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Assessing the Effectiveness of Computer-Aided Instructional Techniques in Enhancing Students' 3D Geometry Spatial Visualization Skills Among Secondary School Students in Tanzania

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Abstract. Proficiency in spatial visualization plays a significant role in learning 3D geometry. Spatial visualization ability can be enhanced through the use of relevant teaching and learning techniques. The study aimed to investigate the impact of computer-aided instructional techniques on improving students' spatial visualization skills in learning 3D geometry, addressing the issue of low spatial visualization ability among students. The study followed a mixed research approach with a quasi-experimental design. Twenty mathematics teachers were purposively selected, and 267 Level-4 students from six ordinary-level secondary schools were purposively chosen for the study. Data were gathered using interviews, and pre- and post-tests of control and treatment groups through the use of computer simulation and animation of 3D figures in the treatment group, while the control group was taught using traditional methods. The Statistical Package for Social Sciences (SPSS) was used to compute descriptive and inferential statistics from quantitative data, while thematic analysis was applied to analyze qualitative data. The results from mathematics teachers' interviews indicate that teachers put less emphasis on enhancing students' spatial visualization abilities. Students from the treatment group outperformed the control groups on spatial visualization ability in terms of test scores. Additionally, an independent sample t-test revealed a statistically significant difference between the control and treatment groups in terms of spatial visualization ability. The computer-aided instructional approach is relevant in enhancing students' spatial visualization abilities. To improve students' spatial visualization skills, the researchers propose in-service training for teachers to incorporate computer simulations and animations into the teaching and learning of 3D geometry.

Keywords: 3D figures**;** instructional techniques; mathematics teachers; simulation and animation; spatial-visualization

1. Introduction

The field of mathematics education has witnessed substantial advances in teaching and learning processes on a global scale. Efforts are being made to enhance the capacity of mathematics teachers by improving their content knowledge and pedagogical skills, as underlined by Pepin et al. (2017) and Ferrini-Mundy (2000). The learning outcomes achieved by students often reflect the quality of teachers' pedagogical and content knowledge. However, several studies (Mamolo, 2019; Valstar et al., 2019) have pointed out that mathematics teachers often lack sufficient knowledge and skills in selecting and applying effective instructional techniques for teaching and learning mathematics. In teaching, learning, and assessment processes it is essential to consider the specific competencies that students need to develop (Bellara & Lototski, 2022). Unfortunately, many teachers tend to employ common methods, regardless of the targeted competencies. In this view, assessing students' prerequisite knowledge for acquiring new competencies, and selection of relevant instructional technique become vital for helping them grasp essential concepts.

Spatial visualization ability is a fundamental aspect of students' development in Science, Technology, Engineering, and Mathematics (STEM) fields (Liu et al., 2023; Newcombe, 2010; Stieff & Uttal, 2015; Sorby & Veurink, 2019). Proficiency in spatial visualization is important for effectively teaching and learning 3D geometry. While it is possible to enhance spatial visualization ability through appropriate teaching techniques, many students struggle with low spatial visualization skills (Lin et al., 2015; Miller & Halpern, 2013; Newcombe, 2010; Sorby, 1999). Despite opportunities available for both teachers and students to learn spatial visualization skills, many teachers still lack the necessary experience in effectively teaching them (Miller & Halpern, 2012; Trimurtini et al., 2021).

The application of spatial abilities, specifically spatial visualization enhances students' learning of geometrical and numerical skills (Hawes et al., 2017). Recognizing the importance of spatial visualization as an essential skill in various scientific and mathematical disciplines, including geometry, educational stakeholders such as curriculum developers, teachers, and students must devise effective teaching and learning approaches to improve students' spatial visualization abilities. One strategy for enhancing learners' ability to solve and apply geometrical problems involves utilizing geometrical thinking techniques, such as mentally constructing and manipulating figures in two or three dimensions through rotations, twists, or folds to observe different geometrical structures (Hardianti et al., 2017). Computer-aided instructional techniques, such as computer simulations and animations, offer valuable tools for developing geometrical thinking skills (Echeverría et al., 2019; Lin & Chen, 2016; Lin et al., 2014; Park et al., 2011; Sedivy & Hubalovsky, 2012). These technologies provide interactive and visual representations that aid students in visualizing geometric concepts and relationships. Integrating computer-aided instructional techniques into the teaching process can support learners in developing a deeper understanding of geometry and its applications.

The study of geometry not only fosters students' logical thinking skills but also enhances their spatial reasoning abilities, enabling them to perceive and comprehend spatial relationships in the world (Davis et al., 2015; Whiteley et al., 2015). Proficiency in geometry, particularly 3D geometry, holds significant importance for students as its principles are applied in various scientific disciplines like chemistry, physics, and engineering (Saxena, 2015; Whiteley et al., 2015). Despite the practical relevance of geometry in our daily lives, it is often inadequately taught and learned, resulting in unsatisfactory learning outcomes (Risma et al., 2013; Susilawati et al., 2017).

In Tanzania's secondary schools, mathematics performance is generally low (Kyaruzi, 2023; Mazana et al., 2020). Furthermore, data from the National Examinations Council of Tanzania (NECTA) reveal that 3D geometry is among the topics that students display less interest in when it comes to ordinary-level secondary school examinations. Figure 1 provides a summary of the percentage of students' performance in selected topics in basic mathematics national examinations, averaged across the years 2017 to 2021 (NECTA, 2017; 2018; 2019; 2020; 2021).

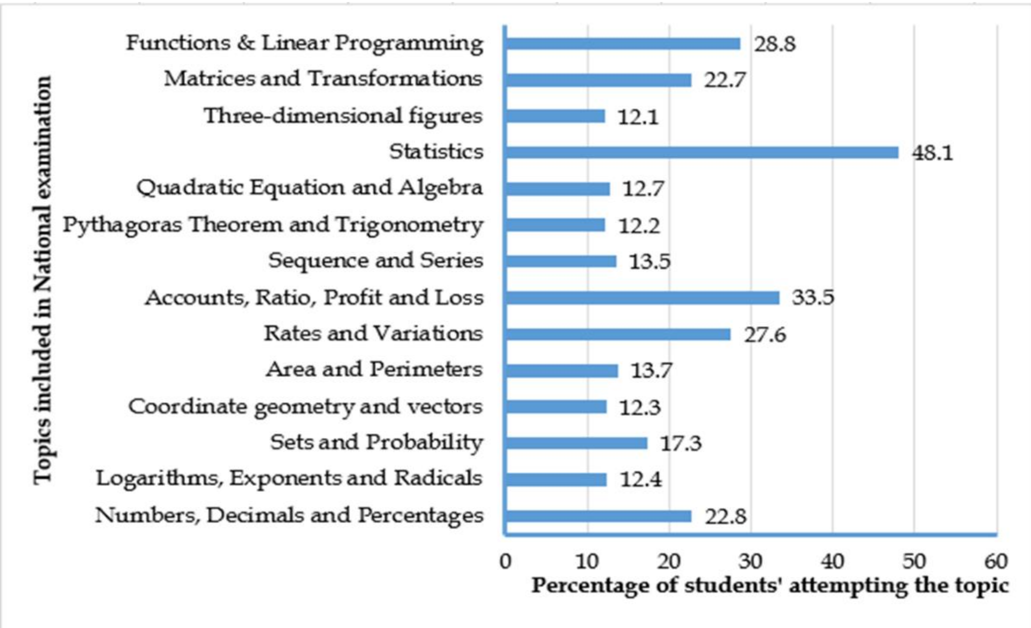

Figure 1. Percentage of students on selection of topics to attempt in basic mathematics' national examinations in Tanzania

Figure 1 indicates that of the total students who took the examination, only 12.1% attempted the questions related to 3D geometry, while 48.1% showed interest in the field of statistics. Several factors contribute to this lack of interest in 3D geometry, including insufficient background knowledge in geometry, limited availability of teaching materials (Cesaria & Herman, 2019; Mazana et al., 2020), weak spatial visualization skills, difficulties in understanding geometric language (Cesaria & Herman, 2019; Jelatu & Ardana, 2018) and teachers' limited knowledge of effective teaching and assessment methods (Cesaria & Herman, 2019; Kitta & Likinjie, 2020).

The studies conducted in Tanzania have revealed that students face challenges when learning 3D geometry due to its abstract nature compared to concrete concepts (Kitta & Likinjiye, 2020; William & Kitta, 2021). Many students struggle with identifying dimensions on 3D figures and measuring angles, area, and volumes (Gilligan et al., 2020; Revina & Leung, 2018). Spatial visualization skills are necessary for students to manipulate and understand 3D figures effectively. Therefore, the purpose of this study was to assess the level of spatial visualization ability among secondary school students in learning 3D geometry. Additionally, the study aimed to assess the effectiveness of traditional and computer-aided teaching and learning methods in enhancing students' spatial visualization skills. Specifically, the study sought to address the following research questions:

Research questions:

1. What teaching techniques do mathematics teachers employ to improve students' spatial visualization ability?
2. What is the initial level of students' spatial visualization ability for learning 3D geometry before the teaching and learning of 3D geometry?

Research hypothesis:
Null hypothesis: There is no significant difference in students' spatial visualization ability for learning 3D geometry between the control group taught using traditional methods and the treatment group taught using computer-integrated methods.

