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Research article

Assessment of content and cognitive dimensions of learners' mathematics performance

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Abstract: This study examined the misalignment between cognitive development and mathematics education in senior secondary schools. Using an ex post facto research design and a descriptive survey approach, data were collected from the Senior Secondary Mathematics Achievement Test (SSMAT), which showed a strong reliability coefficient (r = 0.89). The analysis, which included descriptive statistics and independent sample t-tests, revealed that gender does not have a significant impact on student's performance in SSS2 mathematics across different content areas (number and numeration, algebra, geometry, and everyday statistics) and cognitive dimensions (recall, conceptual understanding, and reasoning). The results highlight the need for a comprehensive approach to mathematics education that balances content coverage and the development of cognitive skills. Addressing this misalignment can improve students' ability to creatively apply mathematical concepts, think critically, and effectively communicate their mathematical ideas, ultimately enhancing overall academic achievement. Our study identifies clear gaps in current educational assessment methods, emphasizing the importance of focusing on content and cognitive dimensions. The results will assist in developing targeted instructional strategies that align with cognitive demands, improve teaching effectiveness, and inform educational policy to enhance student outcomes in mathematics.

Keywords: content dimensions, cognitive dimensions, grade-11 students, mathematics achievement

1. Introduction

Developing fundamental skills and competencies in students is crucial for their success in various academic and professional pursuits. As students progress from secondary school to further education or the workforce, their mathematical abilities become increasingly significant. Despite the critical role of mathematics in intellectual growth and future achievements, there is a growing concern that current educational practices may not fully align with the cognitive development needs of students. This misalignment can hinder students' ability to innovatively apply mathematical concepts, critically analyze problems, and effectively communicate their mathematical thoughts. Consequently, a comprehensive understanding of students' performance in mathematics is imperative for enhancing learning outcomes and implementing effective interventions. Existing research underscores the importance of content knowledge and cognitive skills in mathematics education. Content dimensions pertain to specific mathematical concepts, procedures, and algorithms that students are expected to master, such as algebra, geometry, calculus, statistics, and probability [1]. Evaluating students' performance in these areas can pinpoint specific difficulties in designing tailored instructional strategies [2]. Additionally, mathematical education fosters core skills like problem-solving, logical reasoning, and critical thinking, broadly applicable across academic disciplines and real-world scenarios [3]. This dual focus on content and cognitive skills is essential for developing well-rounded mathematical proficiency in students.

A thorough literature review reveals that while much emphasis has been placed on content mastery, cognitive dimensions such as recall, conceptual understanding, and reasoning have often been neglected. In [4], the authors highlighted the importance of teachers' content knowledge in nurturing students' cognitive skills. Studies by [5] and [6] suggest that content and cognitive dimensions directly impact students' mathematics performance. However, there is a notable gap in research focusing on a balanced assessment that includes both these dimensions. Current evaluation practices prioritize content knowledge, overlooking critical cognitive factors underpinning mathematical competence. This limited approach fails to capture students' abilities in problem-solving, critical thinking, and effective communication of mathematical concepts. Research has demonstrated that focusing too heavily on content knowledge can result in students relying on memorization rather than genuinely understanding the material. As a result, they may struggle when confronted with unfamiliar problems that require higher-order thinking skills [2]. This deficit in cognitive skill development can inhibit students' ability to apply their mathematical knowledge in real-world situations. Furthermore, conventional assessment methods emphasize content and do not offer a holistic view of students' mathematical abilities. This can lead to misguided instructional strategies and interventions. This research aims to tackle the significant gap in evaluating the mathematical performance of senior secondary students by emphasizing both content and cognitive aspects. The current limited assessment methods complicate accurately measuring students' overall mathematical proficiency. They hinder the development of higher-order thinking abilities and misalign assessment with instruction. Teachers risk overlooking students who struggle with cognitive components like problem-solving and reasoning by solely focusing on content. This leads to an incomplete understanding of their strengths and weaknesses.

The purpose of this study is to comprehensively evaluate the mathematical performance of senior secondary school 2 (SSS2) learners, considering both content and cognitive dimensions. The objectives are to identify the content dimensions of students' performance in key areas such as number and numeration, algebraic expressions, geometry, measurement, and everyday statistics; analyze the patterns of cognitive dimensions in terms of recall, conception, and reasoning; and investigate the role of gender in these dimensions. By addressing these gaps, the study aims to improve mathematics instruction, curriculum development, and educational policies, ultimately resulting in better student outcomes in mathematics. Understanding the interaction between content and cognitive dimensions is crucial for developing effective educational strategies. Teachers must be equipped with knowledge and resources to foster both aspects of mathematical competence. This involves incorporating instructional practices that promote critical thinking, problem-solving, and content delivery. Additionally, educational policies should support comprehensive assessment frameworks that provide a complete view of students' abilities. This will guide targeted interventions and the allocation of resources. In conclusion, this study aims to fill a research gap by providing a detailed understanding of how content and cognitive dimensions impact students' performance in mathematics.

The paper follows a structured format, beginning with a brief introduction and rationale for the study. This is followed by a thorough review of related literature and underpinning theory. The third section discusses research methodology, providing information on the context and respondent profiles, as well as the measures, data collection methods, and analytical procedures used. Moving on, the fourth section summarizes the study's results, followed by a discussion section where the results are contextualized within the larger research topic, and more in-depth analysis is provided. Finally, the paper acknowledges its limitations and outlines potential areas for future research.

