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Impact of Error Analysis Techniques on Mathematics' Assimilation among a Cohort of Struggling Secondary School Students

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Abstract: There has been an increasing number of mathematics failures among secondary school students in Africa in the past few years, specifically in Nigeria, as 20% of candidates who sat for the West African Certificate Examination failed in 2023 and an increasing percentage of 27% in 2024. However, there have been diverse attempts by different scholars and policymakers to salvage the situation, but not much success has been achieved. This study, therefore, investigated the impact/effectiveness of Error Analysis Techniques (EAT) on mathematics assimilation among struggling students in a selected secondary school. The study employed a Quasi-experimental research design and purposive sampling method to assign the study participants to different study groups (1 control and 2 experimental groups). Twenty-six (N = 26) participants were selected to participate in the study based on the inclusion criteria.

The study's outcome revealed that Error Analysis Techniques significantly increased students' assimilation/understanding of problematic mathematical calculations. Furthermore, participants in experimental groups 1 and 2 showed better assimilation after the experiment than participants in the control group. The study, therefore, concluded that EAT is efficacious in improving mathematics understanding for struggling students. The limitations and recommendations of the study were further discussed.

Keywords: Error Analysis, Teaching Techniques, Mathematics, Education, Secondary Education, Students, Assimilation.

Introduction

The teaching and learning of mathematics as a subject have always been an essential subject to the success aspiration of any student, regardless of their choice of class (science, commercial, and others), yet remain the most challenging subject within the educational systems (Pongsakdi et al., 2020). The universal recognition of mathematics as a critical subject in a nation's academic programs has led to the concern of many in the thwarting rate of students' performances in the subject, especially at the secondary school level. Such poor performances often lead to non-relevant societal perceptions of the subject being deemed as 'difficult' and 'boring', causing students to develop a sense of 'mathematics anxiety', thus making it more difficult for them to learn the subject (Agberotimi et al., 2021; Caviola et al., 2022; Deleg et al., 2022; Nunes & Moreno, 2021).

The increasing mathematics failure of secondary school students in Africa broadly has been a concern to stakeholders (i.e. teachers, students, parents, administrators, etc.) in the education communities. The study by Zulu (2019) reported that only 9.8% of high school students who attempted the O'Level examination in Zambia passed, indicating a 90.2% failure rate in Mathematics. Similarly, in Uganda, there has been a long-standing history of mathematics failure among secondary school students (Ndungo et al., 2020). Scholars in South Africa have also reported similar concerns of mathematic failure among grade 12 students (Thomas & Anangabor, 2024).

Research Problem

In Nigeria, the problem of students' failure in mathematics has been a consistent concern for parents, teachers, and the community at large. There have been various approaches to finding a stable solution to the prevailing failures in mathematics by different scholars; as such, many researchers identified mathematics anxiety among learners (Agberotimi et al., 2015), poor teaching approach/ teachers' training (Olaseni, 2024), over-crowded class size (Olaseni & Lawal, 2020), insufficient number of qualified teachers in mathematics (Thomas & Anangabor, 2024), lack of teaching aids/ instructional materials (Olaseni, 2024), frequent transfer of mathematics teachers, students' poor socio-economic background, poor teaching methodology, poor curriculum design (Zulu, 2019), and infrastructural decay (Awofala et al., 2022) were the prevailing factors that affect mathematics performances among students. Despite numerous recommendations to address the menace, little has been achieved concerning improving mathematics performances among African students, specifically in Nigeria.

The focus of EAT in mathematics education is to identify and understand the errors that students make that influence the learners' instructional plans and academic outcomes. Despite numerous studies into various teaching strategies for mathematics improvement assimilation, the fundamental impact of EAT on the concept of mathematics assimilation among struggling students of secondary schools remains underexplored. Much of the research on EAT tends to focus on a wide range of student abilities

without differentiating between those who are struggling and those who are performing at or above grade level. A remarkable lack of targeted research concentrates specifically on how EAT techniques influence the academic outcomes of secondary school students struggling with mathematics. Therefore, there is a need to determine if applying EAT to the teaching curriculum would equally assist the teacher in effectively uplifting the struggling students' academic performance in mathematics. EAT has been implemented differently, from formative assessments to individualised feedback sessions. There has not been research comparing different implementation strategies and their relative effectiveness on the assimilation of struggling students in mathematics. Therefore, this research tends to answer an open question of which methods are most beneficial or appropriate for struggling students in mathematics and how teachers should adapt these methods to different contexts and student needs. This study also provided insight into how EAT influences students' anxiety and confidence and the total motivational impact on struggling students in mathematics, which is a gap in existing studies. This study, therefore, aimed to address these research gaps by advancing our understanding of how EAT can be optimised to assist struggling secondary school students in the assimilation of mathematics by targeting the long-term effects, implementation strategies, psychological impacts on students and technological integration.

