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PROCESS ERRORS COMMITTED BY SENIOR SECONDARY SCHOOL STUDENTS IN SOLVING PROBLEMS IN GEOMETRY IN CROSS RIVER STATE, NIGERIA.

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ABSTRACT

This study aimed to identify the process errors made by senior secondary school students in geometry in Cross River State, Nigeria. A sample of 300 students, selected using a proportionate sampling technique, participated in the study. The Geometry Diagnostic Test (GDT) was used to collect data upon validation by mathematics education and psychometrics experts. The instrument was tested for reliability using the Kendal coefficient of concordance (W), with a coefficient of 0.89 providing sufficient evidence of good inter-rater reliability. The data collected were analysed using frequency counts, percentages, and the Chi-square test. The results showed that most students make errors in transformation, process skills, and encoding when solving geometry problems in mathematics. In contrast, the number of students who made reading and comprehension errors was relatively small. The study also revealed that the process errors made by students did not significantly depend on their gender and school location. The findings of this study have implications for teaching and learning mathematics, particularly geometry, in secondary schools. It underscores the need for teachers to focus on the process of arriving at the correct answer rather than just obtaining the right answer, which is a critical component of problem-solving in mathematics. The results also provide a basis for curriculum developers and designers to design appropriate instructional strategies and learning materials to help students overcome the identified process errors.

KEYWORDS: Assessment, instructional strategies, mathematics education, problem-solving, process errors.

INTRODUCTION

Mathematics is considered a vital subject in the school curriculum worldwide, which has strong connections with other subjects such as science and technology. According to Anlbueze (2015), mathematics studies numbers, shapes, computation, measurement, and relationships.

Similarly, Udonsa and Usonsa (2015) define mathematics as studying quantitative relations, structures, numbers, space, and counting. It is common knowledge that the major branches of mathematics are Arithmetic, Algebra, Geometry, Trigonometry, Statistics, Calculus, and Discrete Mathematics.

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Martin and Secor (2014) also acknowledge that mathematics affects all aspects of human life, including economics, politics, geography, science, and technology. Therefore, students need to acquire mathematical competence at all levels of education. This is one of the reasons why mathematics has since been made a compulsory and core subject in elementary and high schools (Esuong et al., 2022; Caspi et al., 2019; Peteros et al., 2019).

Despite the importance of mathematics, students in developing countries constantly do not perform well in the subject (Akugizibwe & Ahn, 2020; Chand et al., 2021; Bosman & Schulze, 2018). In Nigeria, Mathematics has become a subject that students dread the most. According to the Chief Examiners' Annual Reports of the West African Examination Council (WAEC) from 2019 to 2022, only a small percentage of students achieved a passing grade in Mathematics in the Senior School Certificate Examination (SSCE). Specifically, the percentage of students who achieved credit passes in Mathematics was 33.19% in 2019, 31.47% in 2020, 29.79% in 2021, and 28.41% in 2022 (as reported by WAEC in the years 2019-2022). Due to the abysmal performance in the subject in SSCE, many studies in West Africa, particularly Nigeria, are now attracted to understudy the factors responsible for poor performance in Mathematics (e.g., Awofala & Lawani, 2020; Awofala et al., 2022; Esuong et al., 2022; Reddy et al., 2019; Ugwuanyi et al., 2020). Consequently, factors such as teachers' collaboration (Saka, 2021), math anxiety (Barroso et al., 2021; Juniati & Budayasa, 2020; Owan et al., 2019; Semeraro et al., 2020), socioeconomic status (Ersan & Rodriguez, 2020), teaching quality (Arthur et al., 2022; Tambunan et al., 2021), self-concept (Peteros et al., 2020), teachers' use of e-learning systems (Owan et al., 2020), test item sequence and gender (Bassey et al., 2020; Owan, 2020), amongst other factors.

Nevertheless, most previous studies have broadly addressed the problem of students' poor performance in Mathematics. However, when students' performance in mathematics was further analysed into specific aspects of mathematics to determine which areas students had problems to aid better understanding, it was discovered specifically that students performed poorly in word problems (Akanmu & Bala, 2022; Esuong et al., 2022; Iji et al., 2019; Wakhata et al., 2022) and questions related to geometry Akinyemi et al., 2021; Enamhe, 2022; Omere & Ogedengbe, 2022; Usman et al., 2020). For this reason, many mathematics studies in Africa, especially Nigeria, within the past five years, are increasingly becoming interested in understanding the factors affecting students' achievement in geometry and word problems (e.g., Adelabu et al., 2019; Akanmu & Bala, 2022; Enamhe, 2022; Esuong et al., 2022; Omere & Ogedengbe, 2022; Naidoo & Kapofu, 2020). The current study was conducted based on recent developments focusing on geometry.