Alternative hypothesis: There is a significant difference in students' spatial visualization ability for learning 3D geometry between the control group taught using traditional methods and the treatment group taught using computer-integrated methods.

2. Literature Review

2.1. The concept of 3D geometry

Geometry is a branch of mathematics that explores measurement, relationships, and properties of points, angles, surfaces, lines, and solids (Abdul et al., 2022; Saxena, 2015). Within the realm of geometry, 3D geometry stands as one of basic sub-topics. A three-dimensional figure can be defined as an object or shape with three dimensions: length, height, and width (Hartshorne, 2013). In contrast to two-dimensional figures that possess only length and width, three-dimensional shapes introduce an additional dimension commonly referred to as height, thickness, or depth. Examples of 3D figures encompass cubes, prisms, cones, and cylinders. Figure 2 provides visual representations of various examples of three-dimensional figures.

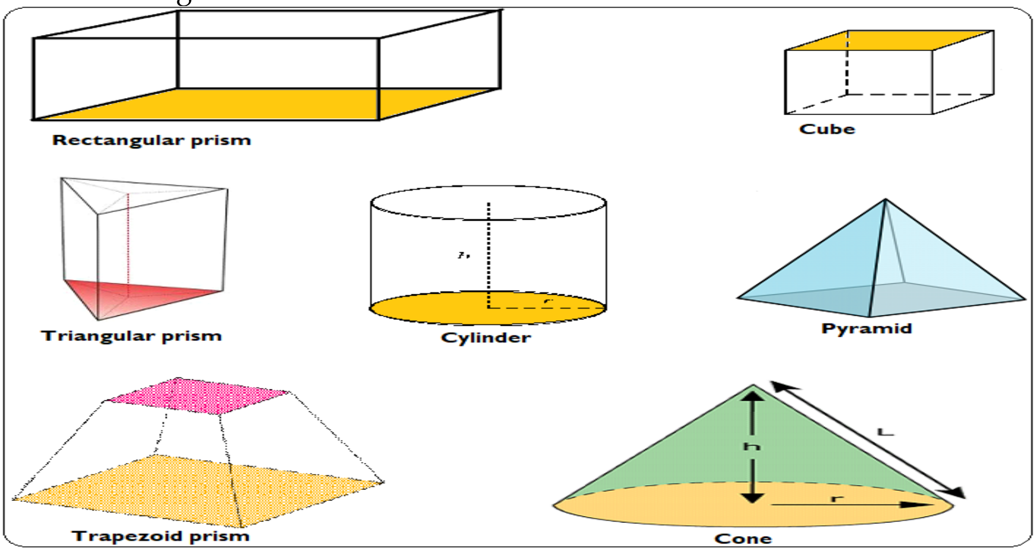

Figure 2. Examples of three-dimensional figures

When distinguishing between a 2D and 3D figure, one must consider the concept of space occupation. A 3D figure occupies physical space and can be measured in terms of both its area and volume, whereas a 2D figure exists exclusively on a plane and can only be measured in terms of its area (Sarkar et al., 2020).

2.2. The concept of spatial visualization

Spatial visualization is one of the subcomponents of spatial intelligence (LeBow et al., 2018; Ramful et al., 2017). Scholars such as Patkin and Dayan (2013) and Mitolo et al. (2015) have categorized spatial intelligence into three fundamental classes: spatial orientation, spatial perception, and spatial visualization. Spatial orientation refers to the ability to accurately and rapidly rotate a two-dimensional or three-dimensional figure while maintaining a fixed spatial reference. It involves mentally manipulating a figure without being distracted by changes in its appearance from different viewpoints. Spatial perception involves determining spatial relationships based on the orientation of objects, without being influenced by irrelevant information.

Spatial visualization, as described by LeBow et al. (2018), encompasses the ability to mentally manipulate, rotate, and transform visual objects. This includes actions such as folding, unfolding, twisting, and shaping objects based on their physical properties. Spatial visualization focuses on understanding relative changes in object positions in space, or the movement of mechanical systems. Unlike spatial orientation and spatial perception, spatial visualization involves complex, multi-step manipulations of information (Geer et al., 2019; Jones et al., 2018; Linn & Petersen, 1985; Sorby, 1999) and relies on non-verbal internal representations of perceived objects.

2.3. Spatial visualization of 3D geometry

Spatial visualization of 3D geometry involves the capacity to manipulate and interact with various 3D shapes using different techniques and materials (LeBow et al., 2018; Lowrie et al., 2019; Nathan et al., 2022; Schmidt, 2015; Xie et al., 2020). Researchers such as Battista (1990) and Idris (2005) have highlighted the significant influence of spatial visualization on success in learning 3D geometry, as it facilitates the logical-intuitive understanding of geometric patterns. Spatial visualization allows for mental manipulation and manipulation of 3D figures in space (İbili et al., 2020). Figure 3 provides an illustration of the spatial visualization of 3D geometric figures.

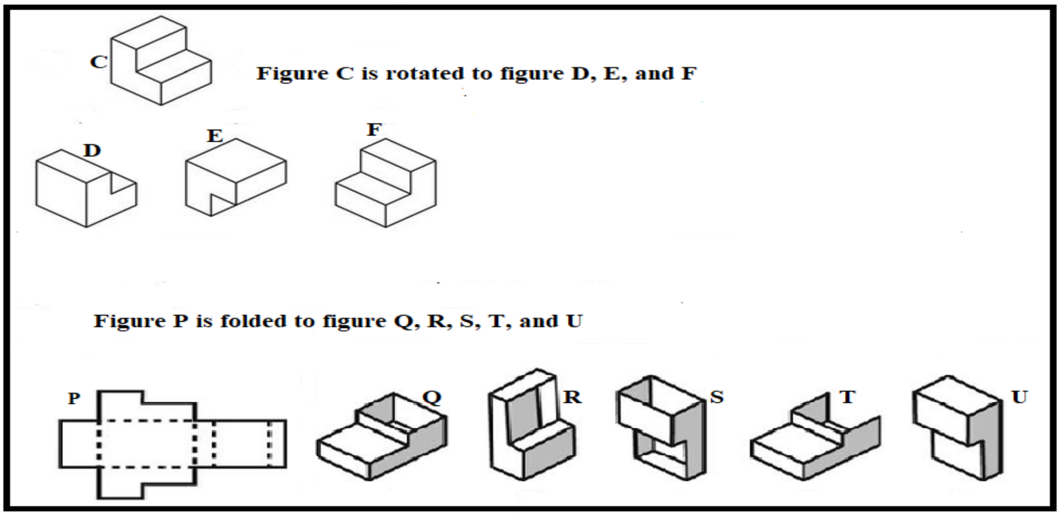

Figure 3. Illustration of spatial visualization of 3D-geometric figures

Figure 3 provides examples of manipulations of 3D figures. Figure C is rotated to create Figures D, E, and F, displaying different views of the same figure. Figure P is folded in various ways, resulting in Figures Q, R, S, T, and U, which exhibit distinctive structures. According to the research conducted by Linn and Peterson (1985), tasks that involve spatial visualization can be approached using different mental processes, and the effectiveness of task performance depends on the meta-techniques employed in accomplishing a particular task. Spatial visualization directly influences students' performance in subjects related to Science, Technology, Engineering, and Mathematics (STEM) (Lowrie et al., 2019). For instance, in the field of chemistry, visualizing the spinning of an electron and understanding the arrangement of electrons in an atom requires strong spatial visualization abilities. Similarly, in physics, comprehending the motion of objects in space necessitates the application of spatial visualization skills.

2.4. Studies in spatial visualization of 3D geometry

Numerous studies have demonstrated the significance of spatial visualization ability in solving geometric problems. Pittalis and Christou (2010) found that students' performance in various types of 3D geometry reasoning, including spatial structuring, representation of 3D objects, and conceptualization of mathematical measurements and properties, is influenced by their spatial abilities. Hawes et al. (2017) also emphasized the importance of spatial ability, including spatial visualization, in students' learning and problem-solving in geometry. Idris (2005) conducted a quasi-treatment study that investigated how the application of spatial visualization techniques can enhance geometry learning. The study involved tasks such as building solids from cubes, copying drawings, counting cubes, and checking the count against the solids. The post-test results indicated a significant difference in geometry test performance between the intervention group and the control group. Similarly, Unal et al. (2009) conducted a study to examine the acquisition of Van Hiele levels of geometric thought in students with high spatial visualization ability compared to those with low spatial ability. The findings of the intervention revealed a significant difference in the geometric level of acquisition between students with high and low spatial visualization skills. These results signify the role of spatial visualization ability in facilitating effective learning of three-dimensional geometry.

Some studies examined effective techniques to improve students' level of spatial visualization. A cross-case comparison conducted by Liao and Wu (2015) concluded that assisting students in creating mental associations between images and real-world objects can improve their spatial visualization ability. This finding was supported by evidence from case study participants with varying spatial visualization abilities who engaged in different spatial visualization tasks. Additionally, it has been observed that strengthening students' ability to perceive whole images rather than fragmented pieces can enhance their spatial visualization skills (Cheng & Mix, 2014). Lowrie et al. (2017) implemented a 10-week intervention program focused on enhancing students' spatial reasoning, which included spatial visualization of geometry. The intervention group showed significant improvement in manipulating 3D geometric figures compared to the control group. In a similar vein, Boakes (2009) conducted a quasi-treatment study to investigate the impact of hands-on activities utilizing spatial visualization techniques in teaching and learning 3D geometry. The treatment group, which learned the material through activities such as paper-folding and card rotation, demonstrated a higher level of spatial visualization ability than the control group, which did not utilize these techniques. These studies confirm that students' level of spatial visualization can be improved through interactive teaching and learning methods.

