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Structural Regression Modelling of Relationship between Mathematics Achievement and Mathematical Reasoning Ability

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ABSTRACT

Using the structural regression modelling technique, this study established the relationship between students' mathematical achievement and mathematical reasoning ability as explained by the indicators of mathematical reasoning ability. Two hundred and eighty (280) Senior Secondary One (SSI) students drawn from population of ten thousand two hundred and eighty (10,280) from twelve (12) Senior Secondary Schools in the Taraba State, Nigeria participated in the study. The participants were randomly drawn from three (3) local government areas of Wukari, Donga and Ibi. The age of the participants ranges from 14-16 years (mean age = 15.20; standard deviation = 1.79). A 24-item Mathematics Reasoning Ability Test (MRAT) consists of a total of 12 subtests. Under each subtest, there are two items. Each item's difficulty and discriminating indices varied from 0.37 to 0.70 and from 0.30 to 0.57, respectively. Every section's reliability index fell between 0.69 and 0.81. A 36-item Attainment in Mathematics Test (AMT) with three sections was also administered to the participants. Each section's reliability index was as follows: 0.71 for number and numeration, 0.76 for algebra, and 0.69 for geometry, using the Kuder Richardson 20 formula. Students' MRAT and AMT scores were analyzed using LISREL version 8.88's maximum likelihood estimations. The structural regression model's results showed that success in mathematics reasoning ability consistently predicted success in mathematics achievement, and the four basic concepts—class, variable, order, and classification—were measures of mathematical reasoning ability. These findings revealed that mathematics reasoning ability predicted success in mathematics achievement. Therefore it is important that teachers implement intervention programs to support students in strengthening their capacity for mathematical thinking and which would eventually raise their mathematical achievement.

Keywords: Class; Mathematics Achievement; Mathematical Reasoning Ability; Order; Structural regression modelling; Variable.

INTRODUCTION

The focus on persistence in STEM subjects, such as computer and mathematical science, is crucial given the demand for workers in these industries. These fields are expected to increase at one of the quickest rates in the USA between 2021 and 2031 (U.S. Bureau of Labour Statistics, 2022). The Department of Employment, Skills, Small and Family Business (2019) predicts considerable employment growth for professionals, notably with software and applications programmers. Other countries are witnessing similar demands for STEM specialists. Similarly, by 2025, it is projected that seven million STEM career opportunities would exist in Europe (Women in Aerospace Europe, 2021). Mathematics, which has long been acknowledged as the mother of all disciplines, is the foundation for the study of sciences, technology, and other fields requiring computations. In addition to being useful for computations, mathematics fosters critical thinking, creativity, and reasoning abilities in humans (Sujata, 2017, Onoshakpokaiye, 2021a). Students' prior mathematical knowledge cannot be transferred unless higher-order thinking skills are developed. In light of suggestions for a stronger focus on creativity, evidence building, and logical reasoning, research on higher-order thinking skills may increase our understanding of the procedures involved in the search for answers (Lester, 2013; Tularam, 2013, Tajudin & Chinnappan, 2017). Through mathematics, the brain is primed and developed for reasoning and critical thinking. Hendriana, Prahmana, and Hidayat (2018) define reasoning as a pattern of cognitive activity that entails making a new claim or coming to a conclusion based on one or more previously accepted assertions. A mathematical foundation serves as the basis for the analytical, creative, and rational reasoning that prioritizes problem-solving skills and enjoys novelty (Lithner, 2008; Fathurrohman, Porter & Worthy, 2017, Hendriana et al, 2018). According to Kanmani and Nagarathinam (2018), reasoning is the capacity to actively apply one's intellect, the application of logic to support facts, and the development of opinions based on either new or current knowledge.

