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Solid Geometry Problems: Transferability Level of High School Students

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Abstract

The study focused on examining the factors that account for transferability of geometry concepts among High School students. To achieve this, the study employed an explanatory sequential mixed-method design with sample of 99 final year students who were selected through multistage sampling techniques from two high schools in two districts in the Upper East Region of Ghana. Solid Geometry Achievement Test (SGAT) and an Interview Guide were used as instruments for data collection. Data was analysed descriptively by means, standard deviations, frequency distribution tables and percentages, and inferentially by Kruskal Wallis Test (Ranks), Tukey's HSD Test as Post – Hoc and One – Way ANOVA. The results revealed inability to apply the concept of ratio and proportion aright, and Mistaking slant height for vertical height of a cone as factors accounting for students' inability to solving non-routine problems in solid geometry.

It was recommended that educators should: design tasks that require students to manipulate ratios within diverse problem settings, thereby enhancing their ability to transfer these concepts to novel, non-routine problems, provide explicit and comparative instruction on distinguishing between different dimensions in three-dimensional figures thereby helping students consolidate their understanding and promote the transfer of accurate dimensional reasoning to other solid geometry problems.

Keywords: *Geometry, Transferability, Routine Problems, Near Transfer, Far Transfer*

Introduction

The goal of education is to ensure that students can apply their acquired knowledge in diverse and unforeseen situations (Rebello, Cui, Bennett, Zollman & Ozimek, 2017). Transferability is fundamental, as it enables learners to retain and effectively utilise their education to solve new problems (Larsen, Endo, Yee, Do & Lo, 2022). Effective teaching methodologies must prepare students to apply their learning to both present and future challenges, ultimately advancing their ability to transfer knowledge into real-world situations (Roberts, Sharma, Britton & New, 2007). Successful transferability entails the retention of information and practical application of learned concepts. However, language challenges can greatly hinder students' ability to understand mathematical concepts, leading to repeated errors and misconceptions. Due to these language barriers, key mathematical ideas are often miscommunicated, disrupting comprehension and limiting transferability. Misunderstanding terminology or the structure of mathematical statements tends to result in repeated mistakes, which ultimately affects the student’s ability to apply knowledge to non-routine problems.

Additionally, the incorrect use of language in describing mathematical concepts—such as confusing the meaning of dimensional terms in geometry—can create confusion that impedes higher-order cognitive processing (Mayer, 2002). Transferability is characterised by the ability to apply acquired knowledge in new contexts, either through near transfer (where knowledge is applied in similar contexts) or far transfer (where knowledge is applied in vastly different situations) (Mayer, 2002). A low or poor performance rate in solid geometry tasks has been attributed to challenges with knowledge transfer

(WASSCE 2011–2021). Chief Examiners' reports between 2011 and 2021 indicate that students struggle to solve solid geometry problems that require them to move beyond basic rote recall to address more complex, non-routine problems. As noted by Surya (2012), one key reason for low achievement is the insufficient opportunity for students to transfer their learning to new concepts, a pattern compounded by language barriers in comprehension.

Mathematics, particularly geometry, nurtures foundational skills and fosters logical reasoning, promoting problem-solving abilities across a range of disciplines such as construction, architecture, and engineering. The effective application of geometry is critical to real-world applications, aligning with the broader goals of mathematical literacy and problem-solving in Ghanaian society (Ministry of Education, 2020). The current curriculum empowers students to demonstrate creative thinking, logical analysis, and self-confidence, with an emphasis on critical thinking and problem-solving as essential competencies (Ministry of Education, 2020). For the Ghanaian educational system to meet this goal, students must progress beyond basic comprehension levels, ensuring that transferability is a part of their cognitive skill development. Low-level knowledge and insufficient transfer skills create barriers to achieving the national objectives of producing adept problem-solvers. Hence, it is crucial for mathematics teachers to refine their strategies and methodologies to ensure that all students engage actively with content, particularly in geometry, where higher order thinking skills such as deductive reasoning, analysis, and problem-solving must be fostered.

Central to this goal is transferability, which is the capacity to retain and apply learned concepts to new challenges (Larsen et al., 2022). This concept encompasses both near transfer, where knowledge is applied in similar contexts (i.e. with same characteristics), and far transfer, which involves using that knowledge in significantly different settings (Mayer, 2002). Effective and appropriate teaching methods should balance retention with practical application to improve the usefulness of education (Roberts et al., 2007). The subject of geometry not only supports the foundations of the logical and analytical thought processes but has numerous practical applications in daily activities for example in the construction of buildings, dams, and highways. This type of practical relevance is advocated in the Mathematics Common Core Program goals for Ghana which intend to grow mathematically literate people who are proficient in problem solving, creativity, and analytical thinking (Ministry of Education, 2020). As such, improving the ease of these skills being transferred is critical for personal achievement, global competitiveness, and national achievement in cultivating proficient problem solvers.

This study adopts Bloom's Taxonomy to analyse students' skill level in resolving both routine and non-routine solid geometry problem. This model provides a comprehensive understanding of the cognitive development spanning from the recalling and understanding stages of thinking to analysing, evaluating, and creating (Maciejewski & Merchant, 2016; Harrison et al., 2017). In this regard, the study aims to identify factors affecting geometry knowledge transfer through this taxonomy with the intent of establishing efficient instructional designs that promote higher order thinking and problem solving (Boles et al., 2015; Hyder & Bhamani, 2016).

Statement of the problem

Orón and Lizasoain (2023) argued that in the context of mathematics education, "transferability of knowledge" is highly relevant. This suggests that for learners to function and handle fresh challenges, especially in mathematics, there are necessary pieces of information that must be learned. Therefore, the way students apply and/or transform their knowledge to novel situations or problems has a profound impact on their ability to resolve mathematical issues. If knowledge gained is not transferable beyond its original or very first context, its utility becomes restricted. (Agustin, Retnowati, Ng & Khar Toe, 2022).

