the essential components for constructing two-dimensional and three-dimensional Euclidean geometry, as well as a set of undefined concepts: points, lines, and planes, and a set of definitions: straight points, planar points, intersecting lines, parallel lines, angles and their measures, the

perpendicularity of a line to a plane, and vertical projection which includes: The perpendicular projection of a point onto a plane, the perpendicular projection of a point onto a line, the perpendicular projection of a line segment onto a line, the perpendicular projection of a line segment onto a plane, and the angle between a line and a plane. In the current study, the skills of Geometric thinking were applied, which include: mental visualization, analysis, inference, understanding relationships, creativity, and innovation, in light of using artificial intelligence sites for teaching Geometric concepts, including: <http://Easy-Peasy.ai>; <http://mathigon.org>; <http://brilliant.org>; in order to analyze the impact of using AI applications in teaching geometry concepts, to recognize the effectiveness of these applications in enhancing class participation and interaction, and to present them as a practical proposal relying on AI with the aim of improving geometric thinking.

Geometric Thinking Test:

The previous theoretical and research literature was reviewed and considering the content of Geometric thinking level tests, the researcher constructed this test based on the characteristics of each level of Geometric thinking from "Van Hiele" levels. What distinguishes the test is that it included an integrated three-dimensional geometric structure, taking into account the components of mathematical construction in general, in addition to achieving the "Van Hiele" levels and the educational and learning experiences they require. In light of the above, (70) test items were prepared distributed as follows: (10) for the skill of mental visualization, (15) for the skill of analysis, (14) for the skill of deduction, (16) for the skill of understanding relationships, and (15) for the skill of creativity and innovation. The test initially consisted of 45 multiple-choice items with four options each, 25 open-ended problem-solving items, and constructing a Geometric proof for situations in geometry.

The initial version of the test was presented to a number of specialists to assess content validity. The test was also trailed with a sample of (40) students outside the main study sample, and students' responses to the test items were analyzed to find the difficulty and discrimination indices, as well as the correlation of each item with the overall test and its skills (mental imagery, analysis, deduction, understanding relationships, creativity, and innovation). To support the reliability of the test, a score of (75%) was set as the criterion for student success on (30%) of the test questions, due to the variety of these questions and the diverse skills assessed in Geometric thinking. The overall test reliability coefficient was calculated using the (Livingston) formula and was found to be (0.81). The reliability coefficients for each skill tested were calculated in the same way, yielding values of (0.78, 0.84, 0.77, and 0.89) respectively.

A score of one was given for a correct answer on multiple-choice questions, and zero for an incorrect answer. Due to the multiple branches of the test items, a score of (75%) and above was adopted as a criterion for student success on each item. An item was awarded one mark if the criterion score of (75%) or above was achieved, and zero otherwise. Additionally, items that required proof construction were given marks if they provided correct, sequentially justified steps, and zero

otherwise. The correlation coefficient for the items with the test was established within the range of (-0.14 - 0.19), while the discrimination indices ranged from (0.29 - 0.73). Thus, the Geometric thinking test, in its final form, consists of (70) items that possess appropriate and acceptable difficulty, discrimination, and correlation coefficients for the purposes of this research.

In addition, the correlation coefficients of the components of the skill of mental imagery with its domain, the correlation coefficients of the components of the skill of analysis with its domain, the correlation coefficients of the components of the skill of inference with its domain, the correlation coefficients of the components of the skill of understanding relationships with its domain, and the correlation coefficients of the skill of creativity and innovation with its domain within the categories: (0.28 – 0.73) (0.38 – 0.76) (0.29 – 0.77) (0.38 – 0.82) (0.37 – 0.79) In succession, all of which are statistically significant ($\alpha < 0.05$).

Study Procedures

1. Identify the targeted Geometrical concepts.
2. Select artificial intelligence applications (such as 3D programs, simulation applications).
3. Implement teaching using these tools with the students.
4. Collect data through observation and tests.
5. Analyze the results and compare them with the previous level.

Study Limitations

There are several issues that may limit the generalizability of the results of this study, contributing to the interpretation of its findings, most notably: the difficulty of selecting a representative sample of questions for each skill of Geometric thinking (visualization, analysis, inference, understanding relationships, creativity and innovation). The study was limited to the application of active learning strategies, and the study sample consisting of first-year secondary school students appears homogeneous in terms of their background in secondary education, as well as their formal study of the unit on geometry; this background may not be sufficient to reveal a specific pattern in mastering Geometric thinking skills. Additionally, the mastery of each skill among the Geometric thinking skills defined by the researcher may correspond to the researcher's observations through previous literature related to Geometric thinking. The application of the study was limited to the second semester of the (2024/2025) academic year at the Directorate of Education in Baghdad/Karkh (III), and the sample was conveniently selected to include (85) first-year secondary students.