Geometry is a branch of mathematics that focuses on studying shapes, their properties, and their relationships (Bassarear, 2012). Its rich history dates back to ancient Egypt, where it was used to measure land, and the Greeks studied the properties of shapes (Cooke, 2007). Research has shown that geometry has enormous potential for making the subject of mathematics come alive and is an exploratory subset of the discipline with links to culture, history, art, and design (Henderson, 2018; Luneta, 2015). Furthermore, geometry develops students' cognitive abilities and helps bridge the gap between concrete and abstract thinking (İbili et al., 2020). It also helps students analyse and interpret the world and equips them with tools that can be applied in other mathematical fields (Özerem, 2012). However, geometry is often challenging for students because they must be able to visualise and describe images, draw shapes, and understand their properties. It also involves developing geometric relationships to determine location, applying transformations, and using symmetry, visualisation, spatial reasoning, and geometric modelling to solve problems. It could be for these reasons that most students do not perform well in this branch of Mathematics, as earlier reported.

Several research studies have found that many students struggle with geometry due to not learning basic terminology before leaving math classes (Ubi et al., 2018; Wonu & Zalmon, 2017). Another study revealed that an inadequate understanding of mathematical symbols makes students unable to solve word problems, leading to poor performance in geometry (Esuong et al., 2022). According to the West African Examination Council chief examiners' report, students have weaknesses in different areas of geometry, such as mensuration, constructions, and circle theorem. In addition, some scholars discovered that many students find geometry tests challenging due to their limited ability to visualise and represent mathematical ideas, difficulties applying computational techniques, problems relating to different geometrical ideas, and inadequate grasp of fundamental geometry concepts (Retnawati et al., 2017). Additionally, Atebe and Schäfer (2011) emphasised the significance of students' general mathematical competencies in understanding geometry. Nevertheless, one major concern derived from a review of related literature is that most recent previous studies are concerned with students' achievement in geometry and the factors contributing to it. Consequently, factors such as GeoGebra (Bhagat& Chang, 2015; Botana et al., 2015; Shadaan & Leong,2013), realistic math education (Laurens et al., 2017), information technology (Kurbonov&Istamova, 2021), augmented reality (İbili et al., 2020), mastery learning strategies (Sood,2013) and peer learning behaviours (Hwang& Hu, 2013), amongst others, have been studied as contributors to students' learning of and achievement in geometry.

From the existing literature, these factors, well featured by previous studies, are all aimed at boosting students' confidence, skills, interest, knowledge and examination preparation. Unfortunately, no previous study in Africa has paid attention to the techniques employed by students when solving geometric problems or the possible errors they make when solving problems in geometry, leading to their poor achievement. This creates a knowledge gap, and there is limited information to suggest that every poor performance in a subject or area within a subject (such as geometry in mathematics) is always associated with factors relating to teachers, the learning environment, instructional patterns or study habits. Sometimes, a knowledgeable student could fail a test or exam not because of poor preparation but due to systematic or random errors committed while solving the problems or associated with the methods used in solving the problems. Bridging this gap, the current study examined the process errors students commit when solving geometry problems. Specifically, the researchers tailored this study towards (i) detecting the process errors committed by students when resolving geometry problems in mathematics; (ii) identifying gender differences in the process error committed when solving geometry problems in mathematics; (iii) detecting process error students make in solving geometry problems in mathematics based on school location. Based on these specific objectives, the study was designed to answer the following research questions and test the hypotheses.

This study is significant because it comprehensively analyses the process errors made by senior secondary school students in geometry within Cross River State, Nigeria. By identifying specific process errors related to transformation, process skills, and encoding, the study provides valuable information that is crucial for educators. The study will enable educators to place greater emphasis on the steps and methods used in solving geometric problems. By doing so, teachers can help students develop a deeper understanding of geometric concepts and improve their overall problem-solving skills. Moreover, the results of the study offer a basis for curriculum developers to design instructional strategies and learning materials that specifically target the identified process errors. Furthermore, the study lays the groundwork for further research into specific instructional methods and interventions that can mitigate the identified process errors.

Research Questions

The following research questions guided the study.

(1) What are the process errors students commit in solving geometry problems in mathematics?

(2) What are the process errors male and female students commit in solving geometry problems in mathematics based on gender?

(3) What process errors do students commit in solving mathematics geometry problems based on school location?

Hypotheses

The following hypotheses guided the study. The hypotheses were tested at the .05 level of significance.

HO_1: The process errors committed by secondary school mathematics students in solving problems in geometry do not depend significantly on gender.

HO_2: The process errors committed by secondary school students in solving problems in geometry do not depend significantly on school location.

Literature Review

Studies on Process Error

According to Elbrink (2014), errors refer to mistakes made by learners when solving problems that can arise from the carelessness, misinterpretation of symbols or text, lack of relevant experience or knowledge, and misconceptions. An error is a deviation from what is deemed correct or true. Luneta and Makonye (2010) characterise these errors as simple symptoms of students' difficulties during the learning process. Students who lack a deep understanding of mathematical concepts naturally make errors when performing operations. These errors are often due to a misunderstanding of the underlying concepts. Identifying process errors is an important and obvious stage in remedying students' misconceptions and errors. Error analysis is an invaluable source of information for teachers. It provides information on students' errors which in turn helps teachers correct students' errors and improves their teaching effectiveness.