Research on transferability have shown some instructional approaches that can facilitate transfer of knowledge (Sugiman et al., 2019; Sweller, 2020). For instance, Sugiman et al. (2019) conducted research on transferability, highlighting the significance of students' ability to transfer knowledge, a factor that could be bolstered by problem-based learning which is entirely goal free. With the performance of high school students in solid geometry being low continually and the chief examiner's report pointing to students' difficulty in application related questions in geometry, becomes a matter of importance to focus research on transferability in solid geometry (WASSCE 2011 - 2021).

More so, since the few related research conducted employed qualitative approach, the current study employed mixed-method approach to enable in-depth and rich data access to categorise Senior High school students' transferability level in solving solid geometry problems, explore the issues accounting for students' transferability and discuss valuable insights and implications for mathematics teaching in the Bolgatanga Municipal and Nabdam District in the Upper East Region of Ghana, while contributing to the body of literature to enhance practice.

Research objectives

The study sought to:

1. Determine students' performance in solving Familiar, Near transfer and Far transfer problems in solid geometry.
2. Explore students' difficulties in transferring knowledge when solving solid geometry problems.

Research hypothesis

To achieve objective four: compare students' ability for solving familiar, Near-transfer and Far-transfer problems in solid geometry across course of study, one hypothesis was formulated as follows:

H_0: *There is no significant difference in the ability of students to solve Familiar, Near-transfer and Far-transfer problems in solid geometry across course of study.*

Literature Review

The revised Bloom's taxonomy

This study is underpinned by Revised Bloom's Taxonomy as it provides a systematic approach for evaluating and improving students' cognitive learning processes. Bloom's taxonomy was invented by Bloom in 1956 and then Anderson and Krathwohl revised it in 2001, categorizing cognitive skills into Remember, Understand, Apply, Analyse, Evaluate, and Create (Orey, 2010). It consists of both the basic skills of information recall and more advanced skills, such as critical thinking, evaluating, and solving problems creatively. The bloom's taxonomy has notable relevance in education because it facilitates deep learning for students beyond the rote memorization of content (Nkhoma et al., 2017).The implementation of Bloom's taxonomy has been extensive in curriculum development, teaching approaches, and evaluation methods. It assists teachers in curriculum development to create instructions that enable learners to achieve desired outcomes, appreciating the objectives and the knowledge to be absorbed (Retno, Arfatin & Nur, 2019). The incorporation of Bloom's taxonomy in assessments enables educators to evaluate students' cognitive development more effectively. Studies indicate that students' ability to integrate information is enhanced, when tests are designed through the application of Blooms taxonomy, as compared to under the rote memorization model (Chandio, Pandhiani & Iqbal, 2016).

In specific fields of mathematics, for example in problem solving situations like solid geometry, The Revised Bloom's Taxonomy is of paramount importance. The students manipulate three-dimensional shapes, use geometric theorems, reason spatially, and solve multi-step problems in solid geometry. Alignment of assessments to Bloom's taxonomy levels allows educators to evaluate if students recall the formulas, understand the usages, analyse properties of shapes, evaluate strategies for approaching the problems, and create solutions to unique challenges.

Application of Bloom's Taxonomy in mathematics education has been documented by several studies. For example, a study on a high school mathematics curriculum implemented Bloom's taxonomy and discovered that structuring lessons by cognitive hierarchies vastly contributed to students' problem-solving engagement (Retno et al., 2019). Also, research on flipped mathematics classrooms by Rothe et al. (2022) studied the levels at which learners process learning materials, and it was noted that deeper processing tasks, including analysis and evaluation, fostered better understanding of concepts.

In active learning combined with mathematics outreach, one study highlighted that students who participated in problem-solving tasks aligned with the higher order thinking levels of Bloom's taxonomy outperformed their peers in reasoning and working through problems (Karaali, 2011). Likewise, Puig et al. (2020) incorporated Bloom's taxonomy to evaluate a gamified pedagogical framework for teaching geometry to learners aged 10 – 13. It was revealed that setting the learning goals within the framework of the taxonomy improved students' geometric reasoning skills and motivated them to actively participate in the lessons.

More evidence on the application of Bloom's taxonomy is evidenced in the work of Sarıtaş (2021), who evaluated a math mobile application and analysed its learning outcomes using Bloom's taxonomy as a classification framework. The applications aimed at comprehension and application levels were useful, but the analysis and evaluation portions of higher order thinking skills could greatly enhance the student's mathematical thinking, as was determined in the study. Similarly, Tüker's (2013) research on near and far transfer in mathematics learning showed that teaching designed following Bloom's principles aided students in transferring knowledge to various contexts within problem solving.

In light of these findings, this study applies Bloom's taxonomy to evaluate students' problem-solving skills in solid geometry. This taxonomy was used to analyse the level of movement between mere rote remembering of geometric concepts and active advanced reasoning and problem solving in students. The application of Bloom's taxonomy will enable a more comprehensive analysis of learners' mental growth and how teaching methods need to change in order to improve instructional outcomes in learning mathematics.

Conceptual Review

Solid geometry

Sánchez et al. (2017) describe solid geometry as one of the core branches of mathematics with significant relevance to engineering, computer science, and physics. Unfortunately, conceptualizing three-dimensional figures is a problem that many students face in their bid to understand geometry resulting in a lack of problem-solving skills (Numan & Hasan, 2017). Robertson and Graven (2019) and Larbi (2021) studies reveal that students are not able to visualize the transformation of geometric objects which is very vital for solid geometry. Another equally important, but often neglected part, is the ability to integrate the concepts of spatial relationships. Many learners are able to perform in solid geometry related task through rote learning rather than understanding the underlying principles and structures due to a weak cognitive foundation formed in their early formative years in education. The steadily growing body of research and teaching practice has sought to address these geometric thinking challenges through several strategies.