2. Review of related literature

Traditional mathematics written assessments often focus on testing students' computational skills and their ability to recall procedures and formulae, reflecting a perception of mathematics as merely the mastery of a set of skills and techniques. While such assessments can help determine whether students have mastered specific material, they fail to capture the broader dimensions of mathematical learning, such as conceptual understanding, critical thinking, and problem-solving [7–9]. In [7], the author critiqued these traditional practices for their reliance on procedural fluency at the expense of conceptual understanding. By emphasizing computations and memorized formulas, such assessments encourage rote learning and do not adequately evaluate students' ability to think critically, solve complex problems, or apply mathematical concepts to real-world contexts. This approach often results in students lacking deeper comprehension, as higher-order cognitive skills such as reasoning and application are overlooked. Brown [8] expanded on this critique by exploring how traditional assessments influence teaching practices, highlighting that the dominance of procedural testing often leads educators to prioritize formulaic instruction, focusing on the "how" of problem-solving rather than the "why".

This approach restricts learners' opportunities to engage with mathematics in meaningful ways, limiting their creativity and critical thinking. Brown’s analysis aligns with the observation that such assessments fail to provide a holistic view of students' mathematical abilities, reinforcing a fragmented understanding of mathematics as a collection of isolated skills and procedures. In [9], the author examined the systemic and cultural factors that sustain these traditional assessment practices, particularly in high-stakes examination systems. Tan argued that these systems prioritize computational accuracy and formulaic applications, often at the expense of fostering broader mathematical competencies. This focus on test performance reduces students' perceptions of mathematics to a mechanical process, further hindering their ability to integrate knowledge, think critically, or solve meaningful problems. Together, these studies provide a comprehensive critique of traditional mathematics assessments, underscoring their limitations in fostering deep learning and broader competencies. They highlight the urgent need for reform in assessment practices to emphasize higher-order cognitive skills, ensuring students are better prepared to apply mathematical concepts in varied and meaningful contexts. This aligns with our argument that a more balanced approach to assessment, integrating both procedural and conceptual dimensions, is essential for holistic mathematics education.

Additionally, written assessment items usually measure skills in isolation from a problem context; they do not assess students' comprehension of mathematical concepts, their ability to integrate knowledge to solve problems, or their effectiveness in communicating mathematical ideas through written language. Educational research has focused on the delivery of content in secondary school mathematics education. A variety of tactics are needed to present content effectively, such as the incorporation of technology, a range of pedagogical approaches, and a well-thought-out curriculum. It has been demonstrated that utilizing technology, such as interactive software and digital materials, improves student comprehension and engagement. According to research [10], by making abstract concepts more interactive and tangible, technology-supported instruction can dramatically increase students' mathematical ability. By influencing how students acquire and understand mathematical concepts, pedagogical approaches—which include direct instruction, inquiry-based learning, and collaborative learning—also play a critical role in the delivery of information. In [11], the authors point out that improving students' mathematics understanding is more successful when instructional strategies encourage problem-solving and critical thinking. These methods encourage active learning, where students engage deeply with mathematical problems and develop a better grasp of underlying principles.

Problem-solving, reasoning and evidence, representation, communication, and connections are among the five process criteria that the National Council of Teachers of Mathematics [12] has recognized as guiding students' mathematical learning. These standards offer a framework for considering how kids should approach learning mathematical concepts as they advance in procedural fluency and conceptual comprehension. By tackling and solving real-world situations rather than doing tedious arithmetic exercises, kids who engage in problem-solving develop their mathematical knowledge and comprehension. In order to cultivate, defend, and evaluate mathematical arguments and solutions, they employ reasoning and proof to give context to mathematical activities and concepts. To help them think through mathematical problems, students create and use representations including diagrams, graphs, symbols, drawings, and manipulatives. As they explain their thoughts and ideas verbally, in writing, and through illustrations, kids also engage in communication. As they pick up new mathematical methods and concepts, students not only develop and apply connections between mathematical ideas but also create links between mathematics and other fields by applying mathematics to real-world scenarios.

The concept of mathematical competency is used to define what it means for a person to successfully learn mathematics. It serves as a sign that a person is proficient in mathematics. The cognitive dimension of mathematics refers to the ability to perform mathematical tasks with proficiency and to demonstrate knowledge, competence, expertise, beliefs, and facility. It also involves becoming a highly productive problem solver. According to [13], the five interconnected and interrelated strands of mathematical ability are conceptual understanding, procedural fluency, strategic competence, adaptive thinking, and productive disposition. "Comprehension of mathematical concepts, operations, and procedures" is the definition of conceptual understanding [13]. The ability to describe mathematical issues in a variety of ways and the understanding that different representations might serve different objectives are important markers of the cognitive dimension [13]. Therefore, an individual's profound understanding of concepts is a result of the numerous connections between various representations that they possess. Assume, for example, a student with a rich knowledge of proportion and number sense. For them, 60% is perceived as 60/100, which is the same as 30/100 + 30/100 or 3/10 + 3/10 (or 6/10) (or 3/5). Using their understanding of decimals, they could be able to relate it to 60% by seeing it as equivalent to 0.60, which is 6 tenths of a hundred or 60 hundredths (or 600 thousandths). Conceptual knowledge is the result of all these relationships between various representations.

Content dimension is the result of all these relationships between various representations. It should be highlighted that representations give pupils a variety of perspectives on abstract mathematical ideas, which, when linked and intellectually organized, enhance conceptual understanding. In contrast to instrumental understanding, which is knowledge acquired by rote or without context, conceptual understanding should focus on relational understanding or knowing what to do and why. The aim of regular mathematics instruction should be to help pupils achieve this relational understanding. Students need to be made aware of the various ways to approach an issue in order to develop conceptual comprehension. Students can construct new information by connecting previously taught material with conceptual understanding. For students, this approach is significantly more advantageous than just memorizing processes and data [14]. Fluency development and retention are enhanced by cognitive dimensions [13].