Several studies have supported the notion and pointed to the many positive roles errors can play in learners' conceptual understanding (Bransford & Donovan, 2005). Padmavathy (2015) observes that mistakes made in the class are catalysts for the learning that took place and describes such errors as springboards for inquiry. Errors are seen as valuable sources of information about the learning process, providing clues that educators should take advantage of to uncover current learners' knowledge and how they come to construct such knowledge (Keith & Frese, 2008). Students' ability to solve a mathematical problem needs to be analysed to find out where the error occurred. One way to analyse students' errors in solving a description form is by Newman Error Analysis (NEA). White (2010) states that if one is trying to answer a mathematical problem, then that person must be able to go through several successive obstacles: Reading, Comprehension, Transformation, Process Skill, and Encoding. The reading error occurs when the student cannot read the words and symbols contained in the problem. Comprehension error occurs when the student can read the problem but fails to get what is needed to solve the problem. The transformation error occurs when the students understand the problem but fail to choose the correct mathematical operations to solve the problem. Process skill error occurs when the student can choose the correct operation to solve the problem but cannot follow the correct procedure. The encoding error stage occurs when the student finishes solving the problem but misinterprets what was meant.

Gender and Process Error

The process errors committed by secondary school students in mathematics could be identified according to gender because the issue of gender influence on students' performance is inconclusive. According to Audu (2018), gender in science is the classification of the role of males and females in science, technology, engineering and mathematics (STEM). Significant gender difference in favour of boys has been reported by researchers (Ariyo, 2016; Kolawole & Popoola, 2011). They also observed that this has often led to an acute shortage of females accessing tertiary institutions' scientific studies and technical training. On the contrary, other researchers found that female students perform better than their male counterparts in mathematics (Shuaibu & Ameh, 2021; Voyer & Voyer, 2014). Similarly, However, Okigbo and Ezeanyi (2021) discovered that male students committed more errors than their female counterparts; there was no significant difference in the frequency of the common process errors committed by SS3 male and female students.

On the other hand, Ajai and Imoko (2015) found that male and female students taught algebra using problem-based learning did not significantly differ in achievement and retention scores, revealing that male and female students can compete and collaborate in mathematics. Similarly, Musimenta et al. (2020) observed that variation in Mathematics performance could not be attributable to gender. The study deconstructs the common gender-biased assumption that girls are naturally a 'weaker sex' and hence likely to embrace subjects considered 'soft' such as language, literacy, communication skills, and social sciences. Such assumptions are commonly fronted inadvertently without considering possible negative consequences. Goni et al. (2015) found no significant differences between gender and Academic performance in Colleges of Education in Borno State. Therefore, the issue of gender-related differences in mathematics is still controversial and needs to be further investigated.

The disagreements in the results of different studies indicate an evidence gap and suggest that further studies are plausible to clarify such disagreements.

While some studies have found significant gender differences in favour of boys, others have found no significant difference or even better performance by female students. Additionally, there is conflicting evidence regarding the effectiveness of problem-based learning and the assumption that girls are naturally weaker in math and more inclined towards soft subjects. Furthermore, only very few studies have focused specifically on the role of gender in process errors in mathematics and, more so, in geometry. The review suggests that further research is needed to clarify these disagreements and to gain a better understanding of the influence of gender on math performance. Therefore, there is a need for this study to focus on gender and process errors committed by students in solving problems in geometry. This study would contribute to the existing body of knowledge by providing insights into the extent of the influence of gender on students' process errors in geometry. The study will use the quantitative approach to collect data on the frequency and types of process errors male and female students commit in solving geometry problems.

Studies on School Location and Process Error

In recent years, there has been growing interest in understanding how the physical location of a school can impact students' academic achievement (Akinwumi, 2017; Murphy, 2019). One area of particular interest is the effect of school location on students' ability to solve problems (Murphy, 2019; Olibie & Ezeoba, 2014). Nevertheless, previous studies on school location have mostly been concerned with students' performance or achievement in Mathematics (e.g., Akissani & Ahmed, 2019; Musa & Samuel, 2019). While some studies have shown a significant variation in students' academic performance or achievement, based on location, others have yielded contrary findings. For instance, Bleeker and Jacobs (2004) found that location was significant in learning aspects of mathematics and basic science involving angles, with rural students exhibiting more learning difficulties than their urban counterparts. Similarly, Alordiah et al. (2015) found that urban students performed better than rural students in Mathematics. However, Ntibi and Edoho (2017) observed no significant difference in the mean performance scores between urban and rural school students in solving problems in mathematics and basic science problems using the independent t-test analysis.

Other studies involving school location and mathematics have paid attention to variables such as mathematics teachers' feedback practices (Mahmud et al., 2019), students' algebraic problem-solving abilities (Telima & Ilama, 2021), attitudes towards mathematics (Ampadu & Anokye-Poku, 2022) and students' mathematical conception (Idehen, (2021). Little or no focus has been paid to school location and students' process errors in solving mathematical problems, especially in geometry. Geometry requires students to think spatially and manipulate complex shapes and figures, making it an ideal area of study to explore the impact of school location on possible errors committed by students. Sometimes, students make mistakes in solving a problem, such as failing to use the correct formula or misinterpreting a diagram. Such mistakes can make them fail to answer given mathematical problems, resulting in low achievement correctly. Instead of focusing on the end (students' achievement) all the time, it makes sense to shift focus to the means (processes) through which the end is reached.