To respond to difficulties learners face, Van Hiele's Theory of Geometric Thinking offers a different instructional approach. The model developed by Van Hiele subdivides geometric reasoning into a series of ordered levels, aiming to clearly determine how to scaffold sequential instruction (Sánchez et al., 2017). The theory posits that the student moves through five stages of geometric comprehension: visualization, analysis, abstraction, deduction, and rigor (Van Hiele, 1986). The most basic step of understanding geometry involves recognizing geometric shapes: pupils see and label a square or triangle. In the analysis stage, they have not yet comprehended relationships, but they are identifying properties of the figures. The abstraction level includes identifying relationships among properties and starting to grasp formal definitions. By the deduction level, students have acquired logical reasoning skills and are able to formulate formal proofs. Finally, at the rigor level, learners move into working with axiomatic systems and analyse geometrical concepts formally (Fuys, Geddes & Tischler, 1988).

Research shows that learners taught using the Van Hiele model seem to possess superior geometric reasoning and problem-solving skills compared to their peers taught with traditional methods (Mamiala, Mji & Simelane-Mnisi, 2021). For instance, Clements and Battista (1992) found that students who learned through the Van Hiele model framework showed greater improvement in the comprehension of geometric relations. The researchers observed that students developed better understanding of geometric properties when they were provided with structured activities that guided them through the levels of Van Hiele geometric model. A similar study conducted by Usiskin (1982) on secondary school students revealed that students who were able to reach the abstraction level at least did lateral problem-solving on complex geometrical shapes with a higher rate of success. This indicates that there is need for better instructional strategies which aim to advance students beyond simple fact learning to deeper analytical reasoning.

As far as solid geometry is concerned, Van Hiele's model systematically outlines the developmental stages of students from mere identification of three-dimensional shapes to sophisticated reasoning about spatial relations. As research suggests, many students tend to be stuck at the visualization stage, where they are unable to move towards the more advanced analytical and abstract levels needed to solve geometric problems efficiently (Burger & Shaughnessy, 1986). This gap can be closed through teaching methodologies based on Van Hiele's theory. For example, Ndlovu and Brijlall (2019) carried out an intervention that was based on Van Hiele's levels of geometric thinking, it included hands-on activities, dynamic geometry software, and guided discussions. Their results demonstrated that students who actively participated in these structured learning activities manipulated and reasoned with three-dimensional objects far better than those who did not.

Transferability level in solving solid geometry problems

Extending the application of mathematical skills beyond the classroom remains a major educational challenge. Students often have great difficulty transferring what they learn in class to new and different situations outside of school (Brophy et al., 2008). This particular problem stems from the lack of conceptual understanding and rote learning techniques that most students have experienced. Students approach problem-solving activities with a memorization mentality rather than reasoning processes. As a result, most students get stuck on novel problems that are presented outside the boundaries of standard textbook examples (Rittle-Johnson & Schneider, 2015).

Transferability is divided into 'near transfer', which refers to use in similar situations, and 'far transfer', which is use in completely new contexts (Nakakoji & Wilson, 2020). Near transfer takes place when students use learned principles on problems or tasks that are slightly different but still fundamentally the same. For example, applying the formula for calculating the surface area of a square to calculate the surface area of a cube is an example of near transfer. On the other hand, far transfer refers to applying a set of problem-solving strategies in a new, more sophisticated and novel context like using solid geometry to create or design an engineering model (Barnett & Ceci, 2002). Research indicates that traditional instructional practices in mathematics mostly advance near transfer or surface application of basic or fundamental concepts devoid of essential problem-solving skill necessary for application in more sophisticated, real-life contexts (Agustin et al., 2022). This challenge reveals that there is a lack of instructional methods that encourage far transfer.

Research reveals students participating in problem-solving tasks that require creative thinking show higher adaptability and advanced reasoning compared to those disciplined in routine exercises (Kubsch et al., 2020). Non-routine problems require students to engage in innovative thinking, logic, and decision-making, all of which aid in skill development. For example, Star and Rittle-Johnson (2008) note that students encouraged to use multiple methods to achieve a solution in mathematics were more adept at problem-solving in new situations as well as transferring their knowledge effectively. Likewise, Hegarty et al. (2018) highlight spatial reasoning as an important factor of transferability, especially in solid geometry, where visualization is critical in three-dimensional relationships. Their study discovered that students who engaged in mentally manipulating geometric shapes could better solve problems requiring far transfer.

Empirical findings support the need for educators to implement instructional strategies aimed at fostering enhanced transfer of knowledge. Learning is most effective when students assimilate new knowledge into their existing frameworks which strengthens their problem-solving abilities across various situations (Polya as cited in Siniguian, 2017). Polya's steps of problem-solving: understanding the problem, devising a plan, executing the plan, and reviewing the solution has been recognized as a guideline for sustaining both near and far transferability in mathematics teaching (Schoenfeld, 1992). This model encourages students to not only think deeply about the problems they are presented with but also reflect on the processes they employed in arriving at the solutions. Thus, enabling them to design efficient strategies for transferability.

In a bid to strengthen transferability in solid geometry, researchers recommend teaching through real-world contexts, dynamic geometry software, and inquiry-based learning (Chazan, 1993). Inquiry-based learning entails guiding students to actively engage with geometric concepts rather than passively receiving information, allowing learners to construct their own understanding. As direct instruction is often less effective, active approaches designed for students at any academic level tend to ameliorate learners' retention rates along with applied problem solving (Kwon et al., 2019).