Research Aim and Research Questions

The focus of this research is to see how the application of the Error Analysis Technique in teaching can help struggling students assimilate mathematics.

Research Objectives

The following research objectives were therefore set to achieve the overall purpose of the study, which are to:

1. Experiment with the impact of Error Analysis Techniques on Mathematics Performance, controlling for the influence of gender among a cohort of students struggling with mathematics.

2. Examine the significant difference in the mathematics performances of the participants before and after the Error Analysis Intervention.

Literature Review

The aim of a literature review is to attain an understanding of the existing findings that have been researched and debate their relevance to the present study while reviewing the gaps intended to fill between the reviewed literature and the topic under study. Therefore, this study presents the literature reviews of other scholars as related to the study under investigation.

According to Sahara Reporter (2024), the West African Senior Certificate Examination (WASSCE) results showed that 503 275 Nigerian students out of 1.8 million who sat for the examination in 2024 failed to pass Mathematics. That is 72.12 per cent, making a 7.69 per cent drop in performance compared to 79.69 per cent recorded in 2023. The study of Awofala and Fatade (2023) revealed that government agencies, teachers, parents, and students are responsible for the country's poor performance in mathematics learning. Also, Awofala et al. (2022) established a significant relationship between mathematics productive disposition and achievement in mathematics among secondary school students, such that mathematics productive disposition contributed 84.3% to the prediction of achievement in mathematics.

Previous studies have shown that students' characteristics, such as truancy/irregularities, significantly affect their overall performances, especially in mathematics (Ferrão, 2022; Khanal, 2019;

Weathers, 2023). However, this may exert serious influence or implications on the outcome of this study, therefore, truancy shall be considered a variable in the study. Similarly, gender has been identified as a decisive factor determining performances in science, technology, engineering, and mathematics (STEM) related disciplines. As such, studies revealed that males perform better in STEM-related disciplines than their female counterparts (Cheryan et al., 2017; Merayo & Ayuso, 2023; Wrigley-Asante et al., 2023). Therefore, the possible influence of gender difference was held constant in the study.

Previous studies showed that learners make numerous errors in the attempt to solve mathematics questions; however, different attempts at better understanding mathematics teaching have been made from time to time in the past (Jerri, 2021; Weigand et al., 2024). Error analysis is a critical area in the teaching and education sectors. The study proposes that in dealing with the problems and issues of mathematics assimilation among learners, EAT will play a vital role, as EAT provides a deep insight for easy assimilation among students. Error analysis plays a dual role in the teaching of mathematics as it assists the teachers in generating new ways of instruction/teaching by revealing the feedback to the learners on the errors they have made. EAT established the normalcy for learners to make mistakes in learning and master how to solve mathematical problems. On the other hand, these mistakes assist teachers in generating new techniques and insights into teaching mathematics for better results.

EAT has been reviewed in the field of language acquisition, where it was established that EAT plays a fundamental role in investigating and identifying second language learners' errors and their causes. EAT was not only found important or beneficial to striving students but also established to assist second language teachers in finding different sources of second language errors and taking some pedagogical precautions towards them (Al-Khresheh, 2016; Cassano & Paciga, 2023).

EAT involves a systematic approach to analysing and correcting errors made by students in mathematical problem-solving. According to Thomas and Anangabor (2024), error analysis encourages students to engage deeply with mathematical concepts by identifying misconceptions and addressing them through targeted instructions. EAT emphasises the importance of understanding student errors to improve teaching practices and enhance mathematical understanding (Lasisi et al., 2024; Thomas & Anangabor, 2024). An argument has it that incorporating error analysis into the teaching of mathematics may lead to improved problem-solving skills, metacognitive awareness, self-regulated learning, and conceptual understanding among students (Desoete & Baten, 2022; Lasisi et al., 2024; Linguabot, 2024).

Despite several interventions or survey recommendations to address the menace of poor mathematics among secondary students in Nigeria. This study attempts to experiment with EAT on the mathematics performance of students. Addressing this gap is crucial for developing targeted interventions that cater to this demographic's unique learning needs and challenges, thereby facilitating their mathematical comprehension and academic success. Against the background of the study, informed the essence of the study.

In response to the lack of knowledge in the literature and practical solutions to poor mathematics performance, the study set to test the efficacy of Error Analysis Techniques on Mathematics Performance among a cohort of students struggling with mathematics.

