

Exploring Grade 8 Students' Errors When Learning About the Surface Area of Prisms

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Abstract

The calculation of the total surface area of prisms forms part of the Mathematics curriculum in South Africa. This paper explores Grade 8 students' errors when learning about the surface area of prisms. The study was guided by the interpretive paradigm and adopted a qualitative approach in a form of a case study design. Data from diagnostic test's responses were analysed using Newman's theory of error analysis. The sample comprised 18 purposively selected Grade 8 students. The study revealed that students committed these errors: failure to differentiate 2-Dimensionals from 3-Dimensionals; calculated the Total Surface Area as the perimeter of polygons; used volume of prisms formula for Total Surface Area; and misunderstanding of mathematical terminology related to surface area of prisms. The study recommends the use of students' errors as tools to guide in designing the intervention activities to remedy misconceptions that students hold when learning about the surface area of prisms.

Keywords: errors, mathematics, prisms students, surface area

INTRODUCTION

Measurement is one of the major topics in the Mathematics school curriculum since it deals with the manipulation of length; area and perimeter of shapes; surface area and volume of prisms, among other topics. Measurement is one of the concepts that manifests itself in most of a human being's day to day activities, for example in the kitchen, laboratory, when driving or travelling by air, conducting population studies as well as in carpentry; all these need some sort of calculation and measurement skills. In addition, the deeper understanding of surface area of prisms supports science, technology, economic life and several other fields (Razzouk & Shute, 2012). Concepts of area measurement, for example, the calculating of the surface area of prisms not merely reinforces students' understanding of three-dimensional measurement, however, it also offers students with a strong basis of understanding multiplication, fractions, and algebraic multiplication (Outhred, & Mitchelmore, 2000; Sarama, & Clements, 2009). The strong foundation in the listed areas empowers students with mathematical skills that are needed in all other topics of Mathematics. This implies that if the concepts of measurement are not well

developed, the students cannot perform up to the expected level of proficiency in Mathematics.

The understanding of 2-Dimensional (2-D) shapes and 3-Dimensional (3-D) objects is considered as an essential component of Geometry and Mathematics learning in primary school (in Australia) (Livy, Downton, A. & Wöller, 2018) and in both primary and secondary school levels in South Africa. Student's understanding of the Total Surface Area of prisms relies on their understanding of 2D shapes' manipulation, for example, area measurement. In other words, 2D's are building blocks of 3D's. Research shows that teachers put too much emphasis on numerical operational skills instead of providing students with more experiences with exploration of formulae, for example, exploration of formulae for area measurement (Huang & Wirtz, 2010). This implies that teachers focus too much on engaging students in formulae manipulation without allowing them to explore how 2D's can be used to build a 3D object and then allow them to calculate the TSA of the build prism.

Students with problems in understanding the properties of geometric shapes and solids cannot be able to perform calculations regarding 2-D shapes and 3-D

Contribution to the literature

- To raise teachers' awareness of the diverse errors that students make when solving problems regarding the surface area of prisms.
- To develop robust interventions in response to the areas that students commit in an attempt to help students understand the calculation of surface area of prisms.

objects. Literature contends that students can understand the relationship between the 2-Ds and 3-Ds when they are offered the opportunity to engage in making prisms and developing the properties of prisms through investigation (Livy et al., 2018). This means that the teaching of 2-Ds and 3-Ds should engage students on hands on activities for them to make meaning from the given scenario.

Despite the notion that the surface area concept forms part of the South African Mathematics curriculum, many students still find it difficult to calculate mathematical problems involving the surface area of prisms. Many students fail to use the appropriate formula and use of correct units (Goos & Markar, 2008). The difficulties encountered are a result of errors that students commit in the process of tackling mathematical questions. Literature highlights that generally; Mathematics students commit different errors, which may include: (i) errors to receive information of the problems (ii) errors in applying formula (iii) errors related to the concept of Euclidean solid (iv) errors in calculating (Aini, Priatna & Priatna, 2019). In the case of prisms, most students do not understand how to calculate the surface area of prisms. Misunderstanding of mathematical problems makes students commit errors as identified in Newman's theory (Fitriani, Turmudi & Prabawanto, 2018). Hasanah and Yulianti (2020) argue that students' errors in measurement emanate from misunderstanding of the notion of the 2-Ds and 3-Ds, negligence in calculations, rush in getting to the solution without an understanding of what is needed, and lack of effort. In a study conducted by Chiphambo, Mashologu, and Mtsi (2020) despite the use of physical manipulative some students still persisted in failing to differentiate a 2-D from a 3-D.