In the teaching and learning of mathematics, reasoning is a crucial component of mathematical aptitude (Sukirwan & Herman, 20180). Using reasoning in nature, manipulating mathematics in simplification, and analyzing the existing components in issue solving in the framework of mathematics and others are some of the objectives of mathematics as stated in Permendikbud Number 58 Year 2014 (Mardiyah & Safa'atullah, 2018). Additionally, (Agustyaningrum, Hanggara, Husna, Abadi & Mahmudii, 2019) asserted that reasoning and proofing are vital to the advancement of mathematics. Accordingly, it is impossible to separate reasoning from mathematics since knowing mathematics necessitates reasoning, which can be developed by exposure to mathematical content [Jufri, Setiadi &Sripatmi, 2016; Saleh, Charitas, Prahmana, & Isa, 2018; Arnawa, Yerizon & Nita, 2019]. Reasoning, according to (Mueller & Maher, 2009), is the process of coming to conclusions based on facts or presumptions. Making inferences from dynamic information is the process of reasoning. The foundation of reasoning is a logical thought process that investigates and links the fundamentals of the issue in order to provide a logical conclusion, assess the truth, or validate a claim or solution. Enhancing one's capacity for mathematical thinking helps students develop a positive outlook that will help them handle challenges in the real world both now and after they are integrated into society. Because it applies special qualities to mathematics as a discipline, mathematical reasoning is significant (Rahmawati, Mardiana, & Triyanto, 2018). Students can solve problems requiring generalization, abstract thought, and simplification once they have mastered some of the special mathematical features. As a result, using mathematical reasoning to solve problems is highly beneficial (Selden & Selden, 2003 9). The capacity to analyze or understand a mathematical problem logically in order to arrive at a solution, distinguishing what is crucial and irrelevant in the process, and providing an explanation or justification for the solution are all components of mathematical reasoning.

Mathematics Reasoning Ability and Achievement

Several studies have shown that young children who are taught mathematical reasoning are more confident, comprehend how these abilities may be used in a wider range of situations better, and are also more willing to take chances to discover what works and what doesn't (Saleh, Prahmana, Isa & Murni, 2018). According to Sujata (2017), Rastogi (1983) asserted that one factor contributing to poor mathematics achievement is the inability to think mathematically and this is crucial for success in math and other topics that need computations or math. There is a substantial association between success and mathematical talent, according to numerous researches (Sumangala, 1995 referenced in Sujata, 2017). Nunes et al. (2007) show evidence of a causal relationship between mathematical aptitude and logical thinking in elementary school children. However, applying logical ideas to mathematics—such as comprehending additive composition, one-to-one and one-to-many correspondences, and the inverse relationship between addition and subtraction—was described as logical competency.

Mukherjee (2012) discovered that reasoning and numerical ability had a significant impact on students' academic success in mathematics. The study looked at the relationship between students' study habits, personalities, and scholastic aptitude and academic achievement in the tenth grade. It was also demonstrated that students' aptitude for reasoning and numeracy were the best measures of their academic development. Sujata (2017) cited research by Muthumanichan (1992) that showed a positive correlation between business performance and reasoning abilities. A study conducted by Ashima, Bhandari, and Rashpalkaur on the impact of aptitude on the rationalization of senior secondary students' mathematical achievement was referenced in

Kanmani and Nagarathinam (2018). Their investigation revealed no significant differences in thinking abilities between male and female senior secondary students. Kanimozhi and Ganesan (2017) discovered a positive association between mathematics achievement and reasoning skills in their study on reasoning skills among higher secondary students. and there was no appreciable variation in the capacity for thought between males and females. Brunner, Krauss, and Kunter (2007) looked at how German pupils performed on topics linked to mathematics. Their findings showed that while girls do slightly better than boys in reasoning ability, boys perform better than girls in specialized mathematics.

The foundational ideas of mathematics, according to Hamley and Jenkins's writings (Adegoke, 2013), are divided into two categories: the concepts of variables, class, order, and correspondence, and the concepts of arithmetical numbers, algebraic symbols, and spatial figures. These are essential to the study of mathematics because they supply the building blocks that make mathematics possible. Additionally, they designate the discipline of study known as mathematics. These ideas are important to mathematical work since most tasks involve classifying data, arranging the data into classes, and finding correspondences that lead to original conclusions. According to Adegoke (2013), an even number is a variable, since there are numerous even numbers that all have the quality of being exactly divisible by two. A variable is a quantity that can take on different values while maintaining the same basic structure throughout. A class is a collection of quantities that have a similar characteristic; a class of even numbers is one that has the condition that all of its members are exactly divisible by two or that all of its members are even. When quantities are placed in a certain order based on a set rule or law, an order is produced; as a result, even numbers can be arranged in either ascending or descending order. If two ordered classes of quantities are arranged side by side such that every pair is constrained by an enunciable law, a correspondence is produced. Accordingly, the sequence of odd and even numbers exhibits a correspondence where each member of one class is distinct from the corresponding member of the other class. Since the concepts of variable, class, order, and correspondence are present in all stages of mathematical work, they might be thought of as the foundational ideas needed to understand mathematics, and they serve as the foundation for mathematical ability exams, together with the concepts of arithmetical numbers, algebraic symbols, and spatial figures (Adegoke, 2013: Lee, 1967).