Theoretical Framework

The current study is underpinned by constructivist theory, which is significantly influenced by the work of Piaget (1953) and Bruner (1966). Constructivist theory elucidates the construction of understanding and knowledge through the active engagement with phenomena and subsequent reflection. This approach posits that students evaluate new information and experiences concerning

their existing beliefs, leading to the adaptation of behaviour or the rejection of learning based on their analysis. Furthermore, constructivism has underscored this experiential learning process, wherein knowledge evolves through experiential transformation. According to Kolb, learning involves four significant styles: concrete experience (feelings towards mathematics), reflective observation (watching the analysis of error), abstract conceptualisation (thinking about the mistakes made), and active experimentation (how to get things done rightly), which further demonstrate the multifaceted nature of constructivist learning.

Mathematics prowess and ability are very helpful in ensuring critical thinking as well as problem-solving skills among students (Lasisi et al., 2024). Nevertheless, it is often found that students come across some difficulties trying to understand the practical application of mathematical concepts.

Materials and Methods

Sample and Participants

The populations of the study are attendees of a public secondary school in Akure identified with records of having a grade benchmark of Fail (F) in their recent school examinations. Twenty-five (n=25) students with F-grades in mathematics were purposively selected across the cluster of various departments (Science, Commercial, and Arts) (Rai & Thapa, 2015). Data collection was conducted from July to September 2023 (during the long vacation), with a maximum of 8 participants per intervention group. Participants were assigned to the 3 study groups, namely;

- Study Group 1 (experimental Group 1): Participants exposed to EAT with complete (100) attendance in class
- Study Group 2 (experimental group 2): Participants exposed to EAT had irregular attendance (truancy rate of 54.5 – 63.6%).
- Study Group 3 (Control Group): Participants not exposed to EAT.

Instrument and Procedure

Questionnaire booklets were made up of the documented used and psychometrically sound instruments for the data collection in the study. The questionnaire was made of two sections, Sections A and B:

Section A: The socio-demographics section measured respondents' data, including research identification number, training centres, gender identity, age, sexual orientation, marital status, and highest educational attainment.

Section B: Mathematics Scheme of Work for Senior Secondary School 2: entails eleven (11) lessons that were used throughout the experiment

Lesson 1: Logarithm

Lesson 2: Progression (Arithmetic & Geometric)

Lesson 3: Quadratic Equation

Lesson 4: Simultaneous Linear and Quadratic Equations

Lesson 5: Approximations

Lesson 6: Logical Reasoning

Lesson 7: Linear inequalities

Lesson 8: Geometry and Trigonometry

Lesson 9: Probability

Lesson 10: Functions and Relations

Lesson 11: Vectors

Data Collection and Procedures

Ethical approval for the study was obtained from the Ethical Review Committees (ERC) of the state Ministry of Education. A letter of introduction was written to the principal of the selected public school, and an assent form (for the students) and informed consent forms (for their parents) were obtained. The study informed accent and consent forms stating the purposes of the study, inclusion and exclusion criteria, risk, right to withdraw, benefits, procedures, logistics plan, and expectations throughout the experiment.

The intervention was delivered by a competent and certified mathematics teacher in strict compliance with the drafted teaching procedures. The teaching intervention(s) was/were structured as follows:

- Stage 1 (Pre EAT Assessment): The research purpose was introduced, and permission to participate in the study was revalidated. Participants were assessed based on the 11 lessons meant for their current level of education.
- Stage 2 (Teaching using EAT): The participants were re-taught using the EAT, in which the harvested error banks were incorporated into the teaching patterns.
- Section 3 (Post EAT Assessment): This stage is marked by a post-teaching assessment to determine the efficacy of the EAT on mathematics assimilation and understanding.

Ethical Considerations

Ethical approval was obtained from the Ethics Review Committee (ERC) of the State Ministry of Education (Approval code #:286_3Q_SMoE_2023). All moral principles itemised in the informed consent form were adhered to throughout the study. Informed assent and consent were sought from the study participants, as well as their guidance.

Data Analysis

The collected data were analyzed using One-Way Analysis of Covariance (ANCOVA), and the t-test of dependent samples was tested for statistical significance. The ANCOVA allows the experimentation of the EAT intervention on mathematics assimilation, holding constant the influence of gender (Dugard et al., 2022). The t-test of the independent sample explains the statistical difference between participants before and after the EAT intervention.