However, previous studies have shown mixed results on the impact of school location on students' academic achievement in mathematics, particularly in solving problems. While some studies have found that urban students outperform their rural counterparts, others have found no significant difference. However, little attention has been given to the relationship between school location and students' process errors in solving mathematical problems, particularly in geometry. Understanding the prevalence and causes of such errors is crucial in developing effective teaching strategies to enhance students' problem-solving skills. Furthermore, the present study can also contribute to the ongoing debate on the impact of school location on students' academic achievement by exploring the impact of location on the prevalence and causes of process errors.

METHODS

Participants

The study population consists of 37169 secondary school students found in 109 public secondary schools in Cross River State. The population is made up of 19308 male students and 17861 female students. The stratified random sampling technique was used to select six (6) secondary schools based on the eligibility criteria that the school is co-educational and is located in urban and rural areas of Cross River State. Co-educational schools were considered over single-sex schools to allow for gender-specific comparisons in the process errors committed by students. Therefore, six public secondary schools met the above criteria and were selected as the sampling frame. Three schools were chosen from rural and urban areas because in the sampling frame, three schools were located in areas that are urban and the other three are in rural areas. A proportionate stratified random sampling technique was used to select a sample of 301 students (Males: n = 150; Females: n = 151) in senior secondary class three (SS3). This means the population (senior secondary class three students) was first divided into strata based on gender (males and females). Then, a proportionate number (14%) of students in the sampling frame were selected from each stratum to ensure that the sample was representative of the population regarding gender. This ensured that both genders were represented equally in the sample. Using stratified random sampling helped reduce sampling bias and increase the accuracy and representativeness of the sample. The sample distribution of this study is presented in Table 1 for clarity.

Table 1: Population and sample distribution of the study

SN	Name of school	Location	Population			Sample (14%)		
			Male	Female	Total	Male	Female	Total
1	Govt. Sec. School. Ikom	Urban	194	216	410	27	30	57
2	Govt. Tech. Coll. Ogada 11	Urban	180	180	360	25	25	50
3	Community Sec. Sch. Ugep	Urban	207	143	350	29	20	49
4	Okum-East Sec. Sch. Ochon	Rural	143	157	300	20	22	42
5	Govt. Tech. College Ekori	Rural	194	216	410	27	30	57
6	Govt. Sec. Sch. Okangha	Rural	156	164	320	22	23	45
	Grand Total		1074	1076	2150	150	151	301

Instrumentation

Geometry Diagnostic Test (GDT) was the instrument used to investigate the process errors in solving geometry problems in mathematics. The instrument was made of two parts, I and II. Part I was used to obtain the personal data of the respondents, like the name of the school, class, school location and gender. Part II consisted of six essay questions in mathematics adapted and modified from West African Examination Council (WAEC) past questions across different years. These questions were within the mathematics curriculum regarding geometry covered in the senior secondary school syllabus.

Validity and Reliability

The GDT was subjected to both face and content validation. The instrument was face validated by two specialists in measurement and evaluation and one mathematics educator. They screened the items regarding relevance, suitability, clarity and coverage. The pilot testing of the instrument involved administering the survey or questionnaire to five SS3 students who were not part of the sample but were part of the population. The pilot testing aimed to identify any issues with the instrument, such as ambiguous or confusing questions, and to ensure that the instrument was valid and reliable.

Pilot testing on a small sample size, such as five students, is a common practice in research to identify and address potential problems with the instrument before it is administered to the actual sample. By pilot-testing the instrument on students who were not part of the sample, the researchers could ensure that any issues with the instrument would not bias the actual sample.

The study employed inter-rater reliability by reproducing each student script into five copies and submitting them to four independent experts for assessment and grading after completing the pilot study. Kendall's W (Kendall& Smith, 1939) was used to test for reliability by analysing the scores of the four independent assessors who graded the students' scripts. The choice of Kendall's W was because it is a test of concordance that can handle essay-type responses and multiple raters, which was the case in this study. Inter-rater reliability estimates of .93 (for reading errors), .92 (for comprehension errors), .82 (for transformation errors) and .85 (for process skill errors) were obtained, as shown in Tables 2, 3, 4, and 5.