2.5. The use of computer simulation and animation to enhance spatial visualization

The use of computer simulations and animations to enhance students' spatial visualization has been studied in various countries. For example, Park et al. (2011) conducted a study to investigate the effects of 3D simulation tools on spatial visualization abilities through lectures and paper-pattern-making activities. The findings indicated that 3D simulation software holds promise as an effective instructional tool for improving students' visualization skills. In other studies, games have been employed to enhance students' spatial abilities. Lin et al. (2014) developed a treasure-hunting game based on theoretical concepts of spatial orientation and spatial memory. The game utilized goggles from mobile devices and computers, accommodating a wide range of models, operating systems, and browsers. These technological tools proved to be efficient and effective in improving students' spatial abilities (Chivai & Mutuque, 2021). In addition, Martín-Gutiérrez et al. (2013) developed a three-dimensional viewer (Diedro-3D) in supporting the teaching of 3D geometry process. The study indicated students' autonomous engagement in learning compared to those who were learning through conventional methods.

Considering the successful interventions conducted in other countries using computer systems to enhance students' spatial visualization skills, it was thought worth to employ similar methods in Tanzania, particularly at the secondary school level, to determine if comparable outcomes can be achieved in the context. The current study intended to use computer simulation and animation in the treatment group and conventional methods in control group to see if computer-aided method of teaching and learning can improve the learning of geometry.

2.6. Theoretical framework

The study is grounded in Van Hiele's theory of geometric thinking (Mason, 2009), which proposes five levels of understanding or reasoning in geometry: visualization, analysis, abstraction, deduction, and rigor. According to the theory, spatial visualization plays a fundamental role in accelerating student's development of geometric reasoning. The levels have fixed order and adjacency properties, meaning that a student must complete the previous level before advancing to the next one. Therefore, visualization skills serve as a foundation for acquiring other geometric competencies, making it a basic aspect of learning geometry.

In line with this theory, the study aims to assess students' spatial visualization ability, which corresponds to the visualization level (level 0) in Van Hiele's theory (Vojkuvkova, 2012). To measure this ability, the study utilizes a standardized spatial visualization test called Spatial Ability Test (SAT) which allows for the evaluation of students' achievement in levels 0 to 2, focusing specifically on their spatial visualization skills.

Additionally, the study incorporates the Theory of Cognitive in Multimodal Learning (CTML) developed by Richard Mayer (Mayer, 2005). According to CTML, students should initially select relevant visual and verbal information to construct coherent mental representations. These mental representations are then integrated with prior knowledge. For example, learners can mentally manipulate 3D figures, change viewing angles, and explore dimensions of objects. The use of computer simulation and animation in manipulating 3D objects can guide learners in improving their spatial visualization ability. By providing instructions on twisting, rotating, folding, or unfolding objects, students can develop a better understanding of object orientations in space.

Overall, the study draws upon Van Hiele's theory of geometric thinking to assess students' spatial visualization ability and incorporates the CTML to investigate the impact of computer simulations and animations on enhancing this ability.

3. Methodology

3.1. Study approach and design

The research approach employed in this study was a mixed research approach, combining both quantitative and qualitative methods (Creswell et al., 2006). This approach allows for a more comprehensive understanding of the research topic by integrating numerical data with qualitative insights.

The study utilized a quasi-experimental design, comparing a treatment group that received computer-aided instruction with a control group that used conventional methods. The quantitative aspect of the study involved the collection and analysis of numerical data. Pre- and post-tests were conducted to measure the spatial visualization ability of students in both groups. The collected data were then analyzed using the Statistical Package for Social Sciences (SPSS) to compute descriptive and inferential statistics. An independent sample t-test was performed to determine the statistical significance of the differences in spatial visualization abilities between the control and treatment groups.

In addition to the quantitative data, the study also incorporated qualitative aspects. Data from interviews with mathematics teachers were collected to gain insights into their perspectives and practices regarding the enhancement of students' spatial visualization abilities. A qualitative analytical technique was applied to identify and analyze emerging themes and patterns in the interview data.

By combining quantitative and qualitative approaches, the study aimed to provide in-depth understanding of the impact of computer-aided instructional techniques on students' spatial visualization skills in the context of learning 3D geometry. The quantitative data offered numerical evidence of the effectiveness of the instructional approach, while the qualitative data provided valuable insights into teachers' perspectives and practices, enriching the overall findings of the study.

3.2. Study location and sampling

The study was conducted in Dodoma region which consists of seven districts and which was randomly selected out of the 31 regions of Tanzania. This selection was made based on the fact that the performance of mathematics in secondary schools across the country is relatively consistent (NECTA, 2017; 2018; 2019; 2020; 2021). Specifically, the research was conducted in two districts: Dodoma city and Chamwino. These districts were also randomly selected on account of the low performance of students in mathematics in the region. According to the Tanzanian secondary education curriculum, the topic of 3D geometry is taught and learned in the fourth year of secondary education (Ministry of Education and Vocation Training, 2005). Therefore, students at the Level-4 secondary school were purposively selected to participate in the study, as they have been exposed to the relevant content. The target population for the study was 800 students from six schools. In order to obtain a representative sample of students for the intervention, a random selection process was employed in the six selected schools. The sample size was determined using the Yamane formula:

That is, $n = \frac{N}{(1+Ne^2)}$ where N represent the population size, e represents marginal error (0.05) and n represents sample size

$$n = \frac{800}{(1+800(0.05^2))} = 267$$

A total of 267 Level-4 students were included in the study, a sample size which was deemed appropriate for conducting the study and drawing meaningful conclusions. The students were selected from six schools, with each school contributing 40 to 50 students to form a single class. As a result, there were three classes in the control group and three classes in the treatment group, distributed across the six schools. The random sampling procedure was used to ensure inclusiveness in terms of gender, academic ability, and physical disabilities, following the recommendations of the education policy.

Additionally, 20 mathematics teachers who were responsible for teaching mathematics in Level-4 classes were purposively selected to participate in the study. These teachers were chosen based on their involvement in the teaching and learning of mathematics, specifically at the Level-4 classes. They participated in interviews to provide insights into their views regarding the enhancement of students' spatial visualization abilities.

Table 1 provides information on the demographic characteristics of the participating students and shows that the majority of the students (149 out of 267) are male. Furthermore, the schools located in urban areas, specifically in Dodoma city, have a larger number of students than the schools located in rural areas, specifically in the Chamwino district.

Table 1: Demographic information of participating students

Characteristic	**Category**	**Frequency**	**Percentage**
Gender	Female	118	44.2
	Male	149	55.8
District	Dodoma city	152	56.9
	Chamwino	115	43.1

Table 2 presents the demographic characteristics of the mathematics teachers involved in the study. The majority of the teachers (95%) hold bachelor's degrees and have more than five years of teaching experience. Among the teachers, there are 12 males and eight females. These tables highlight important details about the gender distribution and qualifications of both the students and the teachers, providing a basis for analyzing the data and understanding the context of the study.

Table 2: Demographic information of participating teachers

Characteristic	**Category**	**Frequency**	**Percentage**
Gender	Female	8	40
	Male	12	60
Academic qualification	Bachelor degree	19	95
	Diploma	1	5

Working experience	Less than 5	1	5
	5 - 10	13	65
	More than 10	6	30

3.3. Data collection instruments

The study utilized the Spatial Ability Test (SAT) developed by Newton and Bristol (2009) to assess students' spatial visualization ability. The SAT was adapted into a multiple-choice format and comprised five categories of 3D manipulation: rotation, folding, unfolding, assembling, and orthogonal projection. During the adaptation process, the SAT was evaluated to ensure its alignment with the Tanzania ordinary-level Education curriculum for teaching and learning 3D geometry. It was confirmed that the test adequately covered the required topics outlined in the curriculum. However, there was a modification in the test's time duration. Originally designed as an aptitude test with a time limit of 20 minutes, the test was adjusted to serve as an achievement test for this study. The purpose of the test was to assess the number of correct answers obtained by each student out of a total of 45 items. Table 3 presents an overview of the different categories of questions included in the SAT, providing a description of the specific types of 3D manipulation assessed in each category.

Table 3: Category of questions from SAT

Item	Type of manipulation
1-30	Rotation
31-35	Assembling
36-39	Folding
40-42	Unfolding
43-45	Orthographic projection

The second instrument used in the study was a semi-structured interview guide. The guide was developed to provide a framework for conducting interviews with mathematics teachers and gathering their perspectives and insights on the enhancement of students' spatial visualization abilities. Prior to its implementation, the interview guide underwent a rigorous review process by peers and experts in the field. Their feedback and suggestions were incorporated into the instrument to ensure its clarity and effectiveness. Some questions were modified and adjusted to make them more easily understandable for the interview participants. The semi-structured nature of the interview guide allowed for flexibility during the interviews, enabling the interviewer to probe deeper into specific areas of interest while maintaining a general structure. This approach facilitated rich and meaningful discussions with the mathematics teachers, enabling the collection of valuable qualitative data for analysis.