Results

This section tests and establishes the stated objectives that address the study's overall purpose. The study revealed the efficacy of Error-Analysis Techniques on Mathematics Performance among

struggling High School Students, holding constant the influence of gender differences. The formulated hypotheses were tested using one-way analysis of co-variance using Statistical Package for Social Sciences (SPSS). The results are presented below.

Objective 1

Study objective one aims to experiment with the effect of Error-Analysis Techniques on Mathematics Performance among a cohort of struggling school students, controlling for the influence of gender. This was tested using a one-way analysis of covariance (ANCOVA), as presented in Table 1.

Table 1

Summary of One-way ANCOVA showing the effect of Error-Analysis Techniques on Mathematics Performance among struggling High School Students

Source	SS	df	MS	F	P	η_p^2
Gender	08.95	01	08.95	0.25	< .05	0.121
Study Intervention	9840.98	02	4920.49	135.24	< .001	0.928
Error	746.05	21	36.38			
Total	60731.00	25				

Outcomes of Table 1 revealed that gender had a significant effect on the mathematics performance of students struggling with mathematics (F (01,21) = 0.25, p < .05; n_p^2=0.012). Indicating that 12.1% of the factor that determines mathematic performance among struggling students was gender. Further analysis revealed that Error-Analysis Techniques had a significant effect on Mathematics Performance, holding constant the influence of gender (F (02,21) = 4920.49, p < .001; n_p^2=0.928). Furthermore, 92.8% (effect size) of the observed change in the participants' performances in mathematics was strictly accounted for by the administered intervention (i.e., Error-Analysis Teaching Techniques). In other words, it implied that the Error-Analysis Techniques intervention exerts significantly different impact conditions on the study groups.

Having established a significant effect, the magnitude of the significant F-value needs to be further established. As such, a multiple-group comparison test was conducted. Consequently, the Scheffe post hoc test was used to compare the study groups since an unequal number of participants represented them. The results are shown in Table 2 below.

Table 2

Showing the Scheffe Post Hoc Analysis of the Efficacy of Error-Analysis Techniques on Mathematics Performance Across the Study Groups

Study Groups	N	$\overline{X}$	Std. E	1	2	3
1 Experimental Group 1	08	63.63	02.15	1		
2 Experimental Group 2	08	55.28	02.13	08.35*	1	
3 Control Group	09	18.42	02.02	45.21*	36.87*	1

Note. * p < .05.

The outcome of Table 2 revealed that participants in experimental group one ($\overline{X}$ = 63.63, SD = 02.15) had better mathematics performance after the experiment than participants in experimental group 2 ($\overline{X}$ = 55.28, SD = 02.13), and control group ($\overline{X}$ = 18.42, SD = 02.02). The difference in the documented mathematic performance of participants in experimental group 1 and group 2 (MD = 08.35;

p < 0.05), experimental group 1 and control group (MD = 45.21; p < 0.05); and experimental group 2 and control group (MD = 36.87; p < 0.05) were significant.

Objective 2

Study objective 2 aims to test whether there will be a significant improvement in the mathematics performance of participants in the experimental groups after the exposure to Error-Analysis Techniques compared to before the intervention. This was tested using a t-test of a dependent sample, as presented in Table 3.

Table 3

Showing the Significant Difference in the Pretest and Post-test Scores of Cohort Students on Mathematics Performance

Intervention		$\overline{X}$	SD	Df	T	P
Mathematics Performance	Pre-Intervention	18.56	04.49	15	06.11	< .001
	Post-Intervention	44.68	21.24			

The outcome of the results revealed that Error Analysis Intervention exerts a significant impact on the mathematics performances of the participants (t (15) = 06.11; p<.001). Further interpretation suggests that the participants' performances in Mathematics increased significantly after the intervention ($\overline{X}$ = 44.68, SD = 21.24) than before the intervention ($\overline{X}$ = 18.56, SD = 04.49).

Discussion

The study establishes the efficacy of the error analysis teaching technique on the mathematics performance of struggling students and the implication of the EAT in improving the learner's academic performance. The findings revealed that EAT had a significant effect on Mathematics performance, holding constant the influence of gender. From the experiment carried out, it was shown that male students dominated the class of struggling mathematics students. This sounds unusual as female students were expected to have the dominant number based on the societal factor of gender preference. Still, the opposite was the case when given the list of struggling students in Mathematics. The findings revealed that students would perform better if taught with EAT, as they showed a significantly improved performance, especially among female students, after the EAT experiment. This outcome agreed with the study's conclusion by Linguabot (2024) that EAT plays a fundamental role in aiding the understanding of second language learners' errors and their causes. EAT was not only found essential or beneficial to the striving students but also a better guide to the teachers. In other words, EAT was not only found helpful in assisting the students in knowing where a step has been missing or misinterpreted when solving mathematical problems but also in assisting the teachers in knowing the areas to focus on when teaching mathematics. This technique has, therefore, made the teaching and learning of Mathematics easier for both the teacher and the students. Similarly, the study of Thomas and Anangabor (2024) reported that EAT emphasises the importance of understanding student errors as a means to improve teaching practices and enhance mathematical understanding.