The Nigerian Educational Research and Development Council (NERDC) developed the secondary school curriculum in Nigeria. In 2005, NERDC developed a mathematics curriculum that is divided into four main areas. These are Algebra, Geometry, Statistics, and Number and Numerizations. An examination of the curriculum reveals that a total of almost fifty different topics are covered in these four sections, including arithmetic percentages, algebraic quadratic equations, geometry's circles theorems, and statistics' measurements of central tendency, dispersion, and probability theories. These are the core mathematical ideas that all secondary school students in Nigeria need to learn. The degree to which a student is able to master these core ideas is determined by their mathematical achievement. In this particular study, the focus was on three areas: Number and Numerations, Algebra, and Geometry. This is because the participants in the research are students in senior secondary school one with age ranging from 14years to 16 years and it is only in senior secondary two (ages 16–18) in Nigeria that students begin studying statistics in-depth. Determining the degree to which these four dynamic processes are indicators and adequate measures of mathematical reasoning ability was the first objective of this study. The second was to present a structural model of the relationships between the basic concepts of mathematical reasoning ability and mathematical attainment. The third goal was to assess the suitability of the two-factor model of mathematical reasoning ability and mathematical achievement and ascertain the degree to which mathematical reasoning ability indicators predict mathematical achievement.

A Structural Regression model (SR) to investigate the connections between the core ideas of mathematical reasoning ability and mathematical achievement was created in figure 1. SR is a type of structural equation model and other examples are Path Analysis (PA) and Confirmatory Factor Analysis (CFA) (Adegoke, 2013; Kline, 2015). When path model (PA) is combined with CFA measurement models, it yields SR model. Similar to PA, SR permits the testing of direct and indirect causal effect hypotheses. These effects, however, differ from PA in that they include a measuring component that, like in CFA, depicts observed variables as indications of underlying determinants. With SR models, a single model can be used to test theories on measurement and structural relations (Adegoke, 2013; Kline, 2015).

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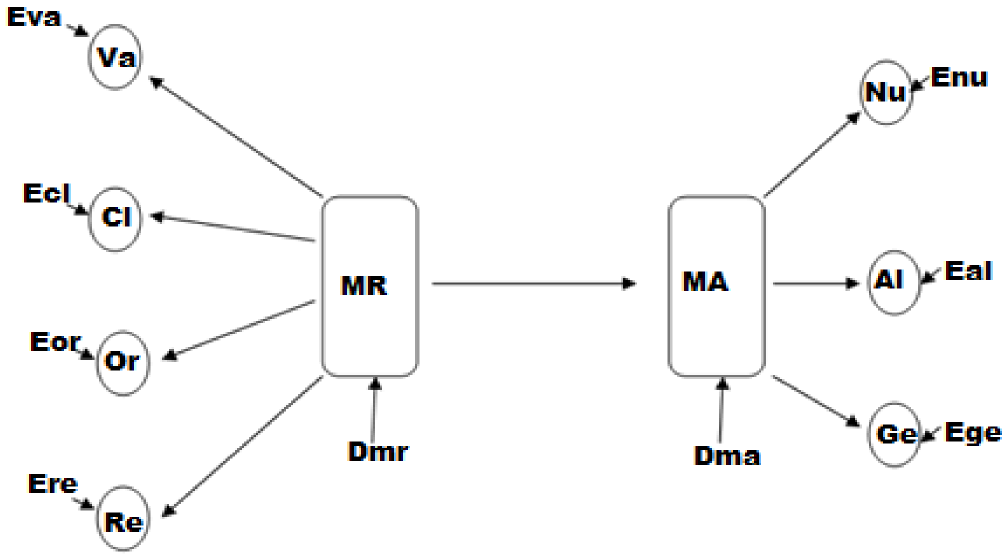

Figure 1: Structural Regression Model for Mathematics Reasoning Ability and Mathematics Achievement

The factors MR and MA in figure 1 are latent traits that are evaluated indirectly based on scores from the indicators. For instance, MR is evaluated based on students' recognition of the four processes of recognition of variable (Va), classification (Cl), order (Or), and recognition of correspondences (Re) in dealing with the simple materials that are fundamental to mathematics, such as arithmetic numbers, algebraic symbols, and spatial figures. MR, a second factor, predicts MA, which is evaluated based on scores in number and numeration (Nu), algebra (Al), and geometry (Ge). Note that the Ds associated with latent traits in the figure reflect omitted causes of latent variable rather than observed variables. Since the causes of exogenous variables are not represented in the models, they are free to vary and covary (Kline, 2005). Es represent errors in the measurement of observed variables, and Ds represent Disturbance (variance) in the latent traits (or factors). The above objectives were accomplished by evaluating the correlations between the latent qualities and their relevant indicators, as well as the maximum likelihood parameters of the proposed model.