3.4. Data collection procedures

The data collection process for this study involved several stages: the pilot study, pre-test, intervention, post-test, and interviews.

Pilot Study:
To ensure the validity of the Spatial Ability Test (SAT) and determine an appropriate time duration for the test, a pilot study was conducted. The test was administered to two different groups of students who had characteristics similar to the target group. The maximum time duration for the test was set at 60 minutes based on the completion times of the students in the pilot study. The test-retest method was used to assess the consistency of test scores, and the reliability coefficient was calculated to determine the reliability of the test. The coefficient, which was found to be 89.5, indicated that the test was reliable.

Pre-test:
The SAT was administered to both the control and treatment groups of students before the teaching and learning process. The aim of the pre-test was to measure the students' spatial visualization ability prior to any instruction. The test was conducted under the supervision of teachers and a researcher, and the time duration for the test was set at 60 minutes. After completion, the test papers were collected, marked by the teachers using a standardized marking guide, and the results were saved in an SPSS template.

Intervention stage:
The intervention stage involved the preparation of lessons on the topic of "Construction and Sketching 3D Figures" in 3D geometry. The treatment group received instruction using computer-aided instructional techniques, specifically computer simulations and animations for 3D manipulations. The control group was taught using traditional instructional methods, such as lectures and hands-on activities. The teaching and learning processes in both groups were conducted for 80 minutes per session, with a total of six sessions per group. The intervention lasted for three months, from April to July 2022.

Post-test:
After the teaching and learning of 3D geometry, the same test (SAT) was administered as a post-test to assess the enhancement of students' spatial visualization skills. The aim was to compare the effectiveness of the traditional instructional methods used in the control group with the computer-aided instructional methods used in the treatment group. The test results were marked and recorded in the SPSS template for analysis.

Interview process:
Semi-structured interviews were conducted with mathematics teachers to gather their perspectives and insights on the enhancement of students' spatial visualization abilities. Each interview lasted for approximately 40 minutes, and the interviewer used probing questions to elicit detailed responses. The interviews were recorded with the participants' consent, and the recordings were transcribed to obtain textual data for analysis.

3.5. Validity and reliability
To ensure the content validity of the test, the alignment of the test items with the intended competencies in teaching and learning 3D geometry was checked. The items were found to be aligned with the required competencies, indicating content

validity. To assess the reliability of the test, a pilot study was conducted using a representative sample from the target population. The purpose of the pilot study was to determine if any adjustments were needed in terms of content and the time required to conduct the test. The average time needed to complete the test was estimated based on the pilot study.

The reliability of the test was evaluated using the test-retest method. This involved administering the test to the same group of students on two separate occasions and calculating the correlation coefficient between the two sets of scores. The reliability coefficient was found to be 89.5, indicating a high level of consistency in the test scores. This suggests that the test results reflect students' spatial visualization abilities rather than random guessing.

By ensuring content validity and establishing reliability through the pilot study and reliability coefficient calculation, the study yielded confidence in the validity and consistency of the test used to assess students' spatial visualization ability.

3.6. Data analysis

Quantitative data from the pre- and post-tests of both the control and treatment groups were analyzed using SPSS version 28. Descriptive statistics were computed to analyze the data, including calculating the mean and standard deviation of the test results. The total number of test items in the test was 45, and each correctly answered item was awarded one mark. The total score for each student was calculated based on the number of items they answered correctly out of the 45 items.

To determine if there was a significant difference in students' spatial visualization ability before and after the teaching and learning of 3D geometry in both the control and treatment groups, inferential statistics were applied. Paired sample t-tests were conducted to compare the means of the pre- and post-test scores within each group, while independent sample t-tests were used to compare the means between the control and treatment groups.

Data from classroom observations and interviews were analyzed thematically using Braun and Clarke model (Braun & Clarke, 2006). The process involved transcribing the recorded interviews with mathematics teachers, identifying patterns, themes, and categories within the data, and assigning labels (coding) to meaningful units of information. The transcripts were reviewed multiple times, and related codes were grouped into broader themes and sub-themes that emerged from the data. The analysis and interpretation of the data within each theme were then conducted, allowing for the identification of key findings and the drawing of connections between different elements of the data.

4. Findings

4.1. Techniques used by mathematics teachers to enhance students' visualization ability

Mathematics teachers' responses from the interviews revealed diverse techniques employed to enhance students' spatial visualization ability. The analysis of the interview transcripts led to the identification of two main themes related to these techniques: interactive teaching and learning techniques, and teacher-directed teaching and learning techniques.

4.1.1 Interactive Teaching and learning techniques

Under the theme of interactive teaching and learning techniques, teachers mentioned various approaches they used to engage students and foster their spatial visualization skills. These techniques involved interactive activities such as group work, problem-solving tasks, hands-on manipulation of objects, and the use of visual aids, including diagrams, models, and educational technology. The teachers emphasized the importance of providing students with opportunities for active participation, exploration, and discussion, which they believed supported the development of spatial visualization abilities. This is evidenced by the following quotes drawn from participants:

> *From mathematics syllabus on the topic of 3D figures, there is a subtopic of constructing 3D figures through the use of patterns of figures that we call nets. So I use those patterns to instruct students to formulate a figure. In doing so, their spatial visualization can be raised. (School C, Teacher 2)*

> *As for me, I sometimes instruct students to go on the board to draw and name the figure. Some of them get confused with some kind of 3D figures such as pyramids. If one student fails to draw, I call others to help. (School A, Teacher 1)*

> *Most of the time I use the techniques such as facilitating students to draw 3D figures such as a cuboid, pyramids, and cylinders. Sometimes I tell them to think about various materials available at school or in their home that are in 3D and then I tell them to draw. (School F, Teacher 1)*

The quotations above indicate that mathematics teachers use some interactive techniques to engage their students in manipulating 3D figures. However, none of them mentioned the integration of technology to enhance students' spatial visualization ability.

4.1.2 Teacher-directed teaching and learning techniques

The theme of teacher-directed teaching and learning techniques encompassed approaches where the teacher played a more central role in delivering instruction. This included methods like lectures, demonstrations, guided practice, and explicit instruction. Teachers expressed the view that providing clear explanations, step-by-step guidance, and structured exercises helped students understand spatial concepts and develop their visualization skills. On this, two teachers were quoted as saying:

> *The techniques I use to enhance students' spatial visualization ability is using a blackboard to draw some figures and then I instruct students to copy the drawings and identify a name of a particular 3D-figure they see from the board. By using this strategy, students can be able to think critically and identify the figures by their names if it is a pyramid, sphere, cube or a cone. (School E, Teacher 3)*

On my side, I used to create some figures during my leisure time through the use of locally available materials such as boxes, or wood. After creating some figures such as cube or a pyramid, I go to the class to show my students so that they can know if I teach them about a 3D figure, they can know how it appears. (School D, Teacher 2)

Some of the teachers interviewed mentioned teaching and learning techniques that were less interactive and did not provide sufficient opportunities for students to engage in various learning activities. These techniques were perceived as not effective in promoting students' spatial visualization abilities, as they focused more on traditional instruction methods such as lectures and demonstrations.
Some participants expressed the belief that spatial visualization is an innate ability and cannot be significantly developed through teaching. According to their perspective, students either possess natural spatial abilities or do not, regardless of instructional strategies employed. They suggested that only those students with a natural inclination towards spatial visualization would be able to understand and improve their abilities, while others may struggle to do so even with instruction.

These differing views among the teachers reflect a range of perspectives on the nature and teachability of spatial visualization skills. While some emphasize the importance of interactive and engaging teaching methods to enhance spatial visualization, others hold the belief that it is a fixed trait that cannot be significantly influenced by instruction. This is echoed in the following quotes:

I don't think it is easy to raise students' spatial visualization ability; I think this is an inborn ability. For example, when I instruct students to make various three-dimensional figures, some of the students are not able to create even a single figure, they just ask their colleagues to make it for them. In this sense, only those with inborn ability will raise their spatial visualization. (School C, Teacher 1)

Another teacher claimed that:

From my understanding, I do not think there is a strategy for enhancing students' spatial visualization ability because it needs only students' thinking. Changing students' thinking is not easy. This is different from changing a student's perception or teaching a student about a certain topic. For me, I do not concentrate on finding techniques to enhance students' visualization abilities. This is raised naturally when they learn other aspects of the topic. (School A, Teacher 3)

The quotes from these teachers indicate a negative perception: that it is impossible to raise students' spatial visualization ability. They perceive that it is an ability that every person is born with, so it is not possible to raise it through instruction.

4.2. Students' level of spatial visualization before teaching and learning 3D geometry

The collected data from the pre-test revealed that both the control group and treatment group had low levels of spatial visualization ability. The mean score for the control group was 19.45, which accounts for approximately 42.2% of the total marks, while the mean score for the treatment group was 20.16, equivalent to 44.8% of the total marks. These results indicate that students in both groups had below-average performance in spatial visualization ability, as their mean scores were below 50% of the total marks. To determine if there were any significant differences in spatial visualization ability between the control and treatment groups, an inferential analysis was conducted. The results of the analysis revealed a t-value of 0.596 and a p-value of 0.000, indicating that the mean performances of the two groups were not statistically significant. This suggests that the control and treatment groups had comparable levels of spatial visualization ability before the intervention. These findings provide baseline information about the initial spatial visualization abilities of the students in the study and establish the equivalence of the control and treatment groups in terms of their spatial visualization skills.