In addition, the study findings revealed that participants exposed to EAT (experimental group 1) performed better in mathematics than those in experimental group 2, indicating that truancy may reduce the effectiveness of EAT among students struggling with mathematics. Further analysis revealed that participants in the control group showed the least performance in mathematics compared to others exposed to EAT. The outcome was consistent with the findings of Lasisi et al. (2024), who elaborated on

other factors responsible for students' failure, including truancy, poor method of teaching, and lack of proper attention from teachers, among others.

Finally, the outcome of this study showed a significant difference between the pre-test and post-test results of the study cohort. The findings showed that students' performances increased significantly after the EAT intervention than before the intervention. The findings support the study of Owan et al. (2023), which opines that incorporating error analysis in mathematics instruction would lead to improved problem-solving skills and conceptual understanding among students. The reason behind the outcome of this study may not be far-fetched from the position of Desoete and Baten (2022), and Lasisi et al. (2024), who posited that incorporating error analysis into the teaching of mathematics may lead to improved problem-solving skills, metacognitive awareness, self-regulated learning, and conceptual understanding among students.

Limitations of the Study

Sample size. The cohort of sampled students might not be considered large enough to represent the broader population of struggling secondary school students in mathematics. Therefore, the generalizability of the findings is limited to the sample size. Further studies may use a larger sample size for a wider generalization.

Time Constraints. The duration of the study was not sufficient to observe the long-term impacts of error analysis techniques on the mathematics assimilation of struggling students. Therefore, Short-term studies may miss out on the learners' gradual improvements or setbacks. Other studies may also examine the long-term effect on the learners' improvement and setbacks.

Resource Limitations. Implementing and assessing error analysis techniques requires specific resources, such as focus software and special training for teachers, which were not available and affordable in the researcher's capacity and the sampled school settings. Thus, the mathematics teachers had to use manual skills. In this line, further studies may consider using these necessary resources to ease the EAT process.

Conclusions

In conclusion, EAT remains an established means of intervention in addressing the menace of poor mathematics performance among students. In other words, EAT significantly impacts students' mathematics performance, such that a noticeable improvement was recorded in knowledge and performance in Maths. EAT enables the students to develop a deeper insight into the established guidelines and mechanisms for solving mathematical problems by analysing their errors. Through this intervention, students were encouraged to take control of their learning as they will become proactive and more self-aware in their learning journey.

Suggestions for Future Research

For future research on EAT, the following is proposed to enable the smooth application and implementation of EAT in secondary schools' curricula to improve students' performances.

The teaching and learning of mathematics are often endowed with different challenges relating to the performance of learners, that is, having learners who struggle to get things right when it comes to solving Mathematical problems (Nauzeer & Jaunky, 2021). The inculcation of EAT in teaching mathematics will serve as a strategic approach to improving students' performance. The application of EAT will enable the teacher to identify, understand and address the fundamental causes of students'

mistakes and, in return, foster a deeper understanding of the concepts of Mathematics while also improving the learners' performance.

The objectives of the implementation of this approach shall be to;

- identify and categorize common errors, develop and strategize the interventions to tackle the error by addressing students' errors directly,
- Encourage students to reflect on their errors to understand the reasons behind the right/correct solutions and foster a growth mindset.
- Finally, to enhance teaching strategies, educators will be equipped with tools and strategies to incorporate EAT effectively into their teaching practice.

The implementation plan shall be as follows:

Teachers' Professional Development: The government, through the Ministry of Education, should plan regular workshops and training to familiarise teachers with the application of EAT and its benefits.

Provision of Required Resources: The required resources should be provided, including error analysis frameworks and their integration into the curriculum, required diagnostic tools, and lesson plans in the context of students' reflections in previous exercises and involvement in peer reviews.

Specified Classroom Activities: Some classroom activities that focus on common errors and encourage group discussion on errors, their possible patterns, and solutions should be strategically implemented.

Finally, strategies should be developed for diagnosing the students' assessments to identify common errors and provide targeted feedback based on the errors to guide the students in correcting their mistakes. A metrics system should also be developed to assess the impact of EAT on the students' performance after implementation.

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Conflict of Interest

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