THE INTEGRATION OF GEOGEBRA 3D TECHNOLOGIES IN PRIMARY GEOMETRY EDUCATION: DEVELOPING CREATIVE PROBLEM-SOLVING SKILLS

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ABSTRACT

This study explores the application and impact of GeoGebra 3D dynamic mathematics software in primary school geometry education, focusing on its role in fostering creative problem-solving skills among young learners. In alignment with Uzbekistan's national educational mandates, abstract spatial concepts in 3D geometry—which often pose significant cognitive challenges for primary students—are addressed through dynamic visual integration. By incorporating GeoGebra 3D interactive visualizations into the primary curriculum, abstract geometric shapes and spatial relationships are transformed into tangible, interactive experiences.

Through an action research methodology involving structured lesson modules, real-time shape manipulation, and open-ended spatial tasks, students engage in visual exploration, hypothesis testing, and collaborative problem-solving. Findings indicate that the integration of GeoGebra 3D significantly enhances students' spatial visualization abilities, boosts creative thinking, and transforms traditional passive learning into an active, inquiry-based process. The paper concludes with pedagogical recommendations for educators on incorporating 3D dynamic tools into early mathematics instruction.

Introduction

Mathematics education at the primary level forms the foundational bedrock for structural logic, analytical thinking, and spatial reasoning. In the context of national educational reforms, the integration of digital technologies and innovative pedagogical frameworks into mathematics instruction is explicitly mandated by the Law of the Republic of Uzbekistan "On Education" [1] and the Presidential Resolution No. PR-4708 "On Measures to Improve the Quality of Education and Develop Research in the Field of Mathematics" [2]. Among its various branches, geometry plays a crucial role in helping young learners understand, interpret, and navigate the physical world around them. However, traditional geometric instruction heavily relies on static, two-dimensional media such as textbooks and blackboards. This traditional approach creates a cognitive disconnect when primary students attempt to grasp complex three-dimensional (3D) spatial relationships, volume, and geometric transformations [3]. Consequently, many students view geometry as an abstract collection of rigid formulas rather than a dynamic exploration of space.

To overcome these instructional limitations, the integration of Educational Technologies—specifically Dynamic Mathematics Software (DMS)—has emerged as a transformative pedagogical framework. GeoGebra 3D offers an interactive, visual environment where geometric shapes can be manipulated, rotated, unfolded, and reconstructed in real time [4]. For primary learners, this dynamic visualization bridges the gap between concrete sensory experience and abstract mathematical reasoning. Instead of passively receiving information, students actively manipulate 3D models, test hypotheses, and discover geometric properties through trial and error.

Furthermore, integrating GeoGebra 3D directly addresses the critical need to cultivate creative problem-solving skills in early education. Modern pedagogical approaches emphasize that learning mathematics is not merely about finding a single correct answer, but about developing flexibility, original thinking, and divergent reasoning. By engaging with open-ended spatial tasks within a 3D digital ecosystem, primary students are encouraged to approach geometric problems from multiple perspectives, design unique structural solutions, and articulate their reasoning visually.

This paper examines the integration of GeoGebra 3D technologies into the primary geometry curriculum. It explores how interactive visual tools enhance spatial visualization, foster learner autonomy, and stimulate creative problem-solving capacity. Ultimately, the study highlights effective pedagogical strategies for transitioning primary geometry education from traditional static instruction toward an active, technology-enhanced learning paradigm.

ANALYSIS AND RESULTS

The integration of dynamic mathematics technologies into primary geometry education provides opportunities to move beyond static representations and promote exploratory, visual, and inquiry-based learning. In particular, three-dimensional digital environments can support learners in constructing, manipulating, and examining geometric objects from different perspectives. Such interaction is important in primary geometry because spatial reasoning involves the ability to mentally represent, transform, and interpret spatial relationships.

GeoGebra provides a dynamic mathematical environment in which geometric objects can be constructed and modified interactively. Its three-dimensional environment extends these possibilities by allowing learners to work with points, lines, planes, solids, measurements, and transformations within a spatial representation. From a pedagogical perspective, the value of such technology is not limited to visualization; rather, it can facilitate exploration and encourage learners to investigate mathematical relationships through dynamic representations [5].