In a study conducted by Hasanah and Yulianti (2020) on 'error analysis in solving prism and pyramid problems,' the outcome revealed that students committed four type of errors as follows: (i) errors in understanding the problem: it is when the students made mistakes in calculating the volume of prism, the formula of a pyramid was used instead of that one of a prisms; (ii) errors in thinking of a plan: it is when students failed to substitute the given dimensions of a pyramid into the formula; (iii) errors in implementation of the plan: this was when students managed to substitute given dimensions into the correct formula, but failed to calculate the volume of prisms and pyramids; and (iv) errors in review occurred when students failed to crosscheck if their responses were correct or not.

Errors two to four differ from the errors identified in this study.

In Mathematics, there are basic principles that a student needs to understand to arrive at the correct solution for the given problems; any misconception in one of the principles can cause the student to arrive at an incorrect solution. Literature highlights that much time and effort need to be invested in teaching students to understand the surface area concepts for the reason that many students still experience problems, specifically when calculating length, area and the volume of prisms (Baiduri, 2019; Istiani, 2017). According to Sisman and Aksu's (2016) study revealed that the conceptual understanding and skills acquisition about length, area and volume measurement cannot be isolated from each other as absence and partial understanding of these concepts affects the performance in the domain of measurement (Battista, 2003; Stephan & Clements, 2003).

Errors that students commit when learning about the surface area of prisms can easily serve as essential tools to diagnose misconceptions or errors, and determining the type of intervention to be designed and implemented to remedy the situation. Misconceptions committed by students in solving problems regarding surface area of prisms are due to lack of conceptual and procedural knowledge of mathematics (Sisman & Aksu, 2016). For example, Hiebert (1986) defines conceptual knowledge as "connected web of knowledge" and "rich in relationships" (p.3) while procedural knowledge is composed of both the knowledge of mathematical symbols and the knowledge of algorithms or techniques that are "step-by-step instructions that prescribe how to complete tasks" (p. 6). In Sisman and Aksu's (2016) study aimed at analysing students' written responses to the surface area measurement tasks, the results indicated a wide range of errors and misconceptions as follows: (i) lack of conceptual knowledge was demonstrated by "confusing surface area with volume" and "believing that a shape has more than one surface." On the other hand, lack of procedural knowledge was evident when the students responded that "surface area equals to length plus width plus height" and "using the volume formula to calculate surface area" (p. 1311). Most of the errors identified by Sisman and Aksu (2016) are similar to what this study has found out. The difference is that this study found errors that were not discovered in Sisman and Aksu's (2016) study, these include: students' failure to differentiate a 2D from a 3D and confusion of Total Surface Area of prism with perimeter of polygons.

Chin and Pierce's (2019) research findings show that in mathematics generally, students' errors patterns are sometimes influenced by problematic conceptions that students might have encountered previously or even lack of knowledge on the presented concept. In some cases, most students committed errors as a result of lack of knowledge of the concepts or faulty learning or carelessness. For example, students' lack of knowledge in a particular concept is what happens in most South African schools where rote learning is promoted just for students to pass the tests and examination without conceptual understanding (Mahlaba, 2020). Rote learning generally leads to students experiencing difficulty to apply simple mathematical concepts to applied scenarios (Faulkner, Breen, Prendergast, & Carr, 2020).