4.3. Students' level of spatial visualization after teaching and learning 3D geometry

(i) ***For the control group***

The results of the post-test indicated that there was an improvement in students' performance on the spatial visualization tests in both the control and treatment groups. In the control group, the mean score increased to 24.11, with a standard deviation of 7.5, which corresponds to 53.58% of the total marks. This indicates an increase of 11.38% from the pre-test performance. However, when a paired sample t-test was conducted, the results ($t = 0.396$, $p = 0.615$) showed that the increase in mean performance was not statistically significant.

These findings suggest that the traditional methods of teaching and learning 3D geometry, which were employed in the control group, did not have a significant effect on enhancing students' spatial visualization ability. Despite the observed improvement in scores, the lack of statistical significance implies that the increase could be attributed to factors other than the instructional methods used. The summary of the results from the descriptive and inferential statistics are given in Table 4 below:

Table 4: Comparison of pre- and post-test results from control group

Test	Means	Std Deviation	t	P-value
Pre-test	19.45	3.2	0.396	0.615
Post test	24.11	7.5		

Test performance trend based on test categories from the control group

The analysis of test items based on categories revealed variations in students' performance. Among the categories, students demonstrated better performance in folding figures than in the other categories. The worst performance was observed in the category of orthogonal projection. When comparing the pre-test and post-test results, a significant change in performance was observed in the category of unfolding 3D figures. However, there were no notable changes in performance in the categories of orthogonal projection and isometric mapping between the pre-test and the post-test. These findings suggest that the teaching and learning of 3D geometry using traditional methods had no significant impact on improving students' spatial visualization ability in the areas of isometric mapping and orthogonal projections. Table 5 provides a visual representation of the performance trend of the control group across the different categories.

Table 5: Trend of test performance based on categories from the control group

Category	Total number of items in a category	Average score out of total items in a category		Percentage of performance in a category	
		Pre-test scores	Post-test scores	Pre-test scores	Post-test scores
Rotation	30	13	16	28.9	35.6
Folding	4	2	3	50	75
Unfolding	3	1	2	33.3	66.7
Isometric mapping	5	2	2	40	40
Orthogonal projection	3	1	1	33.3	33.3

(i) ***For the treatment group***

The use of computer simulation and animation in teaching and learning 3D geometry produced a substantial increase in the average performance of students in spatial visualization tests. The mean score of the test results was (mean = 37.15, SD = 4.36), which corresponds to 82.56% of the total marks. This indicates a significant improvement in test performance, with an increase of 37.76% from the pre-test.

Moreover, the results of the paired sample t-test [t (45) = -56.18, p = 0.000] demonstrated that the increase in mean performance was statistically significant. This supports the alternative hypothesis, suggesting that the use of computer simulation and animation in teaching and learning 3D geometry has a positive impact on enhancing students' spatial visualization ability. The null hypothesis, which stated that there was no positive impact, is rejected, based on the statistical analysis. Table 6 provides a summary of the results obtained from the descriptive and inferential statistical analysis.

Table 6: Comparison of pre and post-test results from treatment group

Test	Means	Std Deviation	t	P-value
Pre-test	20.16	2.93	-56.18	0.000
Post-test	37.15	4.36		

The post-test results from the treatment group imply that the use of computer simulation and animation had a positive impact in enhancing students' spatial visualization ability.

Test performance trend based on test categories from treatment group

From the same categories of test items, the post-test results for the treatment group showed a greater improvement than those of the control group. Table 7 shows the performance trend based on categories in the treatment group.

Table 7: Trend of test performance based on categories from the control group

Category	Total number of items in a category	Average score out of the total items in a category		Percentage of performance in a category	
		Pre-test scores	Post-test scores	Pre-test scores	Post-test scores
Rotation	30	13	24	43.33	80
Folding	4	2	4	50	100
Unfolding	3	1	3	33.3	100
Isometric mapping	5	2	4	40	80
Orthogonal projection	3	2	2	66.7	66.7
Total	45	20	37	44.4	82.2

Based on categories, the analysis shows that the treatment group improved in all categories of test items. This indicates that the use of computer simulation and animation had a positive effect in enhancing students' spatial visualization ability.

4.4. Comparison of test performance between control and treatment groups

A noticeable difference ($p = 000$, $\alpha = 0.05$) in post-test performance was evident, following the teaching and learning process, which employed different instructional techniques in two groups. The summary of their performance is presented in Tables 8 and 9 below:

Table 8: Independent sample t-test of control and treatment groups

Test	Group	Mean	Std. Deviation	t	p-value
Pre-test	Control	19.45	3.2	0.596	0.000
	Treatment	20.16	2.93		
Post-test	Control	24.11	7.5	9.348	0.000
	Treatment	37.15	7.51		

Table 9: Paired sample t-test between control and treatment groups

Groups	Test	Mean	Std. Deviation	t	p-value
Control	Pre-test	19.45	3.2	0.396	0.426
	Post-test	24.11	7.5		
Treatment	Pre-test	20.16	2.93	-56.18	0.000
	Post-test	37.15	7.51		

5. Discussion

5.1. Techniques used by mathematics teachers to enhance students' spatial visualization ability

The findings from the participants suggest that mathematics teachers employ various techniques to enhance students' spatial visualization ability, including both interactive and non-interactive approaches. These findings are consistent with the research conducted by Susilawati et al. (2017), who proposed that the effective use of relevant teaching and learning techniques in 3D geometry can improve students' spatial visualization ability. Several studies, such as those by Lowrie et al. (2017), Park et al. (2011), and Quintero et al. (2015), have highlighted the use of technology, particularly simulations and animations, as effective strategies for enhancing students' spatial visualization ability.

However, the findings also indicate that many mathematics teachers have not fully integrated technology, specifically simulations and animations, into their instruction on 3D figure manipulation. This lack of attention to technology integration may contribute to students' widespread struggles in mathematics, particularly in the area of 3D geometry. These results align with the findings of Hawes et al. (2017) and Lowrie et al. (2017), who concluded that students' spatial visualization ability is closely related to their performance in 3D geometry.

5.2. Level of students' spatial visualization ability for learning 3D geometry before the teaching and learning of 3D geometry

The results of pre-tests conducted on control and treatment groups have revealed that students possess a low level of spatial visualization ability. This inadequacy in prerequisite knowledge can significantly impact their performance in comprehending and applying 3D geometry concepts. These findings align with the conclusions drawn by Battista (1990), Hawes et al. (2017), Lowrie et al. (2017), and Pittalis and Christou (2010), who emphasized the influential role of spatial visualization ability in learning 3D geometry. Furthermore, Cesaria and Herman (2019) conducted research demonstrating that students who lack sufficient geometry knowledge also exhibit decreased interest in problem-solving within the subject. Consequently, these findings emphasize the necessity of employing effective teaching and learning techniques to enhance students' spatial visualization ability.

5.3. Comparison of students' spatial visualization ability in learning 3D geometry between control and treatment groups taught using traditional and computer-integrated methods, respectively

The test performance results obtained from the control group suggest that the teaching and learning techniques employed by teachers had a limited impact on improving students' spatial visualization ability. The lack of significant difference in spatial visualization test performance between the pre- and post-teaching assessments ($t = 0.396$, $p = 0.615$) showed that the increase in mean performance was not statistically significant. The results contradict the findings of Idris (2005) and Hawes et al. (2017), who established a positive relationship between the teaching and learning of 3D geometry and students' spatial visualization ability. However, these results align with the conclusions drawn by Lowrie et al. (2017), emphasized that the teaching and learning of 3D geometry can enhance spatial visualization ability when accompanied by supportive teaching and learning conditions. Factors highlighted by Idris (2005), such as teachers' competence in pedagogical content knowledge (PCK), students' interest in the topic, and effective teaching and learning materials contribute to the improvement of spatial visualization ability in the context of 3D geometry.

On the other hand, the results obtained from the treatment group, where simulation and animation were integrated into the teaching and learning of 3D geometry, demonstrate an improvement in students' test performance in spatial visualization between pre-and post-test [$t(45) = -56.18$, $p = 0.000$]. This significant difference indicates that the teaching and learning of 3D geometry indeed enhanced students' spatial visualization ability. This finding supports the conclusion reached by Boakes (2009), Hawes et al. (2017), Lin et al. (2014), and Park et al. (2011) regarding the influence of learning 3D geometry on spatial visualization ability.

6. Conclusion and recommendations

The current study aimed at assessing the visualization ability of students from selected secondary schools located in Dodoma, Tanzania. The study assessed students' visualization ability before learning the topic of 3D geometry and after learning the topic to see if there was a significant change in test performance before and after the learning topic. The study methodology was guided by the literature that students possess inborn spatial visualization ability, and this ability can be enhanced through the teaching and learning process. The use of a multiple-choice questionnaire helped to make the assessment. The results showed no significant difference in students' test performance conducted before and after teaching and learning 3D geometry when students were taught using traditional methods of teaching and learning. Positive changes in spatial visualization test performance were observed when students were taught through the use of computer-aided techniques, that is, computer simulation and animations on manipulating 3D figures. The adoption of computer simulations and animations for manipulating 3D figures, therefore, has potential impacts on students' understanding and the application of mathematics and STEM subjects in general. This integration of technology fosters students' engagement, interest, and overall performance of the topic.