Table 2: Assessors' ratings of the frequency of reading errors of students

Raters	Student A	Student B	Student C	Student D	Student E
1st	1	2	3	4	5
2nd	2	1	3	4	5
3rd	2	1	3	4	5
4th	2	1	4	3	5
Rj	07	05	13	15	20

$$W = \frac{12S}{N^2(K^3 - K)}$$

Where:

$$S = \sum (Rj - \frac{\sum Rj}{K})^2$$

$$\sum \frac{Rj}{k} = \frac{07 + 05 + 13 + 12 + 20}{5} = 12$$

$$S = (07 - 12)^2 + (05 - 12)^2 + (13 - 12)^2 + (15 - 12)^2 + (20 - 12)^2$$

$$= 25 + 49 + 1 + 9 + 64 = 148$$

$$W = \frac{12 \text{ x } 148}{4^2(5^3 - 5)} = \frac{12 \text{ x } 148}{16(125 - 5)} = \frac{1776}{1920} = 0.925 \approx 0.93$$

Table 3: Assessors' ratings of the frequency of comprehension errors of students

Raters	Student A	Student B	Student C	Student D	Student E
1st	1	3	4	2	5
2nd	1.5	4	3	1.5	5
3rd	1.5	4	3	1.5	5
4th	1	4	3	2	5
Rj	05	15	13	07	20

$W = \frac{12S}{N^2(K^3-K)}$ Where:

$$S = \sum(\mathrm{Rj} - \frac{\sum \mathrm{Rj}}{K})^2$$

$$\sum \frac{\mathrm{Rj}}{k} = \frac{05 + 15 + 13 + 07 + 20}{5} = 12$$

$$S = (05-12)^2 + (15-12)^2 + (13-12)^2 + (7-12)^2 + (20-12)^2$$

$$= 49 + 09 + 01 + 25 + 64 = 148$$

$$W = \frac{12 \text{ x } 148}{4^2(5^3-5)} = \frac{12 \text{ x } 1776}{16(125-5)} = \frac{1776}{1920} = 0.92$$

Table 4: Assessors' ratings of the frequency of transformation errors of students

Raters	Student A	Student B	Student C	Student D	Student E
1st	1	3.5	2	3.5	5
2nd	2	1	3	4	5
3rd	1.5	1.5	3	4	5
4th	1	3	2	4	5
Rj	5.5	09	10	15.5	20

$$W = \frac{12S}{N^2(K^3-K)}$$

Where:

$$S = \sum(\mathrm{Rj} - \frac{\sum \mathrm{Rj}}{K})^2$$

$$\sum \frac{\mathrm{Rj}}{k} = \frac{05.5 + 09 + 10 + 15.5 + 20}{5} = 12$$

$$S = (05.5-12)^2 + (09-12)^2 + (10-12)^2 + (15.5-12)^2 + (20-12)^2$$

$$= 42.25 + 09 + 04 + 12.25 + 64 = 131.75$$

$$W = \frac{12 \text{ x } 131.75}{4^2(5^3-5)} = \frac{12 \text{ x } 131.75}{16(125-5)} = \frac{1581}{1920} = 0.82$$

Table 5: Assessors' ratings of the frequency of process skill errors of students

Raters	Student A	Student B	Student C	Student D	Student E
1st	3	2	4	1	5
2nd	3	2	4	1	5
3rd	2	4	3	1	5
4th	4	2	3	1	5
Rj	12	10	14	04	20

$$W = \frac{12S}{N^2(K^3 - K)}$$

Where:

$$S = \sum (Rj - \frac{\sum Rj}{K})^2$$

$$\sum \frac{Rj}{k} = \frac{12 + 10 + 14 + 04 + 20}{5} = 12$$

$$S = (12 - 12)^2 + (10 - 12)^2 + (14 - 12)^2 + (04 - 12)^2 + (20 - 12)^2$$

$$= 0 + 04 + 04 + 64 + 64 = 136$$

$$W = \frac{12 \text{ x } 136}{4^2(5^3 - 5)} = \frac{12 \text{ x } 136}{16(120)} = \frac{1632}{1920} = 0.85$$

Table 6: Assessors' ratings of the frequency of encoding errors committed by students

Raters	Student A	Student B	Student C	Student D	Student E
1st	1	3	4	2	5
2nd	1.5	4	3	1.5	5
3rd	1.5	4	3	1.5	5
4th	1	4	3	2	5
Rj	05	15	13	07	20

$$W = \frac{12S}{N^2(K^3 - K)}$$

Where:

$$S = \sum (Rj - \frac{\sum Rj}{K})^2 \sum \frac{Rj}{k} = \frac{05 + 15 + 13 + 07 + 20}{5} = 12$$

$$S = (05 - 12)^2 + (15 - 12)^2 + (13 - 12)^2 + (7 - 12)^2 + (20 - 12)^2$$

$$= 49 + 09 + 01 + 25 + 64 = 148$$

$$W = \frac{12X148}{4^2(5^3 - 5)} = \frac{12X1776}{16(125 - 5)} = \frac{1776}{1920} = 0.92$$

Ethical Considerations

The researchers in this study acknowledged the ethical considerations followed when researching process errors in geometry made by senior secondary school students in Cross River State. Approval was sought from relevant ethical committees and regulatory bodies before the study was conducted. All ethical guidelines and regulations were followed, and any ethical issues or concerns were addressed immediately. Informed consent was ensured by informing the participants of the purpose of the study and their rights as participants. Participants were informed that their participation was voluntary and that they could decline or withdraw without any negative consequences. Confidentiality was maintained by keeping the participants' personal information confidential and not sharing it with unauthorised parties. The collected data was kept secure and anonymous, and any identifying information was removed. Privacy was respected by providing participants with a quiet and comfortable environment to complete the test. Participants were not subject to any intrusive or uncomfortable procedures. The participants were selected through a fair and unbiased process to ensure everyone had an equal chance of being selected. Discrimination based on gender, race, ethnicity, religion, or other personal characteristics was avoided. At the end of the study, the participants were debriefed to allow them to ask questions and learn about the study's findings. The implications of the study and how it could impact their education or the education system in general, were explained.