The study answered the following research questions:

1) How do the indicators of each of the latent variables relate to one another?

2) Does the model match the data that was observed?

3) In the event that the model matches the actual data, which fit statistics apply?

4) What kind of factor loadings do each of the latent features have?

5) How well does the ability to reason mathematically predict arithmetic achievement?

METHOD

Participants

Two hundred and eighty (280) Senior Secondary One (SSI) students drawn from population of ten thousand, two hundred and eighty (10,280) from twelve (12) Senior Secondary Schools in the Taraba State, Nigeria participated in the study. The participants were randomly drawn from three (3) local government areas of Wukari, Donga and Ibi. The age of the participants ranges from 14-16 years (mean age = 15.20; standard deviation = 1.79). The participants are the enrolled in science classes. The whole science class (es) from each school were used. 151 (53.92%) boys and 129 (46.8%) girls made up the sample of 280 students.

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Materials

For this survey, two instruments were used. These are: Attainment in Mathematics Test (AMT) and Mathematical Reasoning Ability Test (MRAT)

AMT items were developed by Adegoke, 2013, using the three themes of mathematics: geometry, algebra, and number and numeration. The 36 items' content validity was determined using the test blueprint under Knowledge, Understanding, and Thinking. The discriminating indices were between 0.43 and 0.51, while the difficulty indices for each item varied from 0.38 to 0.75. Each section's reliability index was as follows: 0.71 for number and numeration, 0.76 for algebra, and 0.69 for geometry, using the Kuder Richardson 20 formula.

Also, MRAT was developed by Adegoke, 2013. It was developed by fusing the three main categories of materials used in mathematics education—spatial figures, algebraic symbols, and arithmetical numbers—with the fundamental processes of variable, class, order, and correspondence. It was designed in accordance with Lee's (1967) recommendation, a total of twelve subtests were created to assess the capacity for managing each of the four processes for each of the three categories of materials. Under each subtest, there are two items. Each item's difficulty and discriminating indices varied from 0.37 to 0.70 and from 0.30 to 0.57, respectively. Every section's reliability index fell between 0.69 and 0.81. The highest possible score in the MRAT was 24, meaning that every properly answered question received a score of 1, while incorrect answers received a score of 0.

Examples of item used in the MRAT include:

1. CLA-AN, or Classification-Arithmetical Number: There are five numerals on the left in each of the numerical rows. Of these, four are similar and one is not. Draw attention to the unique one. Once you've completed this, circle the number on the right that you believe would be the best to replace the one you underlined.

Left	**Right**
45, 54, 63, 27, 30	33, 36, 66, 93,

   Because 30 is not divisible by 9, it has been highlighted on the left side of this problem. As the only one of the four numbers on the right that is divisible by nine, 36 has been circled on the right.

2. The ROO-AN, or order-arithmetic number. Some numbers are missing from the following rows, which display the first few digits of a series of integers. Enter the numbers that you believe belong there in the empty areas.

   1, 3, 5, 7, 9, ---, ---

Procedure

This study used three research assistants. They were my colleagues at the department of Science Education, Federal University Wukari. Four weeks were spent gathering the data. All the examinations were given during the regular math period as listed on the official school schedule. This was to prevent any interference with the school's programme. Students took an hour to complete MRAT, although on average, they finished it in fifty minutes. Maximum Likelihood Estimates of LISREL Version 8.80 (Linear Structural Relations; Joreskog & Sorbom, 2003) were used to analyze the collected data.

RESULTS

LISREL Version 8.80 was used to produce the descriptive statistics, which include the mean, standard deviation, and Pearson Correlation coefficient. Additionally, statistics on variance-covariance were acquired.

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The Pearson product moment correlation coefficients between the variables are shown in Table 2. The table displays the mean and standard deviations for every one of the six variables.

