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Discriminant analysis of mathematics achievement and problem-solving skills on gender of senior secondary school students

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Abstract
Researchers often use wrong approach to measure students' achievement and problem-solving skills as regards gender. This study examined if achievement in Mathematics and problem-solving skills could reliably discriminate between male and female students. Non-experimental design was adopted in this study. The population consists SS2 Mathematics students in Ibadan. Simple random sampling technique was used to select three local governments from eleven LGAs and eight public senior secondary schools from each. An intact class 520 SS2 Mathematics students were used as sample for the study. Mathematics Achievement Test (r=0.72) and Problem-Solving Skills Test (r=0.70) were used for data collection. Content validity of the instruments was established using Table of Specification of Mathematics Concepts while Kuder Richardson (KR_{20}) was used for reliability. Data was analysed using DA analysis in R4.2.2 software. Results reveal that Mathematics achievement is a potent and reliable discriminator between male and female students. Also, it was found that problem-solving skills do not reliably discriminate between male and female students. Therefore, it is important that researchers have proper knowledge of variables that could reliably discriminate between categorical dependent variables. Hence, cognitive scales should not be categorised and used as categorical dependent variable if the focus is on group discrimination.

***Keywords**:* Mathematics, Problem-Solving Skills, Gender, Discriminant Analysis

Introduction
Mathematics is an integral part of sciences and applicable to life in its entirety. In learning mathematics, observations have shown that most students memorise some computational concepts because they assume they are difficult, and this could hinder their ability to easily apply such concepts in solving the economic problems that confront them on a daily basis. This often makes them become unsure about the importance accrued to learning Mathematics. The teaching of Mathematics could help students understand its application to other subjects and improves their ability to solve real life problems. Students are also supposed to know how beneficial the learning of Mathematics is to the world of work. Mathematics is expected to model how real life problems could be solved based on the skills acquired in mathematics concepts.

Since formal education was introduced in Nigeria at about 1842, the teaching and learning of Mathematics is based on numeracy and computation such as arithmetic, algebra and geometry embedded in the school curriculum (Awofala, 2012). These subjects were taught in Nigeria as separate subjects in the past and each had different periods on the school time table. At present, they have been pulled together into a single subject called mathematics on the schools' time table. Mathematics teaching and learning with appropriate and functional curriculum has gone through several stages of reform and development in Nigeria and in most countries in the Sub-Saharan Africa (Mefun, 2018). The gaps observed in the pedagogy, assessment and implementation of the old curriculum from 1985 through 2011 necessitated the development of the new mathematics curriculum. For example, rote learning of computational skills which characterised the teaching of mathematics constituted a major problem in the old curriculum (Obioma, 2009; Awofala, 2010, 2012). The old curriculum which has six themes: number and numeration, algebraic process, mensuration, plane geometry, trigonometry, probability and statistics was restructured into five themes which are: number and numeration, algebraic process, geometry, statistics and

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introductory calculus to fill the observed gaps in the old senior secondary mathematics curriculum. However, it would be noteworthy to investigate whether the new curriculum with its emphasis on investment, stocks, shares and other mathematical concepts that were introduced could discriminate between male and female students in Mathematics.

Problem-solving skills could be based on some mathematical concepts that students are expected to be exposed to, implies students capacity to apply their cognition or provide on-the-spot solution to issues and challenges such as entrepreneurship, financial analysis (especially as it relates to the capital market) and investments. Students are expected to be able to proffer solutions to real life problems after being exposed to some mathematics concepts at the upper level of secondary education. According to Rohmah and Sutiarso (2017), the inability of the student to effectively absorb information, inadequate understanding of problem transformation, incomplete comprehension of the subject matter, weak understanding of the idea of a prerequisite, lack of prior experience in solving problems as well as carelessness and sloppiness in the construction process are some of the factors that contributes to errors in solution to mathematical system of linear equations that involves two variables. More so, it was found that there are two factors that often prevent students from giving the correct answers, the first is the issues with verbal fluency and conceptual understanding while the second is the issues with numerical processing ability (Rohmah & Sutiarso, 2017). In other words, students who have low ability need to adopt a plan of solving problems. According to the National Council of Teachers of Mathematics (NCTM) (2000), it was established that solving problems is not only the goal of learning mathematics. In other words, it is an integral part of mathematics and not an isolated piece of the mathematics concepts which students require frequent opportunities to formulate, grapple with, and solve complex problems that involve a significant amount of effort. This implies that students are expected to be able to reflect on their thinking during the problem-solving process such that they can apply and adapt the strategies they develop to other problems and in other contexts.