Additionally, solid geometry problem-solving competencies are enhanced through the development of spatial reasoning within technology-inclusive environments. Interactive tools such as GeoGebra and Cabri 3D enable students to visualize and manipulate three-dimensional figures which enhance their information retention and application to real-world scenarios (Laborde, 2005). According to Olkun (2003), students who used dynamic geometry software as opposed to static textbook diagrams performed significantly better on spatial reasoning tasks. This indicates that the use of technology in teaching solid geometry may enhance practical problem-solving skills.

Moreover, integrating real-life experiences into teaching geometry helps in far transferability because students appreciate the value of mathematical concepts outside the classroom. For instance, Lehrer and Schauble's (2012) research shows that students who work on design-based projects like model architecture or engineering geometry analysis have a better understanding of solid geometry and are more likely to use that knowledge in new, different contexts. These findings support the hypothesis that authenticates that problem-solving tasks enhance the ability of students to transfer skills to other disciplines.

Thus, this study looks at how solid geometry teaching can be designed to encourage both near and far transferability of problem-solving skills. This study seeks to determine what teaching methods, through inquiry-based learning and the use of technology, enable students to acquire long lasting geometric knowledge and effectively use it outside the classroom. Determining the effects of various teaching strategies on transferability will greatly contribute to the improvement of mathematics education and the development of the students' abilities to face real-life problems.

Students' difficulty in solving geometry problems

Mathematics, particularly geometry, pose a unique challenge for students because of the abstract thinking skills required (Adolphus, 2011). While arithmetic primarily focuses on scratching the surface of numbers, at a more advanced level geometry interpretation necessitates visualization, spatial reasoning as well as manipulation and logic. Such requirements make the learnability of geometry difficult for a large number of learners, which results in inadequate problem-solving skills and abstraction applications. This problem is a resultant of a constellation of factors; restricted spatial reasoning skill sets, ineffective problem-solving skills and poor confidence in logical reasoning (Purba et al., 2017). Lack of ability to visualize elaborate 3D figures and their interrelations makes solid geometry concepts exceedingly difficult to understand for learners. Compounding these issues is the student's tendency to employ procedural algorithms devoid of contextual mastery based on fundamental concepts which leads to inadequate skill application.

Rote learning paradigms found in some classrooms is the single most important reason a learner has difficulty grasping concepts related to solid geometry. In the context of the Geometry, Kiarsi and Ebrahimi (2021) strongly criticize teaching strategies based on memorization of procedures accentuating that it does not aid the development of true understanding. Such strategies, rather, foster the conditioning of students for repetitive practice devoid of the reasoning needed to approach non-familiar problems. This creates problems when attempting to apply geometry in practical contexts like engineering, architecture, or design. For example, a learner might calculate a volume of a cylinder yet be unable to estimate how much material he has to construct the said cylindrical water tank. Such a gap demonstrates the need for teaching methodologies that foster advanced learning, deep level of understanding, problem solving skills, and greater competence in learners.

Research indicates that learners grasp geometric relationships better when they are shown visual and kinesthetic aids (Rafi & Retnawati, 2018). Moreover, visual processing plays a critical bridge role in geometry as a discipline. The handling of the three-dimensional models, whether physically or digitally, greatly improves students' intuition and spatial awareness with regards to various geometric properties. Dynamic geometry software, including GeoGebra and Cabri 3D, has been proven to enhance learners' visualization and exploration of geometric relationships far better than static methods (Jupri & Drijvers, 2016). The software enables learners to interact with the objects that they are studying by changing shapes, watching transformations, and internalizing basic geometric concepts. With the integration of technology, geometry instruction can be made more advanced, interesting and effective which promotes better student understanding and retention of concepts taught in solid geometry.

Lastly, self-efficacy coupled with problem solving trust is another notable reason why students reach their mathematical goals. It has been revealed that students who have confidence and trust in their academic achievements tend to interact with complex problems and strive to succeed even when faced with challenges in the attempts to solve the problems themselves (Skaalvik, Federici, & Klassen, 2015). On the other hand, low self-efficacy students tend to opt for easier, less challenging problems, which causes a continuous cycle of underachieving and disappointment. In geometry, where multi-step strategies and the integration of several concepts are frequently required, self-assurance plays a defining role in a student's problem-solving ability. Self-doubt can lead to the ineffective resolution of a problem and too soon result in repeated attempts that achieve no fruitful outcome.

To solve the problem, teachers should work on their pedagogy to raise student confidence levels and positively impact self-attitudes towards problem-solving. Students can develop a growth mindset alongside resilience in mathematics through inquiry-based learning and collaborative problem-solving activities (Kwon et al., 2019). In the inquiry-based learning model, students are provided with geometric concepts to explore through methods of guided discovery, which encourages self-critical thinking as well as self-strategy development. This differs from traditional telling instruction, where students are given the information, and they passively receive without engaging. Students are provided with the opportunity to explore, make mistakes, and refine their reasoning, enabling a deeper understanding through inquiry-based learning which promotes confident reasoning in geometry.

Students become further engaged when applying their knowledge through real-world scenarios. Lehrer and Schauble (2012) highlight the importance of students authentically practicing geometric concepts by equipping them with real-world problem-solving skills. For instance, commanding students to undertake architecture-based projects like floor plan design or constructing three-dimensional models aids learners in grasping the relevance of solid geometry beyond textbooks. Likewise, students applying mathematical reasoning through engineering-based challenges, such as calculating the load-sustaining capacity of structures, prove to aid students meaningfully and expose them to rich reasoning opportunities. Such practices aim to help learners appreciate geometry not as an abstract discipline but rather as a practical tool to solve real-life problems.

To sum up, the current study investigates the ways of improving instructional practices toward learners achieving better learning outcomes in understanding and developing confidence in solving solid geometry. Moving from a culture of rote learning toward stressing vertical and interactive engagement with visual learning tools, inquiry-based learning, and real-world applications blends together to increase students' spatial awareness and problem-solving abilities. Shaping students' self-efficacy takes a considerable share of mathematics spaces, as students' preparedness to approach challenging problems relies significantly on enduring self-beliefs developed and cultivated. Through employing the strategies provided, educators have the tools needed to construct an enduring understanding of solid geometry as well as systems thinking skills that transcend disciplines and contexts.