Development of Spatial Visualization

One of the principal outcomes associated with the integration of GeoGebra 3D is the potential development of pupils' spatial visualization. Primary school learners frequently encounter three-dimensional objects through two-dimensional drawings. Although such representations are useful, they may require learners to mentally reconstruct the spatial structure of an object. Interactive 3D representations provide an alternative by enabling pupils to rotate and inspect objects from different viewpoints.

Spatial visualization is recognized as an important component of mathematical learning. The ability to mentally manipulate and transform spatial objects contributes to understanding geometric relationships and solving spatial problems. Digital dynamic environments may strengthen this process by allowing learners to externalize and manipulate representations that would otherwise have to be maintained mentally.

For example, when pupils construct a cube in GeoGebra 3D, they can identify its faces, edges, and vertices while simultaneously rotating the model. The interaction between visual perception and manipulation can help learners establish relationships between the different elements of a three-dimensional object.

Influence on Creative Problem-Solving

A second important dimension concerns the development of creative problem-solving. Creativity in mathematics is frequently associated with the generation of multiple approaches, flexibility in mathematical thinking, originality, and the ability to elaborate or justify solutions [6].

In a traditional geometry lesson, pupils may primarily follow a demonstrated procedure to obtain an expected answer. A dynamic 3D environment creates conditions in which pupils can modify geometric objects, test conjectures, compare configurations, and investigate alternative solutions.

For instance, pupils may be asked to construct a rectangular prism with a specified volume and investigate how changing one dimension influences the other dimensions. Rather than applying a formula mechanically, pupils can manipulate the model and observe the consequences of their decisions. They can formulate a conjecture, test it through the model, and subsequently explain whether the conjecture is mathematically valid.

Such activities correspond to important dimensions of mathematical creativity, including:

Fluency – generating several possible approaches to a problem;

Flexibility – changing strategies or representations;

Originality – producing less conventional solutions;

Elaboration – developing and explaining a solution in greater detail.

Research on multiple-solution mathematical tasks indicates that allowing learners to generate and compare different solutions can provide opportunities for the development and assessment of mathematical creativity [6]. Therefore, GeoGebra 3D can be particularly useful when it is incorporated into open-ended and exploratory geometry tasks rather than being used only to demonstrate predefined constructions.

Interactive Construction as a Learning Strategy

The analysis also highlights the importance of construction-based activities. Instead of presenting pupils with completed geometric figures, teachers can formulate tasks that require learners to construct the relevant object themselves.

For example, pupils may receive the following task:

"Construct a rectangular prism whose length is twice its width. Change the dimensions while keeping the volume constant. Describe what happens to the height."

The task requires pupils to identify relationships between several geometric quantities. The dynamic model provides immediate visual feedback and allows learners to test different configurations.

Such a learning cycle is consistent with inquiry-oriented approaches to mathematics education, in which learners are encouraged to explore mathematical relationships and develop explanations rather than simply reproduce procedures[7].

The role of technology in this process is therefore closely connected with the design of the learning task. The presence of a digital tool alone does not guarantee conceptual learning. Meaningful learning emerges when technological affordances are connected with appropriate mathematical questions and opportunities for reflection.

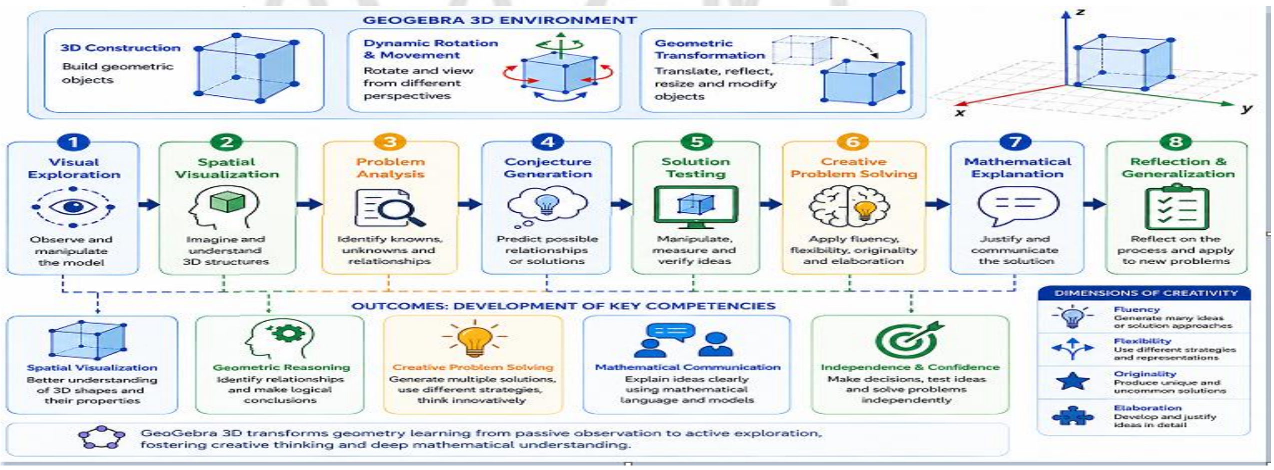
3.4. Development of Mathematical Communication