Table 1: Variables

S/N	Symbol	Variable
1	Va	Variable
2	Cl	Classification
3	Or	Order
4	Re	Recognition
5	Nu	Number and Numeration
6	Al	Algebra
7	Ge	Geometry

Table 2: Pearson correlation coefficient, mean, and standard deviation

	Va	Cl	Or	Re	Nu	Al	Ge
Va	1.000						
Cl	.615*	1.000					
Or	.538*	.588*	1.000				
Re	.823*	.672*	.534*	1.000			
Nu	.846*	.789*	.550*	.697*	1.000		
Al	.578*	.811*	.801*	.612*	.611*	1.000	
Ge	.619*	.801*	.788*	.586*	.651*	.591*	100
Mean	6.51	6.01	5.40	6.98	6.95	5.55	6.54
SD	2.79	2.67	2.40	2.91	2.91	2.38	2.61

Note *$p<0.05$

Research Question One

How do the indicators of each of the latent variables relate to one another?

The core processes of variable recognition, class, order, and correspondence, as well as number and numeration, algebra, and geometry, were anticipated to be indications of mathematical reasoning ability in this study, as detailed in the parts that preceded it. Table 2 show that every variable has a moderate to considerable correlation with every other variable. Actually, a review of the correlations between mathematical reasoning

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ability and mathematics attainment on all the measures reveals that mathematical reasoning ability is a reliable indicator of mathematical attainment.

The strongest link (r =.846) is found between number and numeration and the ability to recognize variables in a particular content. Given the strong and positive correlation that has been found between number and numeration and variable recognition, it stands to reason that students who are proficient at identifying a constant variable among a set of numbers will perform well on tasks involving number and numeration. The identification of correspondences in a particular material and spatial figures have the lowest correlation (r =.534). The correlation coefficient in this study may seem low, but it is actually moderate and, more importantly, statistically significant. The variance-covariance statistics that were collected support the notion that there were strong and positive correlations between the mathematical achievement and numerical indicators.

Table 3: Maximum Likelihood Parameter Estimates of the Structural Regression Model

Parameter	Standardized Estimate	Unstandardized	Std Error	Z
		Factor Loading		
MR → Va	0.54	1.54	0.16	10.41
MR → Cl	0.79	2.15	0.13	16.31
MR → Or	0.78	1.89	0.14	15.99
MR → Re	0.32	0.92	0.13	06.45
AM → Nu	0.56	1.46	-	-
AM → Al	0.84	1.98	0.19	11.01
AM → Ge	0.79	2.0	0.20	10.98
		Measurement Error Variance		
E_{va}	0.68	5.68	0.51	12.41
E_{cl}	0.30	1.94	0.14	12.40
E_{or}	0.29	1.69	0.15	12.39
E_{re}	0.89	7.81	0.71	11.51
E_{nu}	0.71	5.68	0.49	12.31
E_{al}	0.35	1.78	0.16	12.01
E_{ge}	0.29	2.01	0.16	12.01

Research Question Two

Does the model match the data that was observed?

The independence model Chi square analysis, based on maximum likelihood estimates, indicates a correlation between the study's variables of $\chi2$ (13, N = 280) = 365.11, $p < 0.05$. The value of $\chi2$ (21, N = 280) = 621.51, $p < 0.05$, is the minimal fit function Chi Square. While the predicted model fit function Chi Square statistics should not be significant in a very excellent model fit scenario, examination of other fit indices revealed a satisfactory overall model fit.

Research Question Three

In the event that the model matches the actual data, which fit statistics apply?

The parsimony goodness of fit index (PGFI) = 0.51, the comparative fit index (CFI) = 0.75, the normal fit index (NFI) = 0.75, and the root-mean-square-error of approximation (RMSEA) = 0.35 with the 90% Confidence interval are among the model fit statistics that were looked at. In line with Hu and Bentler, 1999; Kline, 2005, these data show an overall excellent model fit.

Research Question Four

What kind of factor loadings does each of the latent features have?

The SR model that consists of two factors, namely Mathematical Reasoning Ability and Attainment in Mathematics, has its unstandardized and standardized maximum likelihood estimates reported in Table 3. As can be seen from Table 3 and Figure 2, nearly all of the factor loadings (standardized coefficients) fall between moderate (0.32, mathematical reasoning ability to recognition of correspondence among given materials) and high (0.79, mathematical reasoning ability to classification), which are both statistically significant (p <.05. For every example, the z-statistic is higher than 1.96. This demonstrates that mathematical reasoning ability may be reliably measured using the four indications of recognition of variable, class, order, and correspondence.