Methods

Research design and population

The study utilised a mixed-method approach to provide answers to the factors influencing transferability of geometry concepts among SHS students.
From a population of 1,024 final year high school students in two schools, a sample of 99 was conveniently selected for the quantitative data. Convenient sampling was used because of constraint of time, and it allowed to collect data from readily available participants. To obtain qualitative data on students' transferability levels in (far and near transferability) solving solid geometry problems, thirteen (13) students out of ninety-nine (99) students were selected for individual interview by the saturation theory. Students were then notified prior to the interview that their information would be kept private and used solely for academic purposes.

Instrument

In this study, a Solid Geometry Achievement test (SGAT) was adopted with two separate essay type solid geometry problems from WASSCE past questions (2014-2019) and a third problem developed by experts based on the Core mathematics teaching syllabus (SHS 1 – 3). The instrument had 3 sections: *Section A: (Familiar Problem)* - one essay type problem with three sub-items. The researcher ensued that the item was solved in class with the teacher since the problem and its solution were inspected accordingly. The rationale for lifting the 'familiar' problem was to find out if candidates could solve problems they had seen and solved in class within few weeks. *Section B: (Near Transfer Problem)* - one essay type problem with two sub-items. The item was lifted from the WASSCE past question. Though very similar to the Familiar Problem, the researcher did not see it in the notes or exercise books of students. It was based on the rationale that if students understood what they were taught in class, they were able to solve the Near Transfer Problem with little or no difficulty. Students were also expected to apply knowledge gained from class to solve closely related problems, otherwise referred to by the researcher as Near Transfer Problem. *Section C: (Far Transfer Problem)*- one composite non-routine problem developed by a mathematics education and assessment expert based on the core mathematics teaching syllabus for SHS 1 – 3. The problem was obviously out of the usual kind of problem students have seen. The item was aimed at measuring higher order learning skills such as application, synthesis, and analysis. Students were expected to think critically and apply a number of previously learnt concepts in order to solve the item in this section.

Reliability and validity

To evaluate the reliability of the measuring scale in this study, a test-retest analysis was performed on the test items. Test-retest reliability examines the consistency of measurements of the same construct administered to the same sample at different times (Drost, 2011). The test items were given to students in a different school, and after two weeks, the same test items were administered again to the same students. The reliability coefficient was 0.72, indicating that the internal consistency of the items in the instrument was good and reliable. The content validity was ensured by examining representativeness of each item concerning the construct being measured. The face validity of the test items was also assessed to ensure that the items appeared to measure the intended construct.

To eliminate research bias and increase participant comfort during interviews, the researcher enlisted a neutral professional, trained in interview techniques (Cohen, 2007). Consistent wording and context for interview questions were maintained for all respondents to ensure reliability. Dependability was addressed by providing participants with the transcribed interview data to verify the accuracy and fairness of the interpretation (Anfara et al., cited in Cohen, Manion & Morrison, 2007). By implementing these procedures, the study aimed to establish the reliability and validity of the measuring scale, thereby enhancing the research's credibility.

Ethical consideration

Consent and clearance letters from the School of Science, Mathematics, and Technology Education was used for permission from the high schools. Before beginning the data gathering process, informed consent was obtained from the participants. They were made aware of the objective of the study and offered the option of performing or declining. Participants' privacy and identities were protected (Creswell, 2014) and assured of confidentiality.

Data collection procedure

Data was collected in this wise: a Solid Geometry Achievement test (SGAT) was administered to the participants in the two schools selected for the study.

The test lasted for one hour, thirty minutes. The items were then collected and scored out of 100. After scoring the items, thirteen students were interviewed to ascertain their challenges or otherwise what inform their way of answering the items.

Data analysis procedure

Data collected was analysed descriptively for research objective one and two by means, standard deviations, tables, frequencies and percentages. While research objective three was analysed inferentially by Kruskal Wallis Test (Ranks) and Tukey's HSD Test as Post – Hoc since the mean difference among the Familiar, Near Transfer and Far Transfer problem across course of study was significant at 5% alpha value. Since the normality assumption was violated, the non-parametric equivalent of One – Way ANOVA, Kruskal Wallis Test (Ranks) was employed to test the null hypothesis at 5% alpha level.

Results and Discussions

Demographic characteristics of respondents

The sample, comprising of 99 students drawn from two schools and three courses are represented by Table 1.

Table 1: Demographic distribution of respondents

Variable	Category	N	%
Course of Study	Science	30	30.3
	General Arts	59	59.6
	Business	10	10.1
Sex	Female	83	83.8
	Male	16	16.2

Source: Field Data (2024)

Table 1 shows that out of 99 respondents, female accounts for 83. In terms of programme of study, about 60% read general arts while 30% read science. The result here implies that most SHS students do not read science, and this is likely to affect government drives for technical education.

Research Question One

What is the ability of students in solving Familiar, Near transfer and Far transfer problems in solid geometry?

The first research question sought to find out final year students' ability for solving problems they have seen and solved before (familiar problems); those that are very much similar to the problems they have solved before (Near Transfer) and those problems that are non-routine or unfamiliar (far transfer problems).

Table 2: Students' ability for solving different problem types

Problem Type	**N**	**Mean**	**SD**
Familiar	99	15.27	2.71
Near transfer	99	11.94	2.95
Far transfer	99	8.43	2.27

Source: Field Data (2024)

The Table 2 illustrates the mean scores, denoting their cognitive abilities on each of familiar, Near transfer and far transfer problems. Clearly from Table 2, it is seen that, the percentage scores of the final year students depict a woeful performance. On the average, students scored approximately 15% on the problem which was solved in class. Considering the fact that the familiar problem was already seen by students few weeks before the data collection, it shows that students underperformed in solid geometry. This, not only confirm the fact that students struggle with solid geometry problems but perform abysmally when they attempt such problems. The woeful performance on familiar solid geometry problem supports the chief examiner's comment on Ghanaian students' weaknesses in solving solid geometry.