The study suggests that, by integrating computer-aided techniques, specifically computer simulations and animations, Tanzanian schools can enhance students' spatial visualization ability, ultimately benefiting their learning experiences in mathematics and other related subjects.

7. Study limitations

This study is limited in the generalization of study findings as it involved a sample of 267 Level-4 students from six ordinary-level secondary schools. The findings may not be representative of all students or educational settings, limiting the generalizability of the results. The study is also limited in the control of confounding variables; the change in students' ability in spatial visualization may be contributed by other external factors such as prior exposure to computer-aided instructional techniques. To enhance the generalizability of the results, it is recommended that future studies expand the sample size and include a more diverse range of students and educational settings. Additionally, efforts should be made to control confounding variables to isolate the impact of computer-aided techniques on students' spatial visualization ability.

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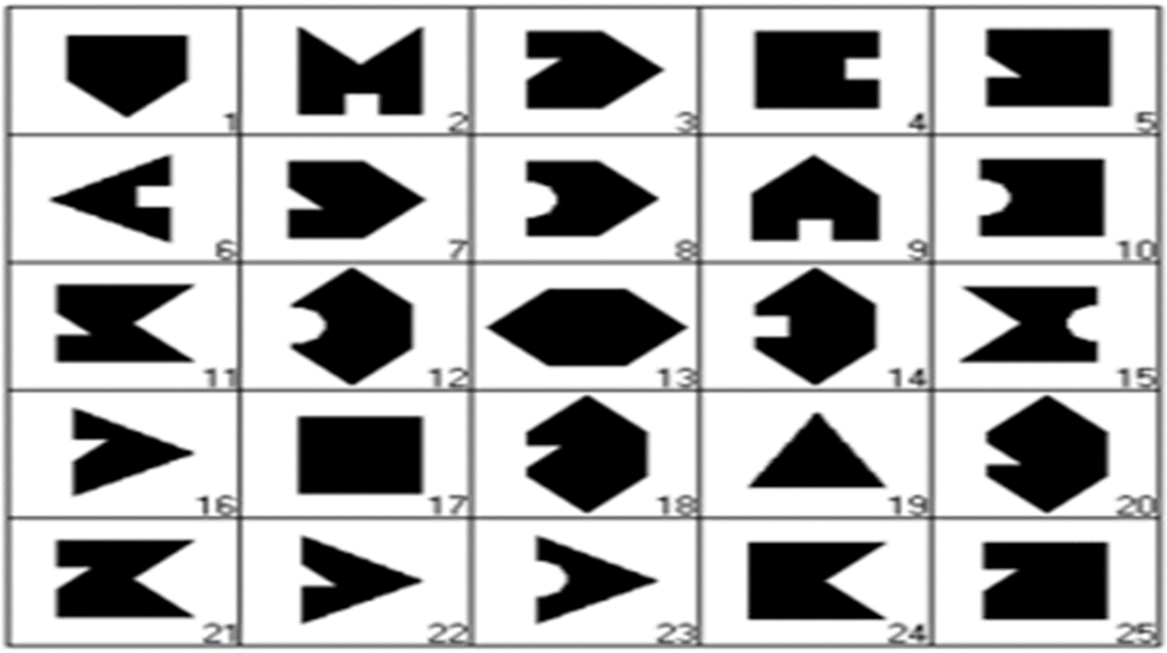
Appendix 1:

SPATIAL ABILITY TEST (SAT)

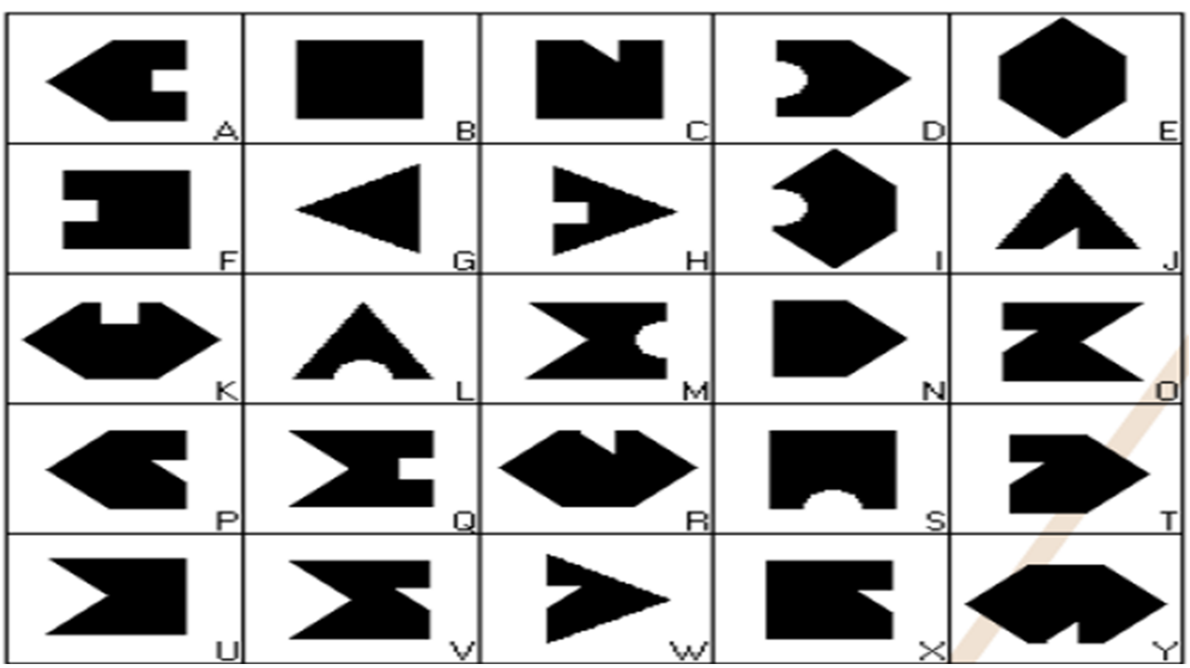
Time is 60 minutes **Student ID…………**

The shapes in Group one and Group two are identical, although some of them may be rotated. Which shape in Group 2 correspond to the shapes (1 to 25) in Group 1?

Group 1



Group 2

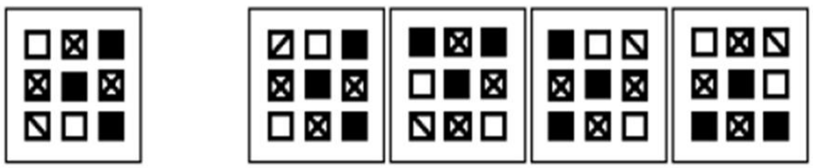


Fill the answers in the table below

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

In the figures shown below, one of the shapes (A-D) is identical to the first figure but has been rotated.

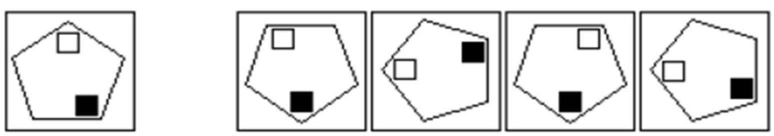
26) Which figure is identical to the first?



A B C D

A B C D

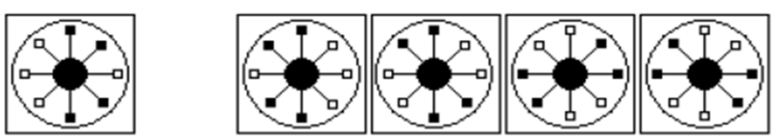
27) Which figure is identical to the first?



A B C D

A B C D

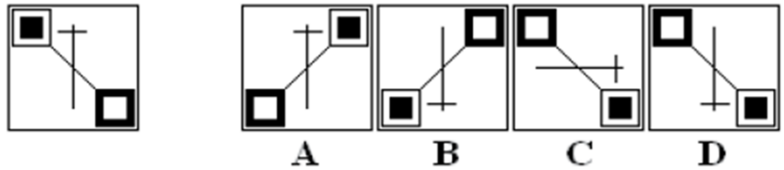
28) Which figure is identical to the first?



A B C D

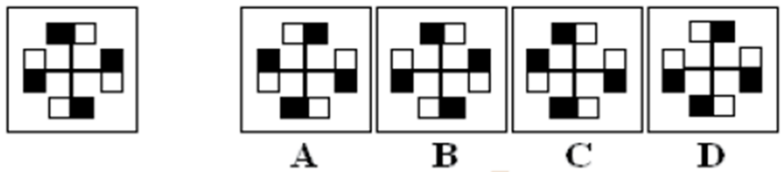
A B C D

29) Which figure is identical to the first?