Data Collection and Analysis

The researcher used mathematics teachers from different schools to administer the GDT to identify the process errors committed by the students. The students used pen and paper to show all their workings. A rubric or scoring guide was developed and provided to the teachers to identify common types of errors. The rubric was created based on previous research or designed specifically for this study. The teachers reviewed the students' responses to identify process errors and carefully looked for specific errors, such as reading, comprehension, transformation, process skills, or encoding errors. Research suggests that identifying process errors in student problem-solving can effectively address misconceptions and difficulties with mathematical concepts (Baroody et al., 1998; Hiebert & Lefevre, 1986). Using teachers as assessors can also help ensure the scoring is reliable and consistent. They utilised their expertise and knowledge of mathematical problem-solving to compare the students' responses with the rubric or scoring guide.

The frequency of process errors was determined by the teachers tallying the number of times each type of error occurred across all student responses. The teachers also recorded individual students' errors to identify patterns and trends. The frequencies of these errors were further grouped according to gender and school location. The data were analysed using descriptive and inferential statistics; hence, frequency counts and percentages were used to answer the research question. Hypotheses were tested using the chi-square test of independence at an alpha level of 0.05. In taking a decision, if the probability value is less than or equal to the alpha value of 0.05 (i.e., $p \le .05$), the null hypothesis was rejected, but if otherwise ($p > 0.05$), the null hypothesis was accepted.

RESULTS

Here the results of this study are presented based on the three research questions and two null hypotheses that guided the study. The results are presented in Tables with the research questions and hypotheses.

Research Question 1

What are the process errors students commit in solving geometry problems in mathematics? The mathematics teachers were asked to identify the process errors students committed when solving geometry problems in mathematics. The ratings they provided are presented in Table 7. According to the data, the most frequent error type committed by students was process skill errors (n = 90, 29.90%). Encoding errors were the second most frequent error type (n = 78, 25.91%), followed by transformation errors (n = 66, 21.93%).

Comprehension errors were committed by 42 students (13.95%) and reading errors by 25 (8.31%). These results indicate that the most common errors made by students were process skill errors, encoding errors, and transformation errors while reading and comprehension errors were relatively infrequent.

Research Question 2

What are the process errors male and female students commit in solving geometry problems in mathematics based on gender? The results, as presented in Table 7, indicate that male students had higher frequency counts of process skill errors (n = 47), encoding errors (n = 41), and transformation errors (n = 38) than their female counterparts, who had frequency counts of 43, 38, and 28 in the same error types, respectively. Regarding comprehension errors, male students had a frequency count of 19, while female students had a count of 23. Finally, for reading errors, male students had a frequency count of 9, while female students had a count of 15. Overall, the male students had a total frequency count of 154, representing 51.2% of the sample, while the female students had a frequency count of 147, representing 48.8% of the participants. The percentage difference between them was 2.4%, indicating that male students recorded a slightly higher frequency of process errors than female students.

Table 7: Frequency of process errors committed by male and female students in solving geometric problems

S/N	Process Error Type	Male		Female		Total	
		F	%	F	%	F	%
1	Reading error	9	5. 84	15	10.20	24	7.97
2	Comprehension error	19	12.33	23	15.65	42	13.95
3	Transformation error	38	24.66	28	19.05	66	21.93
4	Process skill error	47	30.50	43	29.25	90	29.90
5	Encoding error	41	26.61	38	25.85	79	26.25
	Total	154	100.00	147	100.00	301	100.00

Note: F = Frequency counts

Research Question 3

What process errors do students commit in solving mathematics geometry problems based on school location? According to the results presented in Table 8, after identifying process errors, it was found that rural students had higher frequency counts of process skill, encoding, transformation, comprehension, and reading errors than their urban counterparts. Specifically, rural students had frequency counts of 46, 40, 34, 22, and 11 in process skill, encoding, transformation, comprehension, and reading errors, respectively. In contrast, urban students had frequency counts of 45, 38, 32, 20, and 13 in the same error types. Overall, the rural students had a total frequency count of 153, representing 50.84% of the sample, while the urban students had a frequency count of 148, representing 49.16%. The percentage difference between them was 1.64%, indicating that the rural students recorded a slightly higher frequency of process errors than the urban students.