Again, with Table 2, a mean score of 12% on Near Transfer problems which were similar problems to those solved in class, was far below expectation. 12% simply suggest that students could not transfer knowledge acquired to similar problems solved. This depicts a worrying situation. If students are unable to transfer knowledge to solve problems that are very similar to the one's they had seen and discussed, it simply suggest that their conceptual understanding of solid geometry is hampered. The weakness exhibited in solving the Near Transfer Problem clearly imply that students would not be able to perform in the Far Transfer Problem since the Far Transfer Problems require more complex thinking skills. The 8% average performance on the far Transfer Problems further heightens the fact that students are not able to transfer knowledge to solve non-routine problems in geometry. Aside the fact that students underperformed on all Problem types in solid geometry, the mean values in Table 3 suggests that students' ability to solve solid geometry problems decline as problems encountered become less familiar.

The results revealed that the perc"ntag' scores of the final year students on Familiar, near transfer, far transfer and non-routine problems in solid geometry achievement test depict a woeful performance. Students could not solve problems that they are familiar with and was solved in class before, scoring approximately 15% on average. This study not only confirms the fact that students struggle with solid geometry problems but perform abysmally when they attempt such problems. The findings resonate with Agustin, and Retnowati, (2022), whose research revealed Near transfer and Far transfer of knowledge as one of the most pressing issues in learning solid geometry and mathematics in general. This confirms that students have difficulties in learning solid geometry and transferring knowledge to solve problems which are similar to what they already have in a different context. Similarly, the finding of Purba, Sinaga, Mukhtar and Surya, (2017), indicated that Senior High School students face a lot of challenges and continue to struggle with solving solid geometry problems.

Research Question Two

What are the difficulties of students when solving solid geometry problems?

This question sought to identify the difficulties students encounter when solving solid geometry problems. Thirteen (13) students who demonstrated appreciable knowledge through their presentations but could not successfully solve solid geometry problems were interviewed to ascertain the specific difficulties confronting students. The problems that dominated were presented in themes as follows:

Inability to apply the concept of ratio

Both the Familiar and Near Transfer problems required the application of the concept of ratio in order for students to make any headway. Although 22 (22%) of the respondents were clueless regarding all three solid geometry problems, majority who attempted even the familiar problem were not successful simply because they could not apply the initial concept of ratio to determine the height of the cones that were needed to solve subsequent problems. For instance, although K-036 demonstrated evidence of understanding the concepts/problem posed under all three problem types, he could not arrive at the solutions due to an error in the application of proportion.