For students' cognitive capacities, learning mathematics is crucial [15,16]. In this domain of cognition, understanding serves the functions of processing, organizing, and applying knowledge. In the meantime, cognitive ability—which emphasizes brain-based skills—is required to carry out any task, no matter how simple or complex [17]. Brain-based abilities known as cognitive skills are utilized to finish any activity gradually [18,19]. The mental processes involved in gathering, storing, and applying information are referred to as cognitive talents, from which perception, focus, memory, problem-solving, reasoning, decision-making, and the mental processes required to address difficulties in daily life are a few examples. The ability to diagnose problems with learning in students, enhance learning results, track their growth and development, and assess brain function or performance makes cognitive skills crucial. In general, cognitive skills testing offers useful data for managing learning problems and enhancing professional and educational results.

3. Methods

3.1. Respondents, context, and research design

The target population for the study comprised Senior Secondary School Class II (SSS2) students in Ibadan, Oyo State, Nigeria. Ibadan was chosen as the study site because it offers a mix of urban and semi-urban settings, enabling a diverse representation of socio-economic and educational contexts. The sampling procedure followed a multi-stage approach to ensure a robust and representative sample. In the first stage, local government areas (LGAs) within Ibadan were stratified into urban and semi-urban categories. The metropolis comprises 11 LGAs, with six classified as urban and five as semi-urban. From these, purposive sampling was used to select two urban LGAs and one semi-urban LGA. This stratified selection ensured that the sample reflected the population's diverse socio-economic and geographical characteristics. In the second stage, schools were randomly selected from the chosen LGAs. A comprehensive list of senior secondary schools in each LGA was obtained from the Oyo State Ministry of Education. Ten schools were randomly chosen from each selected LGA, resulting in 30 schools. Simple random sampling was employed, giving every school on the list an equal probability of selection, thereby enhancing the study's representativeness. In the third stage, students were randomly sampled from the selected schools. From each school, 20 students were chosen from the SSS2 class.

This process involved assigning numbers to all students on the class rosters provided by the schools and using random number generation to select participants. This method ensured that every student within the eligible class had an equal chance of inclusion in the study. The final sample comprised 400 students, with a gender distribution of 42.5% male and 57.5% female, closely mirroring the demographics of SSS2 students in Ibadan. The average age of participants was 16.4 years (SD = 0.80), consistent with the typical age range for students at this academic level. The study captured a broad spectrum of educational experiences and socio-economic influences by incorporating schools and students from urban and semi-urban areas. We used a descriptive survey research design with an ex post facto approach. The ex post facto design was selected because we were investigating students' mathematics performance, an outcome influenced by pre-existing variables such as content dimensions (number and numeration, algebra, geometry, everyday statistics) and cognitive dimensions (recall, conceptual understanding, and reasoning). These variables could not be manipulated by the researchers, as they are shaped by prior educational experiences, instructional strategies, and assessment practices. The retrospective nature of this approach allowed us to analyze these existing variables without altering the learning environment or testing conditions. Also, we used the positivist research paradigm, which aims to objectively measure and analyze variables to draw generalizable conclusions based on empirical data. The positivist approach relies on quantifiable observations and statistical analysis to test hypotheses and derive conclusions. This paradigm was chosen to ensure that the study's results are based on rigorous, systematic investigation, providing reliable evidence that can be used to improve educational outcomes.

3.2. Instrument

The Senior Secondary Mathematics Achievement Test (SSMAT) was developed as a key instrument for assessing students' mathematics performance. Designed to comprehensively evaluate both content and cognitive dimensions, the SSMAT was carefully aligned with the Senior Secondary School Curriculum, covering critical areas such as number and numeration, algebra, geometry, and everyday statistics. The instrument aimed to measure not only procedural fluency but also deeper cognitive skills, including recall, conceptual understanding, and reasoning. This dual focus ensured that the tool captured a holistic view of students' mathematical abilities. To guide the development process, a test blueprint was used to ensure a thorough representation of both the curriculum content and cognitive dimensions. Initially, an item pool of 80 multiple-choice questions with four options (A–D) each was created. These items were designed to assess students' mastery of mathematical content while challenging their cognitive abilities, particularly in reasoning.

Focus on reasoning

Reasoning was a critical focus in our study, reflecting higher-order thinking skills such as the ability to analyze, infer, and solve problems in unfamiliar contexts. Unlike recall or conceptual understanding, reasoning questions were designed to require students to:

a) Connect mathematical concepts to solve non-routine problems.
b) Justify their solutions with logical steps or evidence.
c) Apply mathematical principles in novel situations, beyond rote application of formulas or procedures.

These items were constructed following established frameworks for assessing reasoning in mathematics (e.g., National Research Council, 2001; NCTM, 2000). Below are examples of reasoning questions from the SSMAT, illustrating their alignment with the reasoning dimension:

Question 1: A farmer wants to fence a rectangular plot of land that measures 50 meters by 30 meters. If the cost of fencing is $12 per meter, and the farmer has a budget of $3,000, will the budget be sufficient? Show your calculations and reasoning.

Rationale: This question requires students to calculate the perimeter of the rectangle, determine the total cost of fencing, and compare it to the budget. Beyond computation, students must logically explain whether the budget suffices and justify their conclusions, demonstrating reasoning skills.