Errors that students committed, exhibit students' learning difficulties in mathematics. The findings of Hamukwaya and Haser's (2021) study on preservice high school teachers and teacher educators' beliefs about the causes of mathematics learning difficulties revealed that most students lack prior knowledge, poor study habits and the beliefs about the difficulty of mathematics. Prior knowledge is of influence to learning, for example, Huang and Wu's (2019) study suggests that students' comprehension of new domain is determined by previous knowledge of connected processes and notions. For example, in the current study, the new domain (Total Surface Area) depends on the previous knowledge (area of polygons). This implies that if students who lack conceptual understanding about area of polygons, cannot solve problems that involve TSA of prisms. The belief about the difficulty of mathematics, is a general world view, many people think and talk about mathematics being a very difficult subject, this view influences many students as they encounter mathematics problems in the classroom.

Research reveals that errors can also help Mathematics teachers to decide on the type of interventions that they can use to remedy the identified problems (Borasi, 1987). This implies that the method that reveals the diagnosis of students' mathematical errors can be done through Error Analysis (Herholdt & Sapire, 2014).

Mathematics is a very important subject; it has a major role to play in an individual's life. Currently, mathematics learning is mandatory for students since mathematical skills have become very important in a majority of jobs globally (Sujadi, 2018). Some of the skills that are of importance include observation, estimation and measurement. These skills are developed as students are engaged in calculating the surface area of prisms.

Research Question

The study was directed by the following research question:

What kind of errors do Grade 8 students exhibit when solving problems regarding surface area of prisms?

Theoretical Framework

Newman's theory of error analysis highlights five errors that can cause a student to get an incorrect solution when solving a mathematical problem. The five errors are: (i) reading errors: student's inability to read and understand terminology and symbols used in a mathematical sentence, (ii) comprehension errors: students' inability to understand Mathematics questions, (iii) transformation errors: students inability to determine the correct method of mathematical solution, (iv) process skill errors: inability of the students to demonstrate process skills of mathematics, and (v) encoding errors: students' inability to copy correctly a mathematical statement and failure to construct meaning out of asked question. Despite the notion that the listed errors are more general to all Mathematics topics, they also manifest when students are required to determine the Total Surface Area (TSA) of prisms. This implies that there is a need for Mathematics teachers to be creative in designing interventions that can assist students in understanding the calculation of the surface area of prisms.

RESEARCH METHODOLOGY

The study explored grade 8 students' errors when learning about the surface area of prisms. The study was guided by the interpretive paradigm and adopted a qualitative approach in a form of a case study design. The qualitative research methodology was employed as it integrates comprehensive analysis and provided a thick description of the occurrences under study (Cohen, Manion, & Morrison, 2007). Eighteen students' diagnostic test scripts were reviewed to generate the qualitative data. Furthermore, the credible data were analysed using the five types of errors suggested in Newman's theory, namely; reading errors, comprehension errors, transformation errors, process skill errors and encoding errors.

Validity

To ensure content validity, the diagnostic test was piloted using seven students who volunteered to write the test. After the pilot, no further alterations were done to the diagnostic test (DT). The DT was later administered to a group of 18 Grade 8 students. In addition, the diagnostic test's questions were analysed and validated by the Head of the Mathematics Department of the research site to regulate