Results

To answer the first question, "Can artificial intelligence applications improve Geometric thinking according to skills (mental visualization, analysis, inference, understanding relationships, creativity and innovation) according to active learning strategies?" the study sample's performance on the

Geometric thinking skills test was analyzed. A criterion for student success was established for each Geometric thinking skill, with a correct answer to (75%) of the questions indicating mastery of mental visualization skills, (70%) indicating analysis skills, (65%) or more indicating inference skills, (60%) or more indicating understanding relationships skills, and (55%) or more indicating creativity and innovation skills. In all these cases, a student's mark is one (1) and otherwise zero.

Thus, each student is given a specific pattern for their performance; for example, the code (11111) means that the student scored a (1) in each of the skills defined for study purposes, indicating that they achieved or exceeded the benchmark on all skills. The code (00001) means that the student scored a (1) only on the first skill and zero on the remaining skills, while the code (01101) means that the student scored a (1) on the first, third, and fourth skills and zero on the second and fifth skills, and so on. The student has been classified within one of the engineering thinking skills based on the sequence of their benchmark achievement in the defined skills. For instance, a student classified under the response pattern (01111) is considered to have mastered the first four skills (mental visualization, analysis, inference, understanding of relationships), reflecting a noticeable improvement in students' understanding of Geometric concepts. Therefore, the accepted patterns are: (00000) meaning that the student did not successfully pass any of the specified Geometric thinking skills according to the benchmark score, (00001) indicating that only the first skill was passed, (00011) indicating that only the first and second skills were passed, (00111) indicating that the first three skills were passed, and (11111) meaning that all have been passed. Subsequently, the percentages of students who recorded these response patterns were calculated, and Table (1) summarizes the percentage of students distributed by the different performance patterns.

Table (1): Percentage distributed according to performance patterns in Geometric thinking test

skills	Frequency		Percentage %	
	Pre	post	pre	post
00000*	55	30	65	35
00001*	39	46	46	54
00011*	34	51	40	60
00111*	39	46	46	54
01111*	25	60	29	71
11111*	27	58	32	68
10000	19	67	22	79
11000	22	63	26	74
11100	36	49	42	58
11110	23	62	27	73
10101	42	43	49	51
00010	27	58	32	68
00100	15	70	18	82
01000	27	58	32	68
10000	30	55	35	65

Table (1) shows that (54%) of the total students have mastered the skill of mental imagery in the post-

test, that (60%) of the total students have mastered the skill of analysis in the post-test, that (54%) of the total students have mastered the skill of inference in the post-test, that (71%) of the total students have mastered the skill of understanding relationships in the post-test, and that (68%) of the total students have mastered the skill of creativity and innovation in the post-test. This aligns with the total students who have mastered all the skills, which is (68%). In addition to the above, the frequencies and percentages were calculated for the Sample in the post-test who achieved the benchmark score on the test items for each of the Geometric thinking skills, and Table (2) shows those percentages.

Table (2): The percentage on the post-measurement of Geometric thinking

skills	Frequency		Percentage %	
	pre	post	pre	post
mental visualization	19	66	22	88
Analysis	17	68	20	80
Inference	26	59	31	69
understanding relationships	29	56	34	66
creativity and innovation	45	30	53	49

Table (2) presents the percentage of the sample who achieved the benchmark score or higher for each skill in the engineering thinking test increased progressively, with the lowest percentage for creativity and innovation skills, followed by the skill of understanding relationships, then the skill of inference, followed by analysis skill, and the highest for mental imagery skill. It is noted that the percentages for achieving the benchmark score across all skills were logical and realistic. For the second question, "What is the level of Geometric thinking according to the skills of mental visualization, analysis, inference, understanding relationships, creativity, and innovation among tenth-grade students?" Therefore, the following hypothesis arises: "There are no statistically significant differences at the significance level of $\alpha < 0.05$ in the Geometric thinking skills of first secondary school students (mental visualization, analysis, inference, understanding relationships, creativity, and innovation) attributable to the teaching method according to active learning strategies." The percentages for the sample were calculated based on the application of the educational unit and the Geometric thinking test (pre-test and post-test). Table (3) summarizes the percentages of sample within each skill distributed according to the test application.