Question 2: The sum of the ages of two brothers is 28 years. Five years ago, the elder brother was three times as old as the younger brother. How old are the brothers now? Explain your reasoning.

Rationale: This problem requires students to translate the problem into mathematical equations, solve the system of equations, and interpret the results in the context of the question. The task evaluates their ability to reason through relationships and constraints.

Question 3: A company manufactures two types of tiles, Type A and Type B. Type A sells for $15 per piece, while Type B sells for $20 per piece. Last month, the company sold a total of 500 tiles and earned $8,500. How many of each type of tile were sold? Provide your reasoning and calculations.

Rationale: This question involves forming and solving equations based on the given conditions, requiring students to apply reasoning to analyze the problem and justify their results.

Question 4: In a village, every family owns at least one dog or one cat. 80 families own dogs, 60 own cats, and 20 families own both. How many families are in the village? Explain your reasoning.

Rationale: This question assesses students' ability to use set theory and logical reasoning to solve a real-world problem involving overlapping groups. Students must demonstrate their understanding of union and intersection concepts while explaining their thought processes.

Importantly, the development process emphasized rigorous validation to ensure the accuracy and effectiveness of the instrument. The initial pool of 80 items underwent trial testing with a representative sample of students to evaluate their clarity, difficulty, and discrimination. Feedback from mathematics teachers and measurement and assessment experts was incorporated to refine the items. Questions that were too easy or too difficult, or those that did not adequately differentiate between high and low performers, were revised or removed. This iterative process ensured that the final test items met the desired standards of quality and reliability. Following this validation phase, 40 items were selected for the final SSMAT based on their statistical performance and alignment with the test blueprint. These items represented a balanced distribution across content areas and cognitive dimensions, including recall, conceptual understanding, and reasoning. The reasoning questions, in particular, were developed to assess students’ higher-order cognitive skills, such as logical analysis, problem-solving, and application of abstract concepts in real-world scenarios.

3.3. Reliability and validity

To ensure the validity of the SSMAT, the test underwent multiple stages of scrutiny. Initially, 80 items were created and subjected to trial testing with a sample of SSS2 learners. Mathematics teachers and experts in measurement and assessment reviewed the items to ensure their accurate representation of the curriculum content and cognitive skills. Based on the feedback and analysis of item difficulty and discrimination indices, 40 items were selected for the final test. The difficulty index ranged from 0.30 to 0.70, and the discrimination index ranged from 0.30 to 0.60, indicating an appropriate level of challenge and the ability to differentiate between high and low performers. The reliability coefficient of the SSMAT, determined to be 0.893 using the Kuder–Richardson formula 20 (KR-20), indicates high internal consistency. The high-reliability coefficient suggests that the SSMAT yields stable and consistent results across different administrations. In essence, the rigorous validation process, including expert reviews and trial testing, ensured that the test items were well-aligned with the curriculum objectives and effectively measured learners' cognitive abilities. The validity and reliability of the SSMAT make it a robust instrument for assessing mathematics achievement, providing accurate and meaningful data for analyzing learners' performance and informing educational practices.

3.4. Data collection procedure and ethical consideration

Data collection involved administering the SSMAT to selected learners in their respective schools, with prior consent from school authorities and the learners' parents or guardians. Respondents were informed about the study's purpose, assured of confidentiality, and told that participation was voluntary. The test was administered under standardized conditions to ensure fairness and consistency. Throughout the data collection process, efforts were made to minimize disruptions to learners' regular academic activities. Test scheduling was arranged at convenient times agreed upon by the school administration to maximize participation and minimize interference with learning. Trained research assistants adhered to a standardized protocol when administering the tests, ensuring consistency and accuracy. Ethical considerations were strictly followed to protect participants' rights and welfare.

3.5. Method of data analysis

The collected data were analyzed using descriptive statistics and inferential statistics. Descriptive statistics, such as mean, standard deviation, frequency, and percentage, were used to summarize learners' performance in different content and cognitive dimensions. Average scores in different content areas provided insights into specific mathematical topics where learners had strengths and weaknesses. An independent sample t-test compared the performance of male and female learners across these dimensions to determine if there were statistically significant gender differences ($p < 0.05$). SPSS software version 26.0 was used to conduct statistical analyses, ensuring accuracy and reliability.

3.6. Common method bias

To address common method bias, several steps were taken. The survey items were designed to minimize ambiguity and leading questions, ensuring the students' responses reflected their true abilities and understanding. The data collection process was standardized to reduce any potential biases introduced by the test administration. Harman's single-factor test was also conducted during the analysis to check for common method variance. This test involved conducting an exploratory factor analysis (EFA) to determine if a single factor accounted for the majority of the variance in the data. Harman's single-factor test indicated that no single factor accounted for more than 50% of the variance, suggesting that common method bias was not a significant concern in this study.

4. Results

Research question 1: What are the content dimensions of SS2 learners' mathematics performance in terms of number and numeration, algebraic expression, geometry measurement, and everyday statistics?

Table 1. Statistics of content dimension of mathematics.

Content Dimensions	Mean	Std Deviation	Minimum	Maximum	Percentage (%)
Number and numeration	8.930	2.236	3	18	50.0
Algebraic	5.100	1.476	1	10	22.5
Geometry	1.820	0.963	0	4	10.0
Everyday statistics	3.040	1.053	0	7	17.5

Table 1 provides a comprehensive overview of SS2 learners' mathematics performance in various content dimensions, including number and numeration, algebraic expression, geometry measurement, and everyday statistics. This table presents key statistical data, including mean scores, standard deviations, minimum and maximum scores, and the percentage contribution of each content dimension to the overall performance of the learners. The data in this table offers valuable statistical insights into how learners performed in each content dimension. In the context of number and numeration, learners achieved an average performance score of 8.93, with a standard deviation of 2.236. The lowest score recorded in this content dimension was 3, while the highest score attained was 18. Notably, number and numeration accounted for 50% of the total percentage of performance.