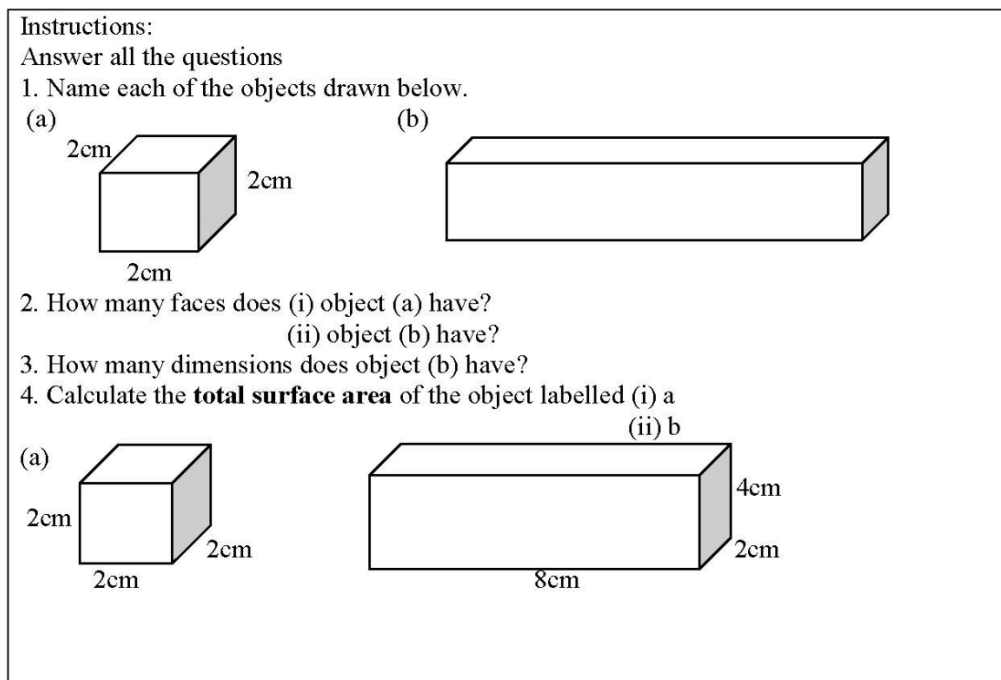


Figure 1. Diagnostic Test (DT)

appropriateness to the grade level and check if the contents were unambiguous.

Reliability

To ensure reliability of this study the subsequent steps as recommended by Shenton (2004) were taken into consideration: The findings from students' reviewed documents are reported in detail and the empirical evidence of how each of the students responded to the DT is presented. The processes of data analysis were well documented (Lacey & Luff, 2007) to make it easy for other scholars to track the procedures in the form of an audit trail at any time.

Data Collection Instruments

As shown in Figure 1, Question 1 required the learners to recognise and name each of the 3-Ds presented diagrammatically since the ability to solve a 3D's surface area starts from the ability to recognise and name the given object. In question 2, learners were asked to write down the number of faces for each of the two 3-Ds. The ability to recognise the 3D's dimensions transforms to the students' comprehension of how to calculate the Total Surface Area (TSA) of that particular object. In question 3, learners had to identify the number of pairs of identical sides. In question 4, students were to compute the Total Surface Area of a cube and a rectangular prism (with known measurements) without the help of a drawing.

Ethical Issues

Letters were written to seek consent from both the principal and the school governing board to conduct the

research in the school. To avoid interference with the regular school programme, data collection was conducted after school hours. To eliminate what could potentially make students uncomfortable to participate in the study, we established what is referred to as "subject to the subject relationship" which is the liberty from professional control (Clarke & Ritchie, 2001, pp. 319, 320), students were encouraged to freely participate in the study regardless of our presence. The diagnostic test was ethically cleared by Rhodes University. The research report that was compiled is free of prejudice towards any of these aspects: age, ethnicity, sexual orientation, race and gender. The study's sample comprised 18 purposively selected Grade 8 students who participated in the research project.

FINDINGS

Presented in this section are the findings that came up from students' diagnostic test responses. The empirical evidence of the findings is presented in Figures 2 to 5, thereafter, a critical analysis is presented in themes under the discussion section.

Figure 2 shows how students responded to Questions 1, 11 out of 18 students (61%) couldn't be able to identify one of the two objects drawn or both, as a cube and/or a rectangular prism, but 39% managed to answer the question correctly.

Figure 3 shows that 67% (L4, L6, L7, L8, L9, L10, L13, L14, L16 & L18) of the students managed to respond to the question correctly while 6 students (33%) could not identify the exact number of faces that the cube has.