Important cognitive domains that are key in mathematics to improve students' problem-solving skills includes: knowing, applying and reasoning. Knowledge application is a major component of problem solving which implies students' ability to apply knowledge and conceptual understanding in problems. For example, it was established that to successfully solve routine problems and reasoning implies the ability to solve unfamiliar or non-routine problems (Mullis et al, 2012). Therefore, in order to tackle some difficulties, knowledge must be transformed. According to Rajkumar and Nachimuthu (2019), students' problem-solving skills should be looked into in order for them to be able to handle real-world situations and offer answers for academic or life-related issues at different educational levels. In other words, if knowledge is contextualised, student could understand where, when and how to apply such knowledge making it problem-based learning. This would be in line with the recommendations of principles and standards in a statement by the National Council of Teachers of Mathematics (2000) in the United States and the third principle of teaching which requires that teachers understand the extent of what students know, need to learn, then challenge and support them to learn well. Schooling is expected to be relevant to settings outside itself. In other words, it is required that account of how learning from the school can be applied in, or transferred to other contexts be envisaged. The transfer of learning in general means the use of knowledge gained in a context be applied to another which could be done in several forms such as: use of mathematics knowledge outside the school domain like in economics, finance, physics, world of work among others.

In a study conducted by Charles-Ogan et al. (2017) on effects of mathematics knowledge on chemistry students' academic performance in gas law in Ignatius Ajuru University demonstration secondary school, found a significant difference in the mean performance of Mathematics high and low achievers in Chemistry. While this has been a nomenclature

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in differentiating between groups using the same construct for the categorization of high and low achievers which may not reliably depict a true picture of the result with analysis of variance. In a study on association between students' problem-solving abilities and their academic achievements at Birjand University of Medical Sciences, Raeisoon et al. (2018) discovered a favourable correlation between students' problem-solving abilities and academic achievement. However, there might be the need to further examine the import of the favourable relationship between students' problem-solving abilities and academic achievement on a categorical dependent variable. According to Arifin (2019) in a study on analysis of problem solving ability based on cognitive style in problem based learning model with diagnostic assessment found that students have a significant effect on the tendency to develop problem-solving skills when problem-based learning model with diagnostic assessments are used. According to a Joshi and Sheela (2020) study, one of the most important responsibilities of the teacher in the modern teaching style is thinking development and instruction. Bintoro et al. (2021) looked at whether students' problem-solving abilities before and after ICT-based lesson studies differed in the mathematics education study program at Universitas Muria Kudus. The results showed that using information and communication technology-based lesson study improved students' ability to solve mathematical problems. There is no doubt that these studies have provided a form of findings or the other. The concern is particularly about the use of these variables which are often in continuous scales being used to predict some categorical dependent variables in order to have a reliable discrimination between such variables.

Diah et al., (2023) investigated analysis of problem solving ability in view of self-confidence in a problem based learning model on blended learning with diagnostic assessment to improve problem solving ability. The study considered the use of problem based model with diagnostic assessment as a way of improving problem solving ability because it was effective in increasing problem- solving ability of students with high self-confidence in problem-solving abilities to understand context of the problem, design a solution to solve the problem, solve the problem and review it. The impact of technological skills on problem-solving abilities was found to be positively and significantly correlated with academic achievement, whereas the relationship between academic achievement and problem-solving abilities was found to be largely insignificant (Alsarayreh, 2023). Nonetheless, it was shown that academic achievement could bolster the beneficial association between acquiring technology capabilities and refining problem-solving abilities. Bayarcal and Tan (2023) in a study on achievement of students in mathematics and problem-solving skills through Open-Ended Approach (OEA) among the Grade 8 students shows that students exposed to OEA had significantly better problem-solving skills than students exposed to non-OEA.

However, one would expect a further investigation that would determine if problem-solving skills could discriminate between female and male students in Mathematics. Learners seem to be unable to transfer problem-solving skills to new situations which could hinder their ability to create their own jobs and solve real life problems. This gap could also affect learners' performance adversely. In the context of this study, problem-solving skills is conceptualised as some real life situations that pertain to the different sectors of the economy of the nation (such as entrepreneurship, financial analysis of the capital market and investments) to which students are expected to provide on-the-spot solutions. This was quantified through students' performance in the problem-solving skill test.