Moving on to algebraic expression, the mean score obtained by learners was 5.10, and the standard deviation was 1.476. The lowest score observed in this content dimension was 1, while the highest score was 10. Algebraic expression contributed to 22.5% of the overall percentage. In the domain of geometry measurement, learners achieved an average score of 1.82, with a standard deviation of 0.963. Most of the students' scores in this content dimension fell within the range of 0 to 4. Geometry measurement constituted 10% of the total percentage. Lastly, in the area of everyday statistics, learners obtained a mean score of 3.04, and the standard deviation was 1.053. The lowest score recorded in this category was 0, while the highest score achieved was 7. Everyday statistics represented 17.5% of the overall percentage of performance.

Research question 2: What pattern of cognitive dimensions of SS2 learners' mathematics performance exists in terms of recall, conception, and reasoning?

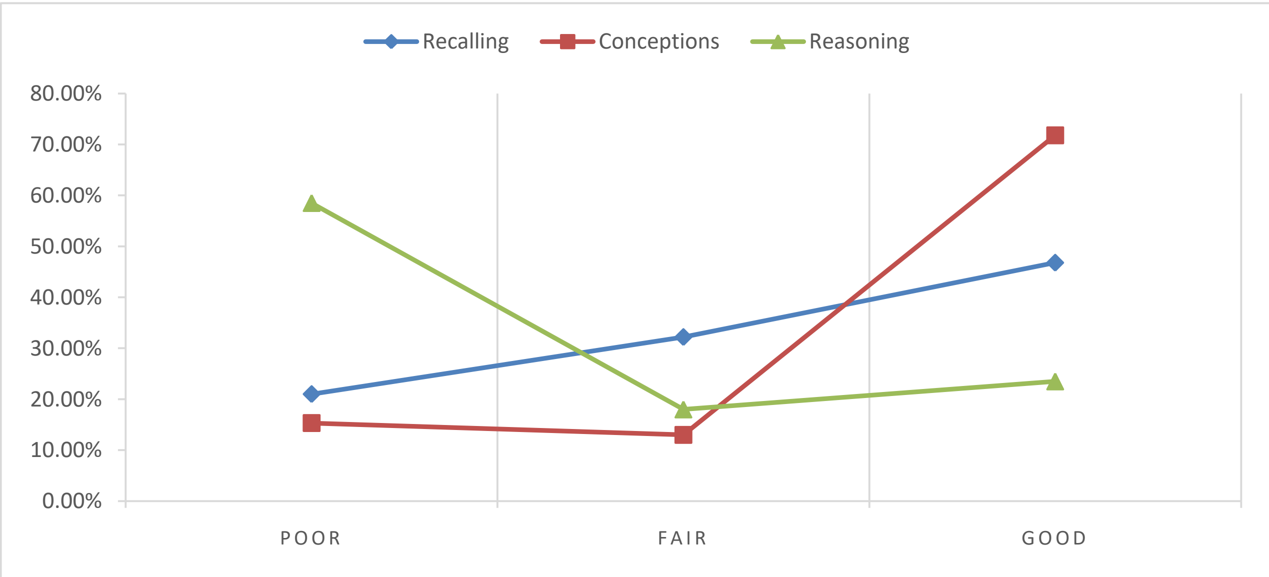

Figure 1. Descriptive statistics showing the patterns of cognitive and content dimensions.

The findings depicted in Figure 1 illustrate the distribution of learners' performance across different cognitive dimensions (namely recalling, conceptions, and reasoning) in mathematics. The figure displays the percentages of learners categorized as poor, fair, and good within each cognitive dimension. Regarding the dimension of recall, the results indicate that 21% of students performed inadequately, while 32% achieved a moderate level of performance. A significant majority, comprising 46.80% of learners, exhibited proficient recall abilities. This suggests that a substantial portion of SS2 students possess a satisfactory capacity to remember mathematical concepts and formulas effectively. In the context of the conception dimension, the data reveals that 15.30% of learners had a deficient understanding, whereas only 13.00% performed at a moderate level. The predominant group, constituting a substantial 71.80% of learners, demonstrated strong conceptual understanding. This implies that a significant proportion of SS2 learners have a solid foundation in mathematical concepts and can apply them effectively.

Finally, the results pertaining to the reasoning dimension show a contrasting pattern. A substantial 58.50% of learners exhibited poor reasoning skills, while only 18.00% reached a moderate level. The smallest portion, comprising 23.50% of learners, demonstrated proficient reasoning abilities. This indicates that the majority of SS2 learners face challenges in logical reasoning and may struggle when it comes to applying mathematical concepts to solve complex problems.

Research question 3: What is the effect of gender on the existing content and cognitive dimension of SS2 mathematics performance?

Table 2. Independent t-test showing the effect of gender on learners' performance in content dimensions.