Table (3): percentage in Geometric thinking skills (pre – post)

skills	mental visualization	analysis	inference	Understanding relations	creativity, and innovation	(χ^2)
pre	% 6.8	% 6.3	% 25.1	% 4.7	% 24.3	74.569
post	% 18.8	% 14.2	% 45.3	% 28.9	% 39.8	

Subsequently, a chi-square test of independence was employed to reveal the significance of differences in the percentages between the pre-test and post-test performances of sample on each Geometric thinking skill. The calculated chi-square value was (74.569), which is statistically significant, indicating that there is a difference between the study sample's performance on the pre-test and post-test of Geometric thinking. The correlation in sample's performance on the Geometric

thinking test is attributed to the application of the educational unit. In order to reveal the strength of the relationship, correlation coefficient (ϕ) was calculated and its value was found to be (0.54), which is statistically significant. Subsequently, the standardized residual test was used for the dimensional differences to uncover the sources of the differences in sample's performance on the Geometric thinking test (pre – post) as shown in Table (4).

Table (4): Values of the standard residual according to Geometric thinking

skills	mental visualization	analysis	inference	Understanding relations	creativity, and innovation
pre	1.4	1.4	- 4.5	- 0.1	- 3.2
post	1.4-	- 1.4	4.5*	0.1	3.2*

*The standard residual is statistically significant if the absolute value is greater than 2.

It is clear from Table (4) that the source of the differences between the classifications of the study sample on the Geometric thinking skills test is classified by the skill of deduction, where the standard residual for the post-application on the deduction skill was (4.5), and the skill of creativity and innovation was (3.2). To measure the extent of the difference in performance of sample on Geometric thinking test according to each of the Geometric thinking skills, a repeated measures (ANOVA) was used.

Given the differences in the number of items for each Geometric thinking skill, where the mental imagery skill has (10) items, the analysis skill (15) items, the inference skill (14) items, the understanding relationships skill (16) items, and the creativity and innovation skill (15) items, the mean for each skill was adjusted to be out of (100) for all skills, and Table (5) shows Means and Standard-Deviations after the adjustment for the performance of the sample according to Geometric thinking skills.

Table (5): means, standard deviations for the performance by skills

skills	No.	mean		Standard deviation	
		pre	post	pre	post
mental visualization	85	45	77	20.7	19.33
Analysis	85	34	65	24.65	20.21
Inference	85	66	75	24.04	22.01
understanding relationships	85	25	45	21.68	19.65
creativity and innovation	85	36	53	23.32	20.21

* The maximum mark for each level after adjustment = (100)

Table (6) presents a summary of the results of the one-way (ANOVA) with repeated measurements on the sample's performance based on Geometric reasoning skills.

Table (6): Results of (ANOVA) according to Geometric thinking skills

Variance	df	Sum of squares	Mean of squares	F	η^2
Between skills	4	3392.131	848.033	14.322	0.68
Between participants	84	4973.542	59.209		
Error	987	1470.431	1.489		
Total	1075	97765.874	90.945		

Table (6) shows statistically significant differences in the performance of first-year secondary students on the thinking skills test attributed to Geometric thinking skills, with a recorded F value of (14.322) which is statistically significant. The effect size (η^2) was calculated to be (0.68), meaning that (68%) of the students' performance on the Geometric thinking test is attributed to the application of the educational unit according to active learning strategies and applications of artificial intelligence, while the remainder is attributed to other influences.

Discussion

The results of the current study in the field of applying a proposed instructional unit according to active learning strategies in light of artificial intelligence applications indicate that the engineering thinking skills, as concluded by the study, showed expected and logical percentages for the skills of mental visualization and analysis, while the remaining skills, represented in inference and understanding relationships, creativity and innovation, were below the desired level. This perhaps requires more attention, as they need a mathematical foundation based on undefined terms, defined terms, and postulates. Additionally, these skills require visual educational tools that may not have been available for this group of students, as well as the ability for spatial visualization and in three dimensions. It is clear that the subject of three-dimensional geometry emphasizes, in a balanced way, the use of visual skills; this is achieved through the representation of all postulates and theories with accompanying visual practical means, and descriptive skills; that is, using language, as there are many undefined terms and precise definitions, postulates and theories, and logical skills; which involve formulating proofs.

This in itself constitutes diverse experiences that have led to a hierarchy in thinking skills among first-year secondary students, with clear individual differences resulting in a variety of skills, and the logical ability, usually associated with higher levels, was found to be superior to spatial ability, which is primarily linked to visual and descriptive analytical skills. In conclusion, the results of this study call for further research in the field of engineering, using larger samples from different areas of those who are and will be exposed to this topic in the future, while focusing on developing measurement tools that possess a high degree of validity and reliability in this field. Since exploratory studies are considered a starting point for experimental studies, the researcher recommends conducting a study related to redesigning engineering units in light of the teaching and learning model proposed by "Van Heel" with its descriptive and inferential skills, and studying the impact of that on developing levels of engineering thinking among students.

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