Table 8: Frequency of process errors committed by urban and rural school students in solving geometric problems

S/N	Process Error Type	Urban		Rural		Total	
		F	%	F	%	F	%
1	Reading error	13	8.78	11	7.20	24	7.97
2	Comprehension error	20	13.51	22	14.4	42	13.95
3	Transformation error	32	21.62	34	22.20	66	21.93
4	Process skill error	45	30.41	46	30.10	90	29.90
5	Encoding error	38	25.68	40	26.10	78	25.91
	Total	148	100.00	153	100.00	301	100.00

Hypothesis 1

The process errors committed by senior secondary school students when solving problems in geometry do not depend significantly on the gender of the students. The results presented in Table 9 show clearly that the χ^2 Calculated value is 3.48, while the χ^2 Critical value is 9.49 at 0.05 alpha level and 4 degrees of freedom. Since the calculated value is less than the critical value at the given probability level and degrees of freedom, the null hypothesis is upheld. This implies that the process errors committed by senior secondary school students when solving problems in geometry do not depend significantly on the gender of the students.

Table 9: Chi-square test of the process errors committed by senior secondary school students in solving geometric problems based on their gender

Gender	Reading Error	Comprehension Error	Transformation Error	Process skill Error	Encoding Error	χ^2_{cal}	χ^2_{crit}	Decision
Male	Oi=9 Ei=12.	Oi=19 Ei=33.9	Oi=38 Ei=33.9	Oi=47 Ei=40	Oi=41 Ei=40	3.48	9.49	Not Significant
Female	Oi=15 Ei=11.7	Oi=23 Ei=32.1	Oi=28 Ei=32.1	Oi=43 Ei=43	Oi=38 Ei=38			

Oi = Observed frequency; Ei = Expected frequency; df = 4; Alpha level = .05

Hypothesis 2

The process errors senior secondary school students commit when solving problems in Geometry do not depend significantly on school location. Table 10 shows that the calculated χ^2 value is 0.29, while the critical value at a significance level of .05 and 4 degrees of freedom is $\chi^2 = 9.49$. The null hypothesis is accepted as the calculated value is less than the critical value at the given probability level. Therefore, it can be inferred that the process errors committed by senior secondary school students in solving problems in Geometry do not depend significantly on the school location.

Table 10: Chi-square test of the process errors committed by senior secondary school students in solving geometric problems based on their school location

Location	Reading Error	Comprehension Error	Transformation Error	Process skill Error	Encoding Error	X^2_{cal}	X^2_{crit}	Decision
Urban	Oi=13 Ei=11. 8	Oi=20 Ei=20.6	Oi=32 Ei=32.3	Oi=45 Ei=44.1	Oi=38 Ei=38.2	0.29	9.49	Not Significant
Rural	Oi=11 Ei=12.2	Oi=22 Ei=21.4	Oi=34 Ei=33.7	Oi=46 Ei=46	Oi=40 Ei=39.7			

Oi = Observed frequency; Ei = Expected frequency; df = 4; Alpha level = .05

DISCUSSION

Process Errors Committed by Students

The study's first finding identified the types of errors students make when solving geometry problems in mathematics. The study found that process skill errors, encoding errors, transformation errors, comprehension errors, and reading errors were the most common errors made by the students. Theoretical implications of the finding suggest that these errors can be attributed to students' lack of understanding of the problem-solving process and the inability to apply the correct methods to solve the problems. This finding implies that teachers should focus on developing students' problem-solving skills and ability to apply the correct methods to solve problems. Regarding the specific errors, transformation errors were caused by students' lack of knowledge about the methods used. This finding is consistent with previous research, which reported that transformation errors were caused by students' lack of knowledge of the methods used (Halim & Rasidah, 2019; Rahmawati & Permata, 2018; Rindyana, 2013). This finding implies that teachers should provide more guidance and instruction on the methods for solving geometry problems.

Process skill errors were found to be caused by incorrect multiplication and addition operations, substituting incorrect information from the problem into the formula used, and being careless and rushed in carrying out the calculation process. This finding is consistent with research conducted by other scholars (e.g., Jha, 2012; Rahmawati & Permata, 2018; Rindyana, 2013; Utami, 2016), which reported that process skill errors were due to incorrect calculation operations. This finding implies that teachers should emphasise the importance of careful calculation and encourage students to spend time with it.

Encoding errors were caused by students not writing the unit at the end of the answer in the previous calculation process and being careless in determining the final result. This finding is consistent with Jha's (2012) research, which reported that the factor causing errors in writing the final answer is that students cannot find the final result accurately according to the completion steps and cannot write the final answer according to the conclusion in the problem. This finding implies that teachers should teach students to check their work and emphasise the importance of paying attention to details when writing the final answer.

Gender and Process Error

The second finding of this study showed that male students had slightly higher frequency counts of process errors than female students. However, the difference was insignificant, indicating that process errors in geometry problem-solving do not depend significantly on the gender of the students. This result corroborates previous studies (e.g., (Leder, 2015; Kola & Taiwo, 2013; Oludipe, 2012; Zemikael & Wondemagnegn, 2022), which also found no significant difference in academic performance between male and female students in mathematics. Moreover, Shaibu (2021) found that both sexes become exceptionally the same in the level of process errors committed in mathematics. However, the result does not support the findings of other studies (e.g., (Ariyo, 2016; 1du, 2014; Igbo et al., 2015; Titus et al., 2016), which showed, on the contrary, a significant gender difference between male and female students. Nevertheless, this study suggests that teachers can adopt gender-neutral teaching strategies to encourage both male and female students to perform well in mathematics. The theoretical implication of this finding is that gender may not be a significant factor in the level of process errors committed in geometry by students. Therefore, future studies can explore other factors influencing process errors in mathematics, such as socioeconomic status and cultural background.