Gender	N	Mean	Std. Dev.	df	T	p-value	Remarks
Male	170	19.02	3.265	398	0.797	0.426	Not significant
Female	230	18.77	2.966				

An independent sample t-test, as displayed in Table 2, was employed to compare the performance of male and female learners in various content dimensions of mathematics, including number and numeration, algebraic, geometry, and everyday statistics. The table presents descriptive statistics for each gender group. The male group consisted of 170 learners, who achieved an average score of 19.02, with a standard deviation of 3.265. On the other hand, the female group comprised 230 learners, with an average score of 18.77 and a standard deviation of 2.966. The t-value calculated for this comparison was 0.797, and the associated p-value was 0.426. These results indicate that any observed differences in the mean scores are likely attributable to random variation rather than inherent differences in ability between male and female learners. Also, results emphasize the importance of equitable instructional practices and provide a critical counternarrative to traditional gender roles that often steer male learners toward STEM fields while discouraging female learners from pursuing them.

Table 3. Independent t-test showing the effect of gender on learners' performance in cognitive dimensions.

Gender	N	Mean	Std. Dev.	df	t	p-value	Remarks
Male	170	18.240	3.231	398	0.259	0.796	Not significant
Female	230	18.150	3.140				

Table 3 displays the outcomes of an independent sample t-test that was conducted to compare the performance of male and female learners in cognitive dimensions (specifically recall, conceptions, and reasoning) within the realm of mathematics. From 170 male learners and 230 female learners, the mean score for male learners was 18.24, with a standard deviation of 3.231, while female learners had a slightly lower mean score of 18.15, along with a standard deviation of 3.140. The t-value, which stands at 0.259, reflects the extent of the difference between the means relative to the variation within the groups. In this case, the low t-value suggests that the observed gender differences in the cognitive dimension of SS2 mathematics performance lack statistical significance. The significance level, denoted as "p-value", is 0.796, resulting in a p-value higher than 0.05 ($p > 0.05$). This implies that there is no substantial disparity between male and female learners concerning their performance in the cognitive dimension of SS2 mathematics. In simpler terms, gender does not play a significant role in determining learners' performance in the cognitive aspect of mathematics.

5. Discussions

Our study investigated the alignment between cognitive development and the content taught in mathematics education among senior secondary learners. Our results revealed several key insights into the content and cognitive dimensions of learners' mathematics performance, as well as the influence of gender on these dimensions. The analysis of content dimensions highlighted that learners performed variably across different mathematical content areas. The studies [5] and [6] underscored the direct impact of content and cognitive dimensions on learners' mathematics performance. Our results build on these studies, offering empirical evidence that aligns with and extends their conclusions. By evaluating both content areas (e.g., number and numeration, algebra, geometry, and everyday statistics) and cognitive dimensions (recall, conceptual understanding, and reasoning), we provide a more nuanced understanding of the interplay between these factors and mathematics achievement. The study by [5] highlighted the importance of aligning teaching practices with Bloom's taxonomy to enhance both content knowledge and cognitive skills. This aligns closely with our findings, particularly in the cognitive dimension of recall, where 46.8% of learners performed well. This suggests that existing teaching strategies may adequately address lower-order cognitive skills, such as recall and memorization. However, as our results show, higher-order skills like reasoning remain underdeveloped, with 58.5% of learners performing poorly in this area. This finding resonates with the exploration of cognitive academic bi-directionality in [6], which emphasizes the need for a balanced approach to fostering both content mastery and cognitive skill development to improve overall mathematics performance. By contextualizing our findings within this framework, we observe that while content mastery (e.g., number and numeration with a mean score of 8.93, representing 50% of the overall performance) is relatively strong, cognitive dimensions like reasoning are not equally emphasized in traditional instructional practices. These gaps in cognitive skill development may explain the limited ability of learners to apply mathematical concepts in unfamiliar contexts [6]. This connection supports our call for instructional reforms that prioritize reasoning and problem-solving alongside content delivery.

Furthermore, geometry often requires spatial reasoning and visualization skills, which might not be as thoroughly developed in learners due to traditional teaching methods that favor rote learning over exploratory and hands-on activities. The disparity in performance across content areas suggests a need for a more balanced curriculum that equally emphasizes all mathematical domains. Algebraic expressions and everyday statistics, which showed moderate performance levels, highlight the areas where learners have a foundational understanding but may need more complex and applied problem-solving exercises to deepen their knowledge. Tailored instructional strategies, such as integrating real-world applications and collaborative learning projects, could enhance learners' engagement and understanding in these areas. Furthermore, continuous assessment and feedback mechanisms can help identify specific learner difficulties and provide timely interventions to support their learning.

In terms of cognitive dimensions, the study found notable differences in learners' recall, conceptual understanding, and reasoning abilities. The majority of learners (46.8%) demonstrated good recall abilities, indicating that they can effectively memorize and retrieve mathematical information. This ability to recall is crucial for foundational mathematics, where fluency in basic operations and facts is necessary for tackling more complex problems [2]. However, the reasoning dimension showed that 58.5% of learners had poor reasoning skills. This gap suggests a need for instructional strategies that enhance logical thinking and problem-solving skills [4]. Reasoning skills are essential for learners to make connections between concepts, apply their knowledge to new situations, and develop a deeper understanding of mathematical principles. The poor performance in reasoning could stem from a traditional emphasis on procedural fluency over conceptual understanding. Learners often focus on learning procedures and algorithms without fully grasping the underlying concepts, leading to difficulties when faced with non-routine problems that require critical thinking [20]. To address this, educators should incorporate activities that promote exploration, inquiry, and the application of mathematical concepts in diverse contexts. Encouraging learners to explain their thinking, justify their solutions, and engage in mathematical discussions can also foster a deeper understanding and improve reasoning skills. By creating a classroom environment that values and nurtures cognitive development alongside content mastery, teachers can help learners build a more robust mathematical foundation.