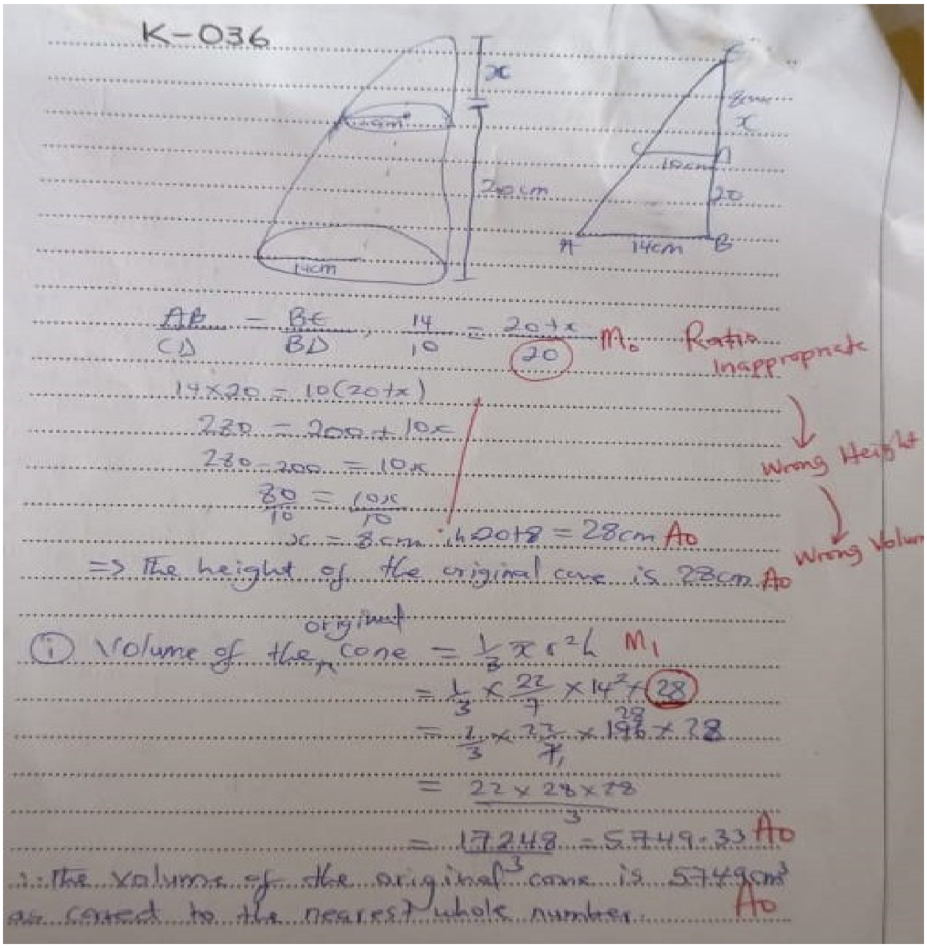

Figure 1: Solution Presented by Participant K-036

A critical analysis of the solution presented by K – 036 reveal *inappropriate ratio* $\left[\frac{\mathbf{14}}{\mathbf{10}} = \frac{\mathbf{20+x}}{\mathbf{20}}\right]$ which led to the *wrong height* [28cm] and culminated into the wrong volume [$5749.33cm^3$]**.** This appeared to be one of the prominent challenges that faced most of the respondents who demonstrated conceptual understanding of the problems but were unable to successfully solve the problems. Very similar to the difficulty faced by K -036 was that of B – 057. She too demonstrated great knowledge of the concepts except for the challenge of wrong application of proportion. Instead of $\left[\frac{\mathbf{14}}{\mathbf{10}} = \frac{\mathbf{20+x}}{\mathbf{x}}\right]$, she presented it as $\left[\frac{\mathbf{14}}{\mathbf{10}} = \frac{\mathbf{20}}{\mathbf{x}}\right]$. This led to a wrong height, $\boldsymbol{x = 14.2857cm}$, instead of 50cm. The wrong height ($= \mathbf{14.2857cm}$) led to an obvious wrong volume for the original cone ($7039.999cm^3$).

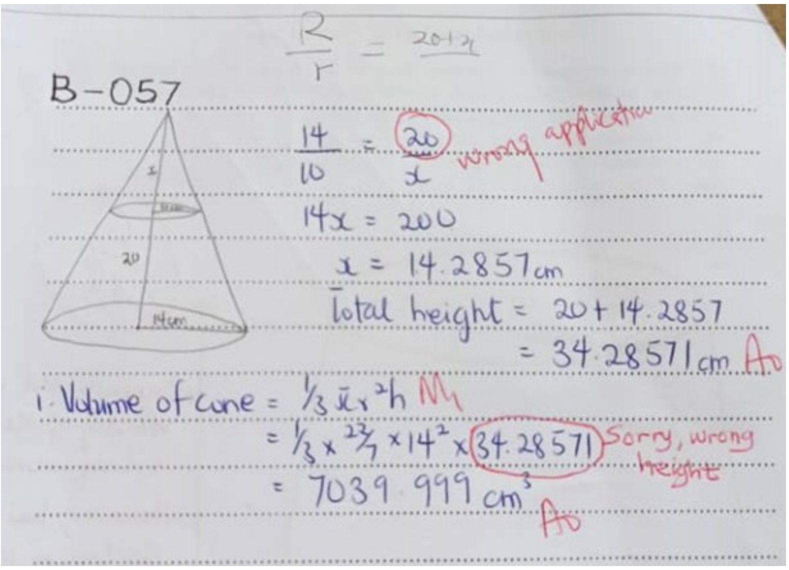

Figure 2: Solution Presented by Participant K-057

In the follow up interview, participants were asked "Can you explain how you used the ratio approach in solving the question?" Here is what the participant had to say:

> Participant K-057: *I tried dividing the greater numbers over the smaller. I was really confused, so I just guessed.*
>
> Participant K-024: *For ratio, I cross multiply after dividing the numbers. So I divided it and multiplied.*

The difficulty posed by the inability of students to apply the concept of ratio and proportion alright, run through all the problem types. Thus, students who 'suffered' on the Familiar problem by not being able to apply ratio and proportion, encountered the same fate on the Near transfer problem. The solutions presented by B – 002, attest to this fact.

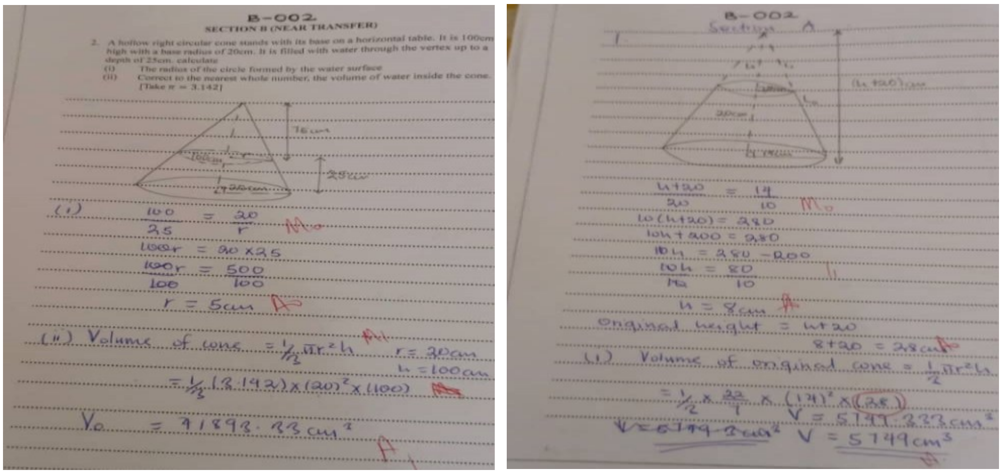

Figure 3: Solution Presented by Participant B-002

To sum up, it could be deduced that, having the conceptual understanding of solid geometry problems without being able to rightly apply other related concepts, such as ratio and proportion in this case could lead to non-performance. Students are most likely going to encounter solid geometry problems that require the application of other related concepts that may not directly be geometry related. Mathematics teachers should take note and model out more related problems for students to practice. Also, real life does not present problems that require an isolated knowledge for solution. Students would always have to apply knowledge from varied sources to solve problems within a given context. Such skill and expertise, which was identified as lacking among even the brilliant students, is transferability. The Common Core Curriculum seeks to place much emphasis on these skills.