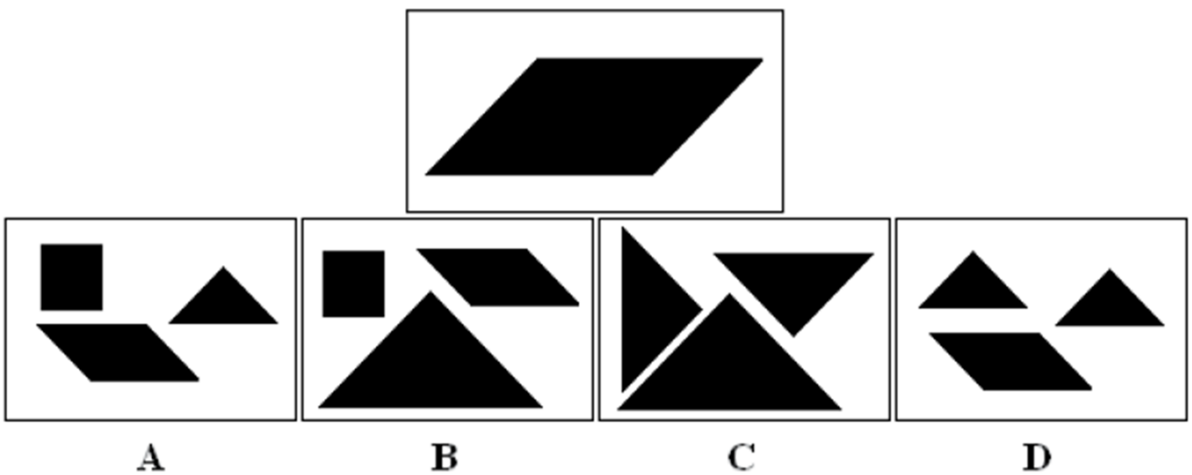
A B C D

30) Which figure is identical to the first?



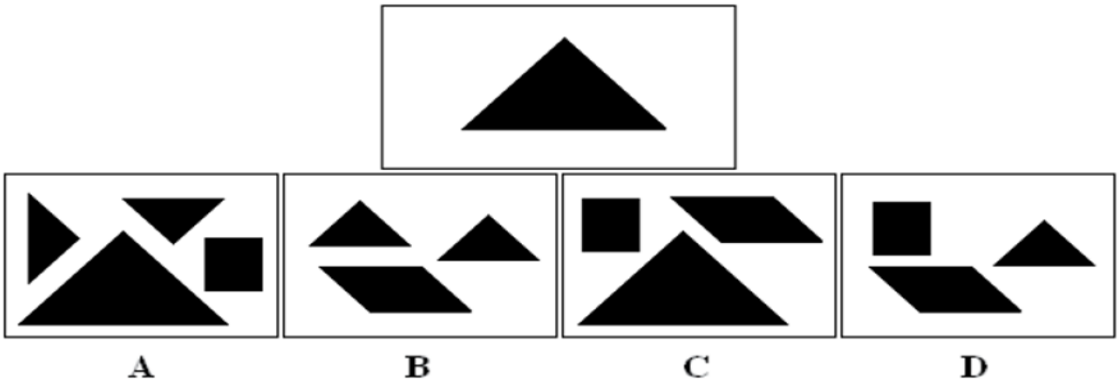
A B C D

31) Which group of shapes can be assembled to make the shape shown?



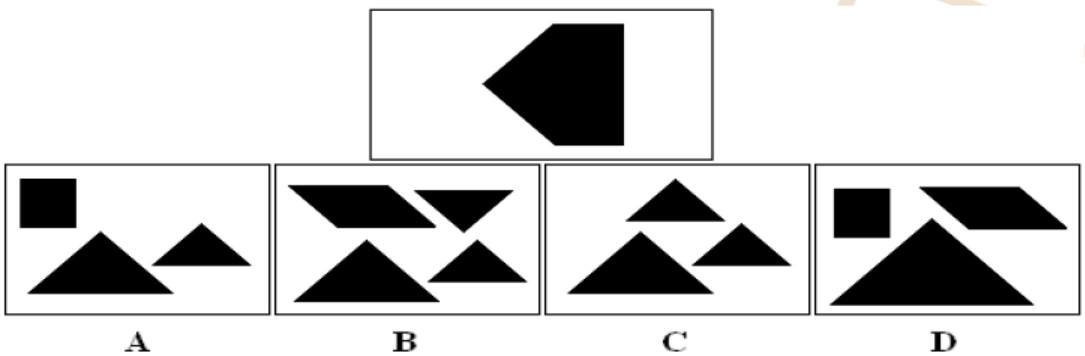
A B C D

32) Which group of shapes can be assembled to make the shape shown?



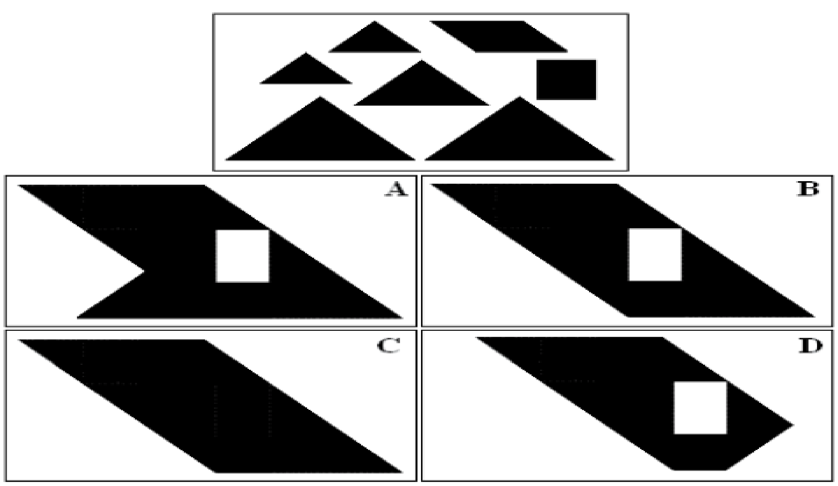
A B C D

33) Which group of shapes can be assembled to make the shape shown?



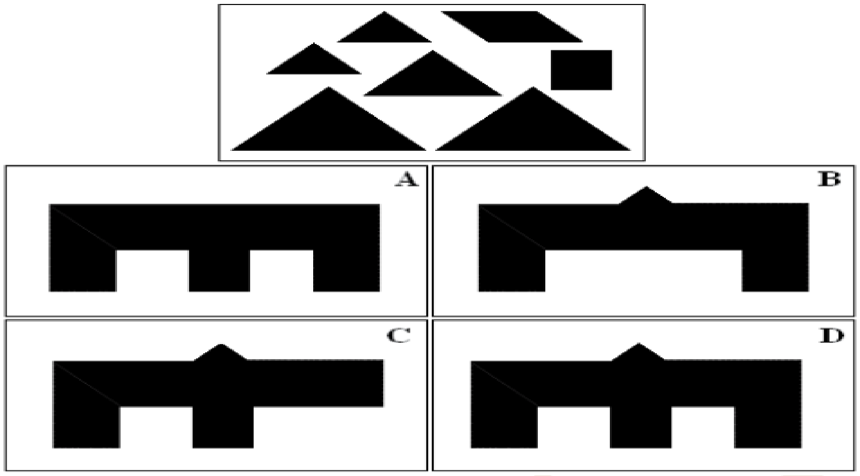
A B C D

34) Which shape can be assembled using all of the individual shapes shown?



A B C D

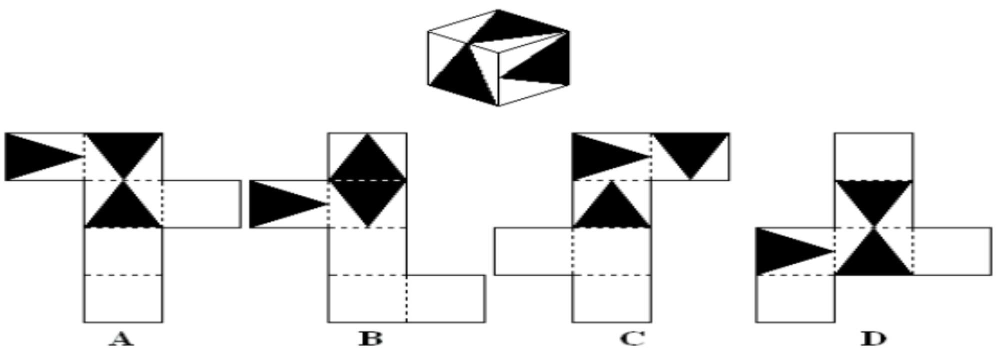
35) Which shape can be assembled using all of the individual shapes shown?



A B C D

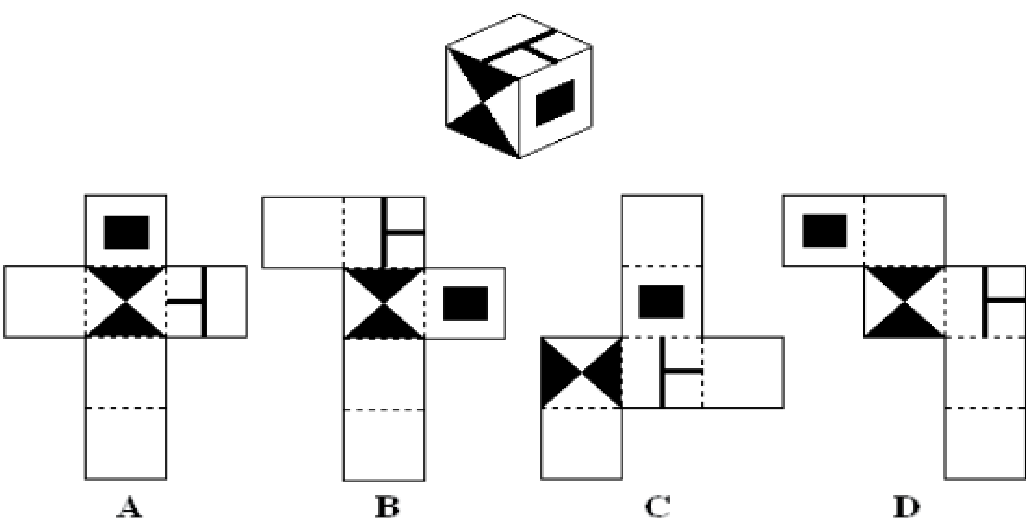
Which pattern can be folded to make the cube shown?