We also examined gender differences in both content and cognitive dimensions of mathematics performance. Our results showed no significant differences between male and female learners in both dimensions. From an educational perspective, our results emphasize the importance of equitable instructional practices. We challenge the pervasive stereotype that one gender is naturally better at mathematics than the other—a misconception that can shape classroom dynamics and influence how learners perceive their abilities. By demonstrating that gender does not significantly impact mathematics performance, we highlight the need for teaching practices that encourage equal participation and engagement from all learners. This is particularly important in fostering a supportive environment where both male and female learners can develop confidence in their mathematical abilities. Furthermore, the absence of significant gender differences underscores that those disparities in performance, where they exist, are more likely influenced by external factors rather than intrinsic ability. For example, differences in access to resources, parental expectations, or cultural norms may create barriers that limit learners' opportunities to excel. This calls for interventions focused on addressing these external factors, ensuring all learners have equal opportunities to succeed. Culturally, our results provide a critical counter-narrative to traditional gender roles that often steer male learners toward STEM fields while discouraging female learners from pursuing them. In many societies, such biases persist despite evidence suggesting that when provided with equitable learning opportunities, male and female learners perform equally well in mathematics. Our results align with contemporary research, such as studies by [5] and [21], which similarly found no significant gender differences in mathematics performance. This alignment reinforces the need for educational policies and practices that actively dismantle stereotypes and promote gender equity in STEM education. To translate these results into practice, we recommend targeted teacher training programs that address unconscious biases and emphasize the importance of equitable teaching strategies. Parental and community advocacy initiatives are also critical, as they can help shift societal perceptions about gender roles in education. Moreover, ensuring equal access to resources, such as tutoring, extracurricular support, and technological tools, can further level the playing field for all learners.

6. Implications of the study

The results of this study have several practical implications for educational practice and policy. Educational policymakers and curriculum developers should ensure a balanced focus on both content knowledge and cognitive skills. Emphasizing reasoning and problem-solving within the curriculum can help bridge the gap identified in learners' cognitive performance. Activities that encourage critical thinking, application of concepts, and real-world problem-solving can enhance learners' overall mathematical competence. Curriculum developers should also consider integrating interdisciplinary approaches that connect mathematics with other subjects, making learning more relevant and engaging for learners. Also, teachers should adopt instructional strategies that foster critical thinking and reasoning skills. This includes incorporating more problem-solving activities, encouraging exploratory learning, and using real-life applications of mathematical concepts to enhance understanding. For instance, using project-based learning, where learners work on extended tasks that require them to apply mathematical concepts in practical situations, can promote deeper learning.

Additionally, teachers should use formative assessments to gauge learners' understanding regularly and provide timely feedback and support. Additionally, continuous professional development for mathematics teachers is essential to effectively equip them with the skills to integrate cognitive development into their teaching practices. Training should focus on pedagogical techniques that promote higher-order thinking skills and address diverse learning needs. Professional development programs should also provide opportunities for teachers to collaborate, share best practices, and reflect on their teaching methods. By staying informed about the latest research and innovative teaching strategies, educators can continuously improve their instructional approaches and better support their learners' learning.

7. Conclusions

Our study underscores the importance of a comprehensive approach to mathematics education that integrates content knowledge with cognitive skill development. While learners showed proficiency in recall and basic numeration, significant gaps in reasoning skills highlight the need for targeted instructional strategies. Additionally, the absence of gender differences in performance suggests that efforts to support learners in mathematics should be gender-inclusive. These findings emphasize the need for educational stakeholders to prioritize both content and cognitive dimensions in curriculum design and instructional practices. By addressing the identified gaps in cognitive development, teachers can help learners develop the critical thinking and problem-solving skills necessary for success in mathematics and beyond. A balanced approach to mathematics education can also enhance learners' confidence and motivation, leading to improved academic performance and long-term achievement. Furthermore, ensuring equitable access to quality mathematics education for all learners, regardless of gender, can contribute to closing achievement gaps and promoting social equity.

8. Limitations and future directions

We identified some limitations that should be acknowledged. First, the sample was limited to learners from Ibadan, Oyo State, which may not represent the entire population of senior secondary learners in Nigeria. The results may, therefore, not be generalizable to other regions with different educational contexts and resources. Additionally, the study relied on the SSSMAT, which, despite its high reliability, may not comprehensively capture all dimensions of mathematical performance. We did not account for other factors, such as learners' attitudes, motivation, and learning environments, which can significantly influence performance. Second, the cross-sectional nature used limits the ability to draw causal inferences about the relationship between content and cognitive dimensions. Longitudinal studies that track learners' performance over time would provide more robust evidence on how cognitive skills develop concerning content mastery. Hence, future research should consider using a mixed-methods approach to gain deeper insights into learners' learning experiences and the contextual factors influencing their mathematics performance.

Future research should also consider a broader and more diverse sample to enhance the generalizability of the results. Including learners from different regions, school types, and socio-economic backgrounds can provide a more comprehensive understanding of the factors influencing mathematics performance. Longitudinal studies could provide deeper insights into how cognitive skills develop over time in mathematics education. Such studies would help identify critical periods for intervention and the long-term impact of various instructional strategies on learners' cognitive and academic outcomes. Additionally, experimental studies examining the effectiveness of specific instructional interventions on improving cognitive dimensions of mathematics performance would be valuable. These studies could test the impact of different teaching methods, such as inquiry-based learning, collaborative problem-solving, and technology-enhanced instruction, on learners' reasoning and critical thinking skills. Teachers and policymakers can make informed decisions to improve mathematics education and support learner success by identifying evidence-based practices that enhance cognitive development.