Research Question Five

How well does the ability to reason mathematically predict arithmetic achievement?

The calculated coefficient of 1.05 (z = 11.11) from Figure 2 indicates that mathematical achievement was rather well predicted by reasoning ability. According to the computed coefficient of 1.05, mathematical achievement rises by 1.05 units for every complete unit increase in reasoning ability.

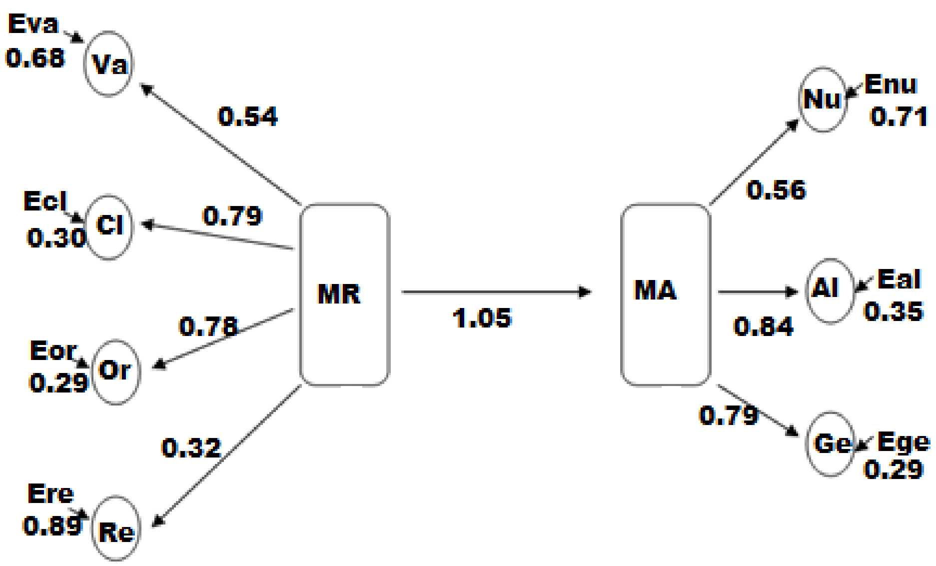

Figure 2: Standardized solutions of the hypothesized structural regression model

DISCUSSION

This study's objectives were to provide an explanation for the four fundamental markers of the mathematics reasoning ability exam and to create a model that would aid in the explanation of the connection between mathematical reasoning ability and secondary school mathematics achievement. The structural regression analysis's factor loadings demonstrated that the four basic concepts of mathematical reasoning abilities are the recognition of variables, categorization, order, and correspondence among the materials provided in mathematical problems. The result was in agreement with Adegoke 2013, Hamley, 1934 and Lee, 1967. Empirical data from Adegoke, 2003 and Heng-Yuku & Sllivan, 2000 also showed that mastery of the four processes of variable recognition, classification, ordering, and correspondence recognition are necessary for success in mathematics studies. This is due to the fact that these ideas are fundamental to mathematical work, where the majority of problems are resolved by classifying the data provided, arranging the classes in an ordered manner, and identifying patterns that lead to original conclusions.

Number and numeration, algebra, and geometry are reliable measures of mathematical achievement, as demonstrated by the factor loadings of the structural regression model.

Data analysis revealed that the two batteries of ability and achievement tests in mathematics were similar in that students' performance on the former seemed to predict their performance on the latter. This finding corroborates empirical evidence from Nunes, Byrant, Barros, and Sylva, 2012; Choudhury and Das, 2012; Heng- Yuku & Sullivan, 2000;). For instance, Nunes, Byrant, Barros, and Sylva (2012) found that mathematical reasoning ability did make independent contributions to the prediction of mathematical achievement. Similarly, Choudhury and Das (2012) found that geometrical ability contributed significantly to students' achievement. These results suggest that proficiency in the four processes of variable recognition, categorization, ordering, and correspondence recognition may be related to mathematical achievement. This is due to the fact that most mathematical problems include class recognition within given data, class ordering, and correspondence analysis to arrive at a unique solution. For this reason, these concepts are central to mathematical work. Arithmetical numbers, algebraic symbols, and spatial figures are examples of basic mathematics that require the capacity to perform these operations.

Implications of Findings and Recommendations

The results of this study demonstrated that a student's achievement in mathematics is significantly influenced by their level of mathematical reasoning abilities. Hence, it is imperative that educators acknowledge this and implement remedial initiatives that will enhance students' capacity for thinking.

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