Another important result concerns mathematical communication. During 3D activities, pupils can be required not only to construct geometric objects but also to explain the reasoning underlying their constructions.

For example, pupils may be asked to explain why two objects have the same volume, identify which dimensions have changed, or describe the relationship between length, width, and height. In this context, mathematical vocabulary becomes connected with visual and manipulable representations.

Terms such as *face, edge, vertex, length, width, height, surface,* and *volume* are no longer encountered only as abstract definitions. Instead, pupils can use them while referring directly to a model that they have constructed or modified.

The use of dynamic representations can therefore support communication between visual, symbolic, and verbal forms of mathematical representation. This is consistent with the broader view that mathematical understanding involves coordinating multiple representations rather than relying exclusively on symbolic procedures[8].



1-photo: Conceptual model of Geogebra 3D integration in primary geometry learning developing creative problem-solving skills

Comparative Analysis of Traditional and GeoGebra 3D-Supported Learning

The pedagogical characteristics of traditional geometry instruction and GeoGebra 3D-supported instruction can be compared across several dimensions.

Table 1. Comparative Analysis of Traditional and GeoGebra 3D–Supported Learning

Learning Dimension	Traditional Approach	GeoGebra 3D–Supported Approach
Representation	• Mainly static images and drawings	• Dynamic three-dimensional models
Interaction	• Primarily observation	• Construction and manipulation
Spatial reasoning	• Relies more heavily on mental visualization	• Supported by dynamic rotation and transformation
Problem solving	• Often procedure-oriented	• More exploratory and inquiry-oriented
Solution generation	• Frequently focused on an expected method	• Opportunities for multiple approaches
Feedback	• Mainly provided by the teacher	• Immediate visual feedback during manipulation (V = 27, A = 54)
Creativity	• Often treated as an additional activity	• Can be embedded within the problem-solving process
Mathematical communication	• Frequently follows problem solving	• Can occur throughout exploration and construction

This comparison indicates that GeoGebra 3D offers particular affordances that can be used to create richer mathematical activity when embedded within appropriate instructional strategies.

This comparison should not be interpreted as evidence that technology automatically produces better learning outcomes. Rather, it indicates that digital environments offer particular affordances that can be used to create richer mathematical activity when they are embedded within appropriate instructional strategies.

Research on technology-enhanced mathematics education similarly emphasizes that the effectiveness of digital tools depends on how teachers integrate technological affordances with mathematical and pedagogical goals [9].

Changes in Pupils' Learning Behaviour

The learning activities considered in this study suggest several potentially important changes in pupils' classroom behaviour. In conventional geometry tasks, pupils may initially depend on teacher demonstrations or previously learned procedures. In a dynamic 3D environment, the possibility of immediate manipulation can encourage experimentation and independent investigation.

Three aspects are particularly relevant.

First, pupils can become more willing to test mathematical assumptions. Instead of accepting an initial answer, they can modify the model and examine whether the proposed relationship remains valid.

Second, pupils can demonstrate greater independence in selecting solution strategies. A single problem may be approached through construction, measurement, comparison, transformation, or decomposition.

Third, pupils can increasingly use visual evidence to support mathematical explanations. Instead of merely stating that two objects are equal or different, they can demonstrate the relationship through the constructed model.