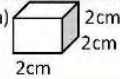
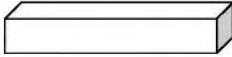
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| | <p>1. Name each of the objects drawn below</p> <p>(a)  (b) </p> |
| L1 | <p>(A) $A = l \times B$ $2 \times 2 \text{ cm}$ $= 4 \text{ cm}^2$</p> <p>(B) $A = l \times B$ $8 \times 2 \text{ cm}$ $= 16 \text{ cm}^2$</p> |
| L2 | <p>a Cube ✓</p> <p>b Rectangular prism</p> |
| L5, L5, L6, L7, L11, L12, L13, L14, L16 & L17 | <p>(A) Square</p> <p>(B) Rectangle</p> |
| L15 | <p>(A) Square Prism</p> <p>(B) Rectangular Prism</p> |

Figure 2. Students' response to question number 1

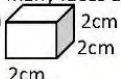
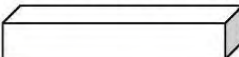
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| | <p>2. How many faces are on each of the objects labelled (a) and (b) below?</p> <p>(a)  (b) </p> |
| L1 | <p>(a) a cube</p> <p>(b) Rectangular prism</p> |
| L2 & L11 | <p>L2: 2. a Cube have 4 faces</p> <p>L11: 2.9 The square got four faces.</p> <p>3. The rectangle got six faces.</p> |
| L5 | <p>1. Object a has 4 faces</p> <p>ii Object b has 3 faces</p> <p>object b has 1 different</p> |
| L12 & L17 | <p>L12: (A) have 4 faces</p> <p>(B) has 4 faces</p> <p>L17: 2. a) it has 4 faces</p> <p>b) it has 4 faces</p> |

Figure 3. Students' response to question number 2

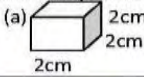
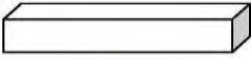
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| | <p>3. How many dimensions does object (b) have?</p> <p>(a)  (b) </p> |
| L2; L3; L6; L8; L9; L10; L15; L17 & L18 | <p>3 D 2 different sides</p> <p>3 There are two different sides</p> <p>3. There are 2 sides</p> |
| L1 & L4 | <p>They are 6 different sides object (b).</p> |
| L11 | <p>3. (a) The size are equal</p> |
| L5 | <p>3. object b has 1 different size</p> |
| L13 | <p>3 square all sides are equal</p> <p>3. rectangle 4 sides a equal 2 are equal</p> |
| L7; L12 & L14 | <p>3, 3 different sides</p> <p>3 sides</p> |
| L16 | <p>Did not respond to the question</p> |

Figure 4. Students' response to question number 3

As indicated in Figure 4, 83% of the students could not respond to both Question 3a and 3b correctly. Seventeen percent of the students managed to indicate that the cube and the rectangular prism, each one has three dimensions.

As illustrated in Figure 5, 44% of the students use the volume formula to answer the question. Another group of 11% responded to the same question as follows: Area = $l \times l$ and $l \times b$, in question 4 'a' and 'b', respectively. Twenty-two per cent of students added the dimensions of a cube to get 6cm and those of a rectangular prism to get 14cm. Instead of answering questions 4 'a' and 'b' separately, 17% of the students combined the two to get 20cm. The last group made up of 6% of the students decided to respond to both Questions 4a and 4b as follows: 'they are six different sides object'.

The data generated from students' responses to the diagnostic test resulted into the following three themes: application of incorrect formula, misunderstanding of mathematical terminology and failure to differentiate 2-Ds from 3-Ds. The descriptive analysis of the findings is presented below.

DISCUSSION OF THE FINDINGS

In this section we discuss the findings of the study. The discussion uses Newman's theory as the lens of mathematical error analysis focussing on the following extracted themes: application of incorrect formula, misunderstanding of mathematical terminology and failure to differentiate 2-Ds from 3-Ds.