Author contributions

Joshua Oluwatoyin Adeleke: writing—original draft and editing, conceptualization, supervision, proofreading of the manuscript; Hameed Adedeji Balogun: writing—original draft and editing, conceptualization, project administration, writing literature review; Musa Adekunle Ayanwale: methodology, data curation, data analysis, writing—original draft, writing—review and editing. All authors have read and approved the final version of the manuscript for publication.

Use of Generative-AI tools declaration

We declare that we did not use Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

The authors declare that there is no conflict of interest in this manuscript.

Ethics declaration

Ethical considerations were rigorously upheld to safeguard the rights and welfare of participants. Respondents were informed about the study's purpose, assured of confidentiality, and made aware that their participation was voluntary.

References

1. Ayanwale, M.A., Efficacy of item response theory in the validation and score ranking of dichotomous and polytomous response mathematics achievement tests in Osun State, Nigeria. *Nigeria. doi*, 2019.
2. National Council of Teachers of Mathematics, Principles to Actions: Ensuring Mathematical Success for All. Reston, VA: NCTM, 2020.
3. Ayanwale, M.A., Calibration of polytomous response mathematics achievement test using generalized partial credit model of item response theory. *EDUCATUM Journal of Science, Mathematics and Technology*, 2021, 8(1): 57–69. https://doi.org/10.37134/ejsmt.vol8.1.7.2021
4. Borko, H., Jacobs, J. and Koellner, K., Challenges and promises of using video to study and support teacher learning in mathematics. *ZDM Mathematics Education*, 2019, 51(5): 779–792.
5. Akinboboye, J.T. and Ayanwale, M.A., Bloom taxonomy usage and psychometric analysis of classroom teacher made test. *African Multidisciplinary Journal of Development*, 2021, 10(1): 10–21. https://doi.org/10.4038/kjms.v3i2.25
6. Peng, P. and Kievit, R.A., The development of academic achievement and cognitive abilities: A bidirectional perspective. *Child Development Perspectives*, 2021, 14(1): 15–20. https://doi.org/10.1111/cdep.12352
7. Bergsten, C., Critical factors and prognostic validity in mathematics assessment. *ICTM2, at Crete*, 2002.
8. Brown, R.G., Does the introduction of the graphics calculator into systemwide examinations lead to change in the types of mathematical skills tested? *Educational Studies in Mathematics*, 2010, 73(2): 181–203. https://doi.org/10.1007/s10649-009-9220-2
9. Tan, K., Assessment for learning in Singapore: unpacking its meanings and identifying some areas for improvement. *Educational Research for Policy and Practice*, 2011, 10(2): 91–103. https://doi.org/10.1007/s10671-010-9096-z
10. Li, Q. and Ma, X., A meta-analysis of the effects of computer technology on school students' mathematics learning. *Educational Psychology Review*, 2010, 22(3): 215–243. https://doi.org/10.1007/s10648-010-9125-8
11. Hiebert, J. and Grouws, D.A., The Effects of Classroom Mathematics Teaching on Students' Learning. In F. Lester (Ed.), *Second Handbook of Research on Mathematics Teaching and Learning*, 2007, 371–404. Charlotte, NC: Information Age.
12. National Council of Teachers of Mathematics, (Principles and standards for school mathematics. Reston, VA: National Council of Teachers of Mathematics, 2000.
13. National Research Council, Adding it up: Helping children learn mathematics. J. Kilpatrick, J. Swafford, and B. Findell (Eds.). Mathematics Learning Study Committee, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: National Academy Press, 2001. Retrieved from: http://www.nap.edu/catalog/9822.html.

14. Gunawan, W. and Hadi, S., The effect of a Realistic Mathematics Education (RME) approach and reasoning ability on students’ conceptual and procedural understanding. *Contemporary Educational Researches Journal*, 2024, 14(2): 90–102. https://doi.org/10.18844/cerj.v14i2.9318
15. Ding, M., Hassler, R. and Li, X., Cognitive instructional principles in elementary mathematics classrooms: A case of teaching inverse relations. *International Journal of Mathematical Education in Science and Technology*, 2021, 52(8): 1195–1224. https://doi.org/10.1080/0020739X.2020.1749319
16. Layne, T., Yli-Piipari, S. and Knox, T., Physical activity break program to improve elementary students’ executive function and mathematics performance. *Education 3-13*, 2021, 49(5): 583–591. https://doi.org/10.1080/03004279.2020.1746820
17. Anderson, K., Gong, X., Hong, K. and Zhang, X., The impacts of transition to middle school on student cognitive, non-cognitive and perceptual developments: Evidence from China. *Education Economics*, 2020, 28(4): 384–402. https://doi.org/10.1080/09645292.2020.1749234
18. Shen, Z., Tan, S. and Siau, K., Use of mental models and cognitive maps to understand students’ learning challenges. *Journal of Education for Business*, 2019, 94(5): 281–289. https://doi.org/10.1080/08832323.2018.1527748
19. Trinidad, J.E., Understanding student-centred learning in higher education: Students’ and teachers’ perceptions, challenges, and cognitive gaps. *Journal of Further and Higher Education*, 2020, 44(8): 1013–1023. https://doi.org/10.1080/0309877X.2019.1636214
20. Makar, K., Ben-Zvi, D. and Bakker, A., (Eds.) *International handbook of statistical reasoning*, Springer, 2020.
21. Arigbabu, A.A. and Mji, A., Is gender a factor in mathematics performance among Nigerian pre-service teachers? *Sex Roles*, 2004, 51(11): 749–753. doi: 10.1007/s11199-004-0724-z.

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