School Location and Process Error

The third finding of this study indicated that rural students had higher frequency counts of process errors in all categories than urban students. However, the difference was again insignificant, indicating that process errors in geometry problem-solving do not depend significantly on the school location. This finding strengthens the findings of a previous study which found no noticeable disparity in the average mistakes made by students from urban and rural areas when taking the geometry test (1du, 2014). However, this finding contradicts the results of other studies (e.g., Agbaje & Adebisi, 2014; Musa et al., 2016; Okereke & Onwukwe, 2011), which earlier documented that the performance of urban students is generally higher than that of their rural counterparts. Additionally, the finding does not align with the result of Yazdanpanah (2014), whose study suggests that location has a statistically significant relationship with students' performance in Mathematics. The study also disagrees with Bleeker and Jacobs (2004), who found that location was significant in learning aspects of mathematics involving angles, with rural students exhibiting more learning difficulties than their urban counterparts.

Limitations and Prospective Research Directions

The study's limitations include the fact that the study was conducted in only one education zone in Cross River State and the sample size was relatively small, which may limit the generalizability of the findings to other education zones in the state. Future research could explore the process errors made by senior secondary school students in geometry across multiple education zones in Cross River State using a larger sample size. This would enable a more comprehensive understanding of the process errors made by students in geometry and the factors that may contribute to them.

The rubric used by the assessors to detect process errors made whilst taking the Geometry Diagnostic Test (GDT) may not have been comprehensive enough to capture all the process errors made by senior secondary school students in geometry. Additionally, there is a tendency for assessors' subjectivity bias in grading the errors made by students, which may not accurately report their process errors. Therefore, future research could consider developing a more comprehensive rubric for detecting process errors in geometry. This could involve the input of a wider range of experts in mathematics education and measurement and evaluation to ensure that the rubric captures all relevant process errors made by students. Furthermore, future research could consider using a more objective approach to grading process errors made by students, such as using a computer-based grading system, to reduce subjectivity bias. The study did not consider external factors such as students' socioeconomic status, family background, and previous educational experiences, which may impact their performance and process errors in geometry. Future studies could also explore the impact of external factors, such as socioeconomic status, family background, and previous educational experiences, on students' performance and process errors in geometry. This could provide more insights into the factors that influence students' performance in geometry and inform interventions to improve their learning outcomes.

Despite the limitations, this study on the process errors of senior secondary school students in geometry in Cross River State provides valuable insights into the common process errors students make in solving geometry problems in mathematics. The study contributes to the knowledge of teaching and learning mathematics, particularly geometry, in secondary schools in Nigeria. It highlights the importance of arriving at the correct answer rather than just obtaining the right one, a critical component of problem-solving in mathematics. This study also provides a basis for teachers and curriculum developers to address the identified process errors and to design appropriate instructional strategies and learning materials that can help students overcome these errors. Furthermore, the study underscores the importance of assessing and addressing the process errors made by students, often overlooked in traditional assessments that only focus on the final answer. The findings of this study can inform the development of more comprehensive assessment tools that consider the process errors made by students in mathematics. This can help teachers identify areas of weakness and tailor their instruction to meet the individual needs of their students. It underscores the need for a more comprehensive approach to teaching and learning mathematics, particularly geometry, in secondary schools. It also provides a basis for further research to explore the identified process errors in greater depth and to develop more comprehensive assessment tools that consider the process errors made by students in mathematics.

CONCLUSION

Based on the study results, it can be concluded that senior secondary school students in the Ikom Education Zone of Cross River State make various process errors when solving geometry problems in mathematics, with most errors being in transformation, process skill, and encoding. However, the errors do not depend significantly on the students' gender and school location. This conclusion implies a need for a more focused and effective approach to teaching geometry in senior secondary schools, particularly in the Ikom Education Zone of Cross River State. The study suggests that students are making errors in transformation, process skill, and encoding, which may be attributed to a lack of understanding of geometry's underlying concepts and principles. Therefore, teachers must emphasise the importance of the steps in arriving at the right answers and adopt teaching methods that promote a deeper understanding of the subject matter. Additionally, the study found no significant difference in the process errors made by students based on their gender and school location. This suggests that process errors in geometry may be a common problem across different student populations and highlights the need for a universal approach to teaching and addressing these errors. The study's findings also have implications for developing curriculum and teaching materials for geometry in senior secondary schools. The focus should be on the correct answers and the process involved in arriving at those answers. Developing materials that emphasise the underlying concepts and principles of geometry could help reduce process errors and promote a deeper understanding of the subject matter.

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