36)



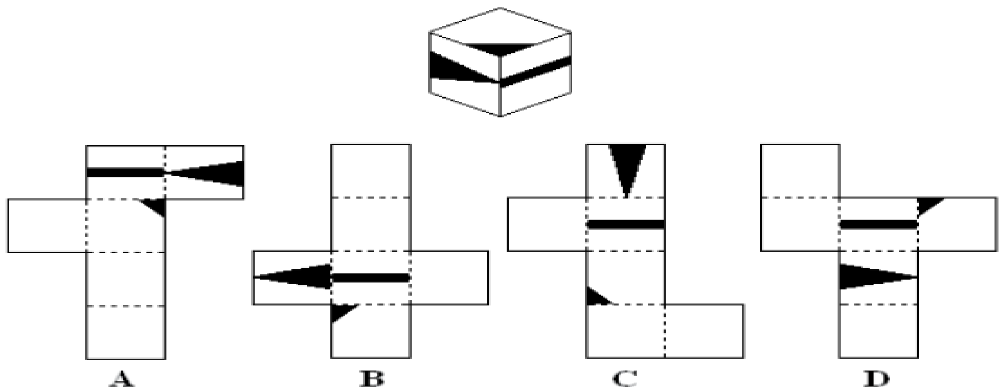
A B C D

37)



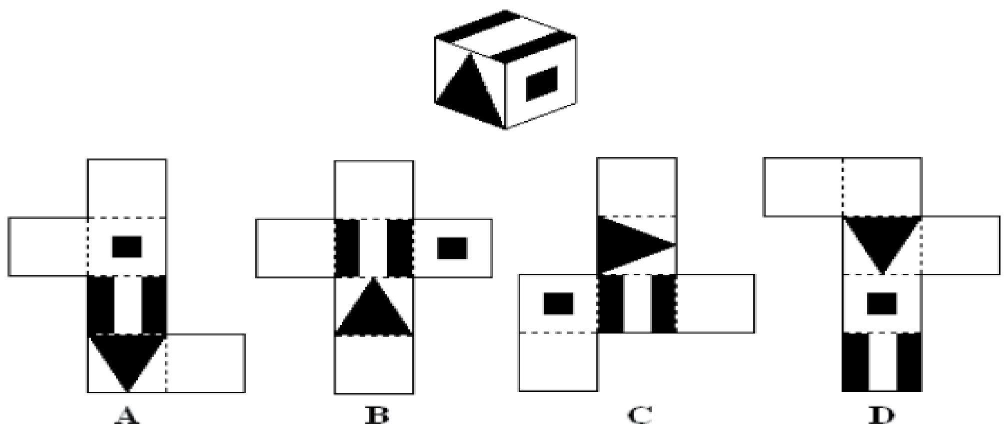
A B C D

38)



A B C D

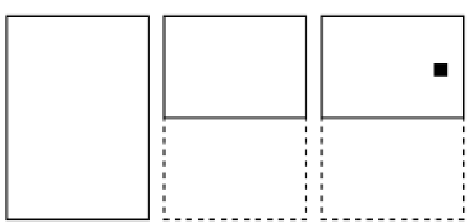
39)

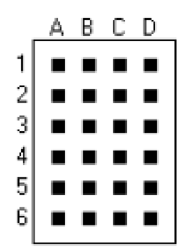


A B C D

The drawings show a sheet of paper which has been folded. The dashed lines indicate the whole sheet, each drawing represents a single fold. The black square shows where a hole was punched. Where do the holes appear when the sheet is unfolded?

40)

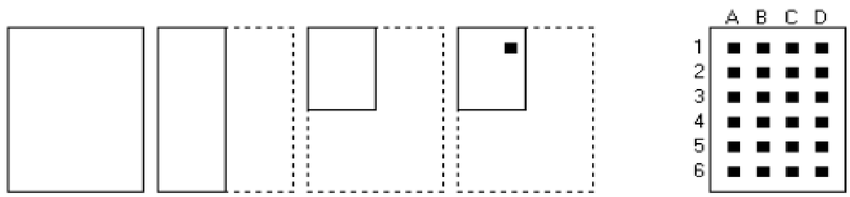




A	B	C	D
2C,5C	2D,5D	3D,3D	2C,2D

A B C D

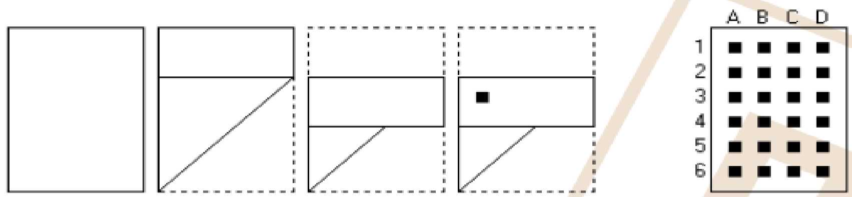
41)



A	B	C	D
1B,1C,5B,5C	2B,2C,5B,5C	1B,2C,6B,6C	1B,1C,6B,6C

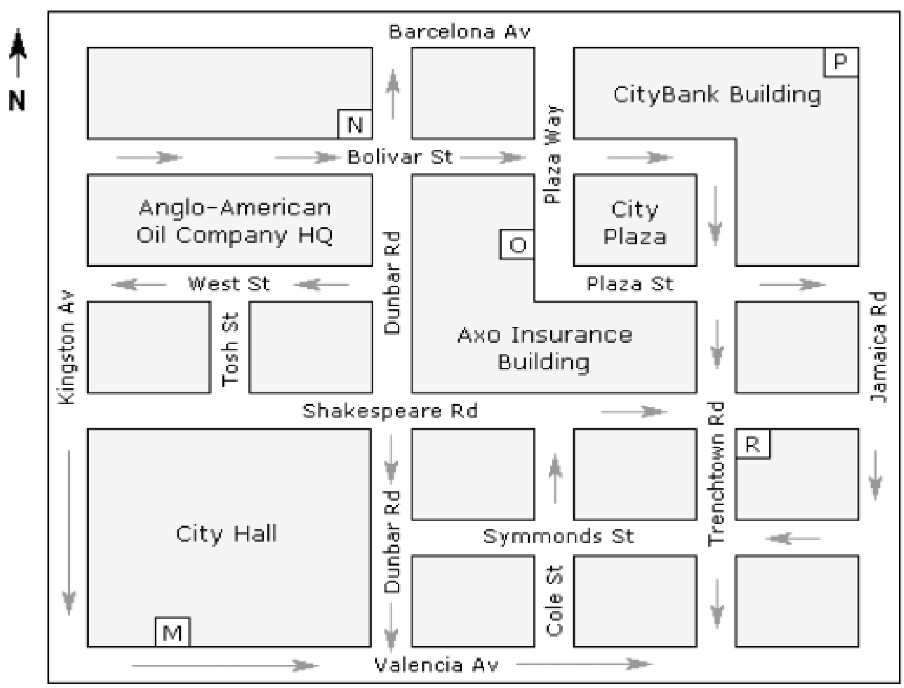
A B C D

42)



A	B	C	D
3A,2A,6D	3A,5A,6D	3A,5A,3D	3A,2A

A B C D



43) Officer Perez is in Tosh St with City Hall to her right. What direction is she facing?

A	B	C	D
North	South	East	West

44) She turns and walks to the junction with West St. She then turns right and walks to the next junction before turning left. Where is location 'O' in relation to her position?

A	B	C	D
North	South	East	West

45) Officer Martinez starts from location 'M' and proceeds as follows: left onto Valencia Av - heading East, second left - heading North, second right - heading East, second left - heading North. He proceeds North for two blocks. What is his location?

A	B	C	D
N	O	R	P

Appendix 2: Interview Schedule Instrument (Teachers)

I. General particulars:

School ID: ……………… Teacher ID………………...Date...……./………/2022

Sex: Female ( ) Male ( )

Section A: Teacher's demographic information.

1. For how long have you been teaching Mathematics at the secondary school level?
2. Would you please tell me your highest qualification?

Section B: Interview questions

1. What do you think are the necessary pre-requisite knowledge your students supposed to possess for effectively learning of 3D geometry?
2. What are the competencies students are supposed to acquire in teaching and learning of 3D geometry?
3. What are the teaching and learning techniques do you use to enhance students' spatial visualization ability through teaching and learning of 3D geometry?
4. What are instructional strategies do you think are the most effective in enhancing students' spatial visualization abilities?