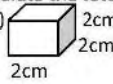
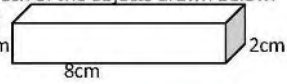
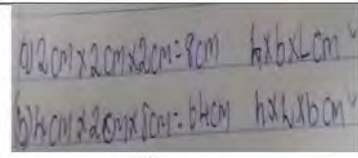
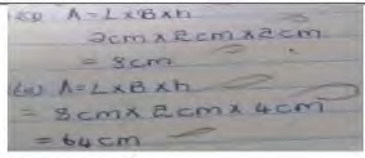
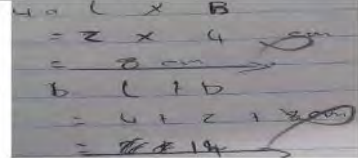
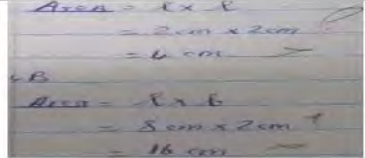
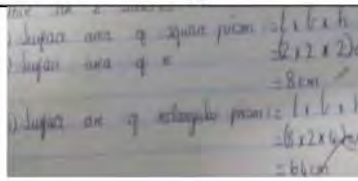
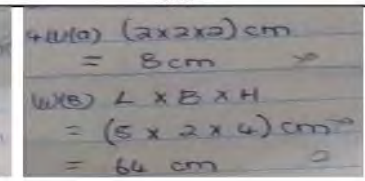
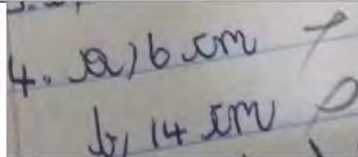
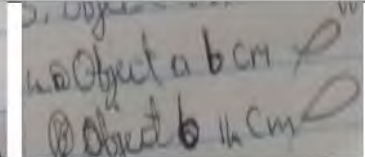
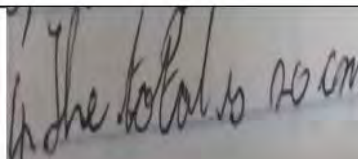
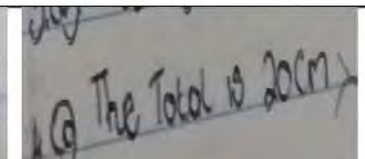
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| | <p>4. Calculate the total surface area of each of the objects drawn below:</p> <p>(a)  2cm 2cm 2cm</p> <p>(b)  4cm 8cm 2cm</p> | |
| L1 & L16 |  <p>L16</p> |  <p>L1</p> |
| L2 & L10 |  <p>L2</p> |  <p>L10</p> |
| L3, L7, L9, L14, L15 & L18 |  |  |
| L4, L5, L12 & L17 |  |  |
| L6, L8, L11 & L13 |  |  |

Figure 5. Students’ response to question number 4

Theme 1: Application of Incorrect Formula

Figure 2 shows how students responded to Questions 1, 11 out of 18 students (61%) couldn’t be able to identify one of the two objects drawn or both, as a cube and/or a rectangular prism. Such errors are also cited by Aini, Priatina and Priatina’s (2019) study which found out that students committed errors related to the Euclidean solid.

As illustrated in Figure 5, 44% of the students confused the formula to calculate TSA of the cube and a rectangular prism with that of the volume. This finding is consistent with Sisman and Aksu’s (2016) study which revealed that students confused the use of the volume formula for the surface area. Another group of 11% responded to the same question differently because of the word ‘area’ that appeared at the end of the phrase ‘total surface.’ The students’ calculations were written as if the question required them to calculate the area of the objects, hence two students calculated their responses as follows: Area = $l \times l$ and $l \times b$, in question 4 ‘a’ and ‘b’, respectively. The confusion of area of a rectangle formula with the formula to calculate TSA of prisms can be interpreted as a transformation error as revealed in Newman’s theory. Several researchers also documented

the results which show college students’ poor understanding of surface area (Cohen & Moreh, 1999; Gilbert, 1982; Light et al., 2007). This is exact what Mahlaba (2020) highlighted that most students are trained to memorise for the tests and examination, they cannot apply what have learnt in a new situation. Errors like the ones present in this paragraph imply that there is a need of designing robust interventions to enhance students’ understanding from the level where the teaching and learning of surface area is introduced.

Theme 2: Misunderstanding of Mathematical Terminology

As Figure 3 illustrates that 33% of the students could not identify the exact number of faces that the cube has. The errors committed by 33% of the students were due to reading where most of them had a problem with the understanding of terminology, for example, the exact, mathematical meaning of the term ‘faces’ was not well understood. This is in agreement with Aini, Priatina and Priatina’s (2019) study which revealed that students lack understanding the concept of prism. This implies that if students are not conceptually clear about prisms there is

no way that they can respond to basic questions regarding prisms correctly.