These forms of activity are compatible with learner-centred approaches in which mathematical knowledge is developed through active engagement, investigation, and communication.

GeoGebra 3D and the Creation of a Creative Learning Environment

The analysis further indicates that the effectiveness of GeoGebra 3D depends substantially on the pedagogical design of learning activities. Simply displaying a three-dimensional model is unlikely to produce meaningful changes in creativity. The teacher needs to design tasks that require pupils to predict, construct, manipulate, compare, justify, and reflect.

Effective GeoGebra 3D activities should therefore incorporate at least four elements:

- An open or semi-open mathematical problem that permits more than one approach;
- An opportunity for digital construction and manipulation;
- A requirement to explain or justify the obtained solution;
- A reflection stage in which pupils compare different approaches.

This approach changes the role of technology from a presentation instrument into an environment for mathematical inquiry. The teacher remains an important mediator who selects appropriate tasks, guides exploration, asks questions, and supports reflection.

Generalized Results

Based on the analysis, the integration of GeoGebra 3D into primary geometry education can be conceptually associated with four interconnected educational outcomes: spatial visualization, geometric reasoning, creative problem solving, and mathematical communication.

The first outcome provides pupils with opportunities to perceive and manipulate geometric structures. The second supports the identification of relationships and the development of mathematical explanations. The third encourages pupils to search for alternative solutions instead of merely reproducing procedures. The fourth enables pupils to communicate and justify their reasoning.

Therefore, the principal pedagogical implication of the study is that GeoGebra 3D may strengthen the transition from visual perception to mathematical reasoning and from procedural problem solving to creative mathematical activity.

However, the technology itself should not be considered the independent source of learning improvement. Its effectiveness depends on the interaction between technological affordances, teacher mediation, task design, pupils' prior knowledge, and opportunities for reflection. This perspective is consistent with research emphasizing the importance of instrumental orchestration and teacher guidance in technology-supported mathematics learning.

DISCUSSION

The findings suggest that GeoGebra 3D can provide an effective learning environment for primary geometry by connecting visual experience with active mathematical investigation. Unlike conventional instruction based mainly on static diagrams and predetermined procedures, a dynamic three-dimensional environment allows pupils to examine geometric objects from different perspectives and explore their properties more flexibly.

GeoGebra 3D can also change the nature of pupils' interaction with geometry. Instead of simply applying known rules, learners can manipulate representations, observe changes, test ideas, and compare different approaches. Such activities can support creative problem-solving by encouraging flexibility in selecting and adapting solution strategies. Multiple-solution tasks have similarly been recognized as an effective context for developing mathematical creativity [6].

The findings further emphasize that the effectiveness of GeoGebra 3D depends on appropriate teacher guidance and task design. Digital manipulation alone does not guarantee conceptual understanding; pupils need opportunities to explain, justify, compare, and reflect on what they observe. Therefore, the teacher remains an important mediator who connects technological interaction with mathematical meaning.

Another important consideration is the combination of digital and traditional representations. GeoGebra 3D can complement physical models, drawings, symbolic representations, and verbal explanations, helping pupils connect concrete experience, visual perception, and abstract mathematical reasoning.

Overall, the main contribution of GeoGebra 3D is not visualization alone, but its potential to create conditions for active exploration, flexible reasoning, independent investigation, and creative engagement with geometric problems. When supported by purposeful tasks and effective teacher mediation, it can contribute to a more interactive and learner-centred approach to primary geometry education.

CONCLUSION

The study concludes that the integration of GeoGebra 3D can effectively support primary geometry education by making geometric concepts more interactive, visual, and accessible. Its use provides pupils with opportunities to explore three-dimensional objects, examine geometric relationships, and approach problems through different strategies. The findings indicate that GeoGebra 3D can contribute to the development of spatial understanding, mathematical reasoning, and creative problem-solving skills.

However, the effectiveness of the technology depends on purposeful task design and appropriate teacher guidance. Therefore, GeoGebra 3D should be used not simply as a visualization tool, but as a learning environment that encourages pupils to explore, reason, justify, and communicate mathematical ideas.

Overall, the integration of GeoGebra 3D represents a promising approach to developing a more interactive, creative, and learner-centred model of primary geometry education.

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