Inability to sketch the problem

The Near transfer problem (2nd problem) was presented as a story problem without any supporting diagram. To solve the problem, students were expected to demonstrate their conceptual understanding of the problem through the kind

of sketches they make of the problem. A close study of students' work revealed three categories of students who attempted solving the Near transfer problem: those that attempted solving without any sketch, those that made wrong sketch of the problem and those that got the sketch right.
In the follow up interview, participants were asked "Why didn't you sketch when solving the question?" Here is what the participant had to say:

> Participant B-002: *I don't know for this question we need to sketch.*
>
> Participant B-023: *I don't understand the question.*
>
> Participant K-041: *I know for this type of question, I need to sketch but I always get it wrong.*

All respondents who attempted solving without any sketch as well as all who got the sketch wrong could not solve it right. It is noteworthy however that, all who got the sketch right either got all the marks allocated (10 out of 40) to the Near Transfer problem or got some of the marks. Those who could not score the full marks were challenged by the concept of slant height.

Mistaking slant height for vertical height of a cone

The fact that only two of the 99 students had good knowledge of the clear difference between the vertical height and the slant height of a cone, is worth noting. Almost all the respondents had no idea about the difference between the slant height, and the vertical height, otherwise referred to as height, h. The follow-up interview on 13 students whose work revealed some degree of conceptual understanding revealed that, a third student, B – 011, seem to have understood the difference between the two types of heights (in relation to a cone). This is because, her response, when asked:

> *'even though you quoted $\pi r l$ rightly as the curved surface area of a cone, you still used the wrong value for slant height. What could have accounted for that?'*

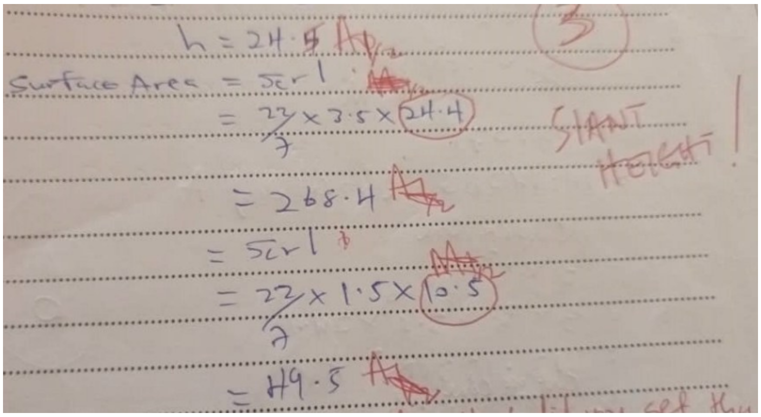

Figure 4: Solution Presented by Participant B-011

Her response was:

> *'I actually know that the slant height is not the same as the vertical height. But, I just don't know what happened to me when I was solving this very question' [B-011].*

Drawing from the works of students, it became clear that 98% of the students did not know that slant height was not the same as the vertical height of a cone. This was a major challenge for students who even demonstrated conceptual understanding of the problems. The implication for mathematics teachers is that emphasis must be placed on the difference between the two types of heights in relation with cones. Teachers may also have to be intentional about the types of examples they work out with students in class. These practical exposures could create an appreciable consciousness within students about the difference between slant height and vertical height of cones.

Summing up the difficulties of students when solving solid geometry problems, the data revealed three key difficulties: Inability to apply the concept of ratio and proportion alright; Inability to sketch the problem; and Mistaking slant height for vertical height of a cone. It came out clearly that, no matter how students had mastery over solid geometry problems, their inability to transfer knowledge on ratio and proportion, inability to make appropriate sketches of story problems as well as mistaking slant height for the vertical height of cones posed significant difficulties for students while solving solid geometry problems. The findings are in line with the findings of Numan and Hasan (2017); Surya (2012); Purba et al. (2017). For instance, Surya (2012) indicated that one key reason for low achievement is the insufficient opportunity for students to transfer their learning to new concepts, a pattern compounded by language barriers in comprehension.

Findings, Conclusions and Recommendations

Findings

The study revealed the following key findings:

1. The percentage scores of the final year students on Familiar, near transfer, far transfer and non-routine problems in solid geometry achievement test depict a woeful performance. Students could not solve problems that are familiar with and were solved in class before, scoring approximately 15% on average. This study not only confirms the fact that students struggle with solid geometry problems but perform abysmally when they attempt such problems.
2. Three difficulties were pronounced amongst students when solving solid geometry problems. These were: Inability to apply the concept of ratio and proportion alright; Inability to sketch the problem; and Mistaking slant height for vertical height of a cone.

Conclusion

Based on the findings, the study concluded that:

1. majority of students encounter difficulties transferring knowledge from what they have learnt to solve non-routine problems. The main difficulty might be drawn from their inability to think critically and logically and applying problem solving strategy, both in general and specific terms. The results of the study showed that the average percentage scores, students performed poorly on achievement test in Familiar, near transfer, far transfer and non-routine problems in solid geometry. This confirms the fact that students struggle with solid geometry problems.
2. the pronounced difficulties in solving solid geometry problems reveal specific areas where students struggle. The inability to apply ratios and proportions correctly, difficulties in sketching problems, and confusion between slant height and vertical height in cones indicate gaps in foundational understanding and spatial reasoning.

Recommendation

The study recommends that educators should:

1. design tasks that require students to manipulate ratios within diverse problem settings, thereby enhancing their ability to transfer these concepts to novel, non-routine problems.
2. provide explicit and comparative instruction on distinguishing between different dimensions in three-dimensional figures thereby helping students consolidate their understanding and promote the transfer of accurate dimensional reasoning to other solid geometry problems.

Conflict of Interest Statement

The Authors declare no competing interest.

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Atepor: Conceptualisation, design, analysis, supervision, writing. Ayambire: Writing, Editing/reviewing, data acquisition, data analysis. Yarkwah: Supervision, final approval

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Generative AI Statement

As the authors of this work, we minimally used the AI tool (ChatGPT) for the purpose of summarising. After using this AI tool, we reviewed and verified the final version of our work. We, as the authors, take full responsibility for the content of our published work.

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