In Figure 4, Question 3, Only 17% of the students managed to indicate that a rectangular prism has three dimensions and those three students regard dimensions as sides, this simply shows that most students are not conversant in mathematical terminology. These findings reflect on the literature's revelations on how some students are more likely to commit errors related to the concept of Euclidean solid (Aini, Priatna, & Priatna, 2019).

As illustrated in Figure 5, in question 4, twenty-two per cent (22%) of students decided to add the given dimensions of a cube to get 6cm and those of a rectangular prism to get 14cm. Both groups, could not use the correct mathematical methods. Research revealed that such errors are due to either students' misunderstanding of mathematics questions or/and difficulty in application of simple mathematical concepts to a new scenario (Faulkner et al., 2020; Fitriani, Turmudi, & Prabawanto, 2018). Such errors can be interpreted as transformation errors. Instead of answering questions 4 'a' and 'b' separately, 17% of the students combined the two to get 20cm. They simply added the dimensions of both a cube and a rectangular prism. This problem emanated from the misinterpretation of the word 'Total Surface Area' in the question, the misinterpretation of the term 'TSA' made students add the given dimensions in both diagrams without taking into account what the question required them to do. The findings are in agreement with 'Sisman and Aksu's (2016) studies which found out that most students responded in writing that 'surface area equals to length plus width plus height'. Such errors can be interpreted as reading and comprehension errors. The last group made up of 6% of the students decided to respond to both Questions 4a and 4b as follows: 'they are six different sides object'. The students could not comprehend the given mathematical problem, therefore, this is interpreted as a comprehension error.

Theme 3: Failure to Differentiate 2-Ds from 3-Ds

In Figure 3, Question 2, for those students who answered that the cube and the rectangular prism, each has three faces, could not understand the difference between a 2-D shape and a 3-D object drawn on the paper. Since a 3-D on the paper only shows three faces, this led students to conclude that it has three faces. The findings pointed out in earlier research by Hasanah and Yulianti's (2020) on 'error analysis in solving prism and pyramid problems,' found out that students committed errors in understanding the problem, for example, the misunderstanding of the difference between 2-Ds and 3-Ds. This is categorised as comprehension error. In another study by Chiphambo, Mashologu, and Mtsi (2020) it was revealed that although physical

manipulatives were integrated into the intervention to help students understand the difference between a 2-D and a 3-D on a flat surface, in a post-test some students still considered a 3-D as a 2-D. This implies that there is a lot that needs to be done to address such misconception.

However, in Hasanah and Yulianti's (2020) study findings, the last four identified errors differed from the errors identified in this study as follows: error two student failed to substitute of numerical values into the formula; in errors three students failed to implement the plan as a result the answer calculated were incorrect; and the fourth type of errors, students couldn't review whether their responses were correct or not.

As indicated in Figure 4, 83% of the students could not respond to both Question 3a and 3b correctly. In that group of 83%, fifty percent of the students responded that each of the prisms has two dimensions while 33% answered that 'six sides'. According to Newman's theory, even though the majority of students had different responses, the fact of the matter is that all students exhibited the same type of errors, i.e., reading and comprehension errors.

CONCLUSION

From the findings the following conclusions regarding students' errors were made:

- The students confused the formula to calculate the TSA of a prism with that of its volume
- The students could not be able to differentiate a 2-D shapes from a 3-D object when both of them are drawn on the paper.
- The students confused of the formula used to calculate the Total Surface Area of prism with that of the perimeter of polygons.
- The students failed to understand the terminology used, for example, the term, 'faces, dimensions,' etc.

RECOMMENDATIONS

We recommend that Mathematics teachers integrate real life objects to address errors that students hold when learning about the surface area of prisms. In addition, we recommend that teachers should find out errors that students exhibit when learning about surface area and 3-Ds so that it can be easy for them to design intervention activities to remedy the situation.

One of the limitations of this study is failure to interview students to support their mathematical thinking per response, the data were lost. Despite the limitation, the study has brought to light errors that students make when learning about TSA and mathematics teachers are informed on the areas that need more attention when teaching the topic.

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