The concept of gender discrimination where a set of continuous predictor variables that could predict a categorical variable is not obvious in the literatures compared to when gender is being used as a predictor or moderating role in a study which in most cases does not conform with assumptions of using some statistical tools. The term gender could be referred to as the natal distinction between two beings which cannot

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change. Another definition of gender is the variety of genetic, behavioral, physical, and mental traits that relate to and distinguish between the male and female populations (Adigun et al., 2015). It was found that girls performed better than boys in reading scores, top GPA distribution in high school, and college attendance, according to studies conducted in the US and a few other industrialised nations (Fortin, et al., 2015). The global occurrence of women outperforming men in academic pursuits prompts further inquiries into the reasons behind this inequality. For instance, is it just a coincidence that most of elementary and secondary school instructors are females during the times when women were supposed to accomplish more and behave better than men?

Christine (2015) claims that gender prejudice causes boys to participate more actively in the teaching and learning process in the classroom than girls do. Research conducted worldwide on students studying at varying levels revealed a noteworthy disparity in academic achievement across genders. According to a study by Eshetu (2015), there was no statistically-significant difference in average result and subject-wise analysis between male and female students in regional examinations. Similarly, Goni et al. (2015) found no discernible gender difference in academic performance among college-bound students in their study. Even though girls were less engaged in classroom interactions during teaching and learning than boys, a different study by Fatokun and Omenesa (2015) found no discernible variance in gender difference on academic attainment. Stated differently, this suggests that pupils of any gender could attain excellent academic results. Nnamani and Oyibe (2016) found that male post-primary students had a poorer mean academic success score than female students in their study of gender and academic accomplishment of secondary school students in social studies. According to Faisal et al. (2017), there is no discernible gender difference in the academic performance on multiple choice and short essay problems.

Put differently, gender pertains to the obligations, positions, prospects, limitations, and requirements of both men and women in every facet of the social environment (Filgona & Sababa, 2017). The writers also mentioned that, regardless of gender, male and female students can receive the same treatment when it comes to instruction and learning, as well as similar opportunities, levels of encouragement, and involvement. According to Palt (2018), gender diversity must be prioritized and women's contributions to the development of scientific solutions to local problems must be acknowledged by African nations. According to Adeyemi et al. (2019), depending on the subculture of the group, the influence of peer groups can have either beneficial or detrimental effects on male and female students' academic achievement. Further research on gender disparities is therefore necessary because it is becoming more and more obvious that male children are threatened in educational institutions across the globe (Mwihia, 2020).

Thus, the perception that science-based courses are preserved for males was found to indirectly affect females' interest and performance in subject, especially at the senior secondary school level (Workman & Heyder, 2020). A major intriguing explanations on disparity between gender and learning outcomes relates to the dynamics of students interaction with their teacher. While studies on gender difference have been much on use of mean and standard deviation as well as t-test measures to establish if there are gender differences. This study advance a paradigm shift by investigating the discriminant role of mathematics achievement and problem-solving skills with respect to gender. More so, the senior secondary curriculum was developed to improve the quality of teaching and learning of Mathematics and problem-solving skills that could ensure that male and female learners are able to solve real life problems within and outside the walls of the classroom. Based on the foregoing, the trend of transferring mathematical knowledge of concepts e.g. number and numeration, algebraic process, geometry and statistics among secondary school students based on gender has not sufficiently been differentiated. Previous studies have found that the ability level of students in any subject is a function of their performance in such subject. However, in spite of this, a clear category of which gender could be favoured in solving everyday life challenges in

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the different sectors of the economy still persists among senior secondary school students which could also not exclude the inappropriate statistical techniques required to establish such differences. It is against this background that this study sought to adopt the use of discriminant analysis (DA) to investigate if mathematics achievement and problem-solving skills could reliably discriminate between males and females of senior secondary school students in Ibadan, Oyo State.

Research Questions

1. Which of the predictor variables do male and female significantly discriminated?
2. Do Mathematics achievement and problem-solving skills reliably discriminate between female and male students in Oyo State?

Methodology

The study adopted non-experimental design of correlational type. This design was chosen because there was no manipulation of variables, rather, the extent to which the predictor variables predict the outcome variable was assessed. The study population comprises Senior Secondary (SS) 2 Mathematics students in Local Government Areas in Ibadan metropolis, Oyo State. Simple random sampling technique of open ballot without replacement was used to select three LGAs (Ibadan North, Ibadan North West, and Ibadan South West) from the eleven LGAs in Ibadan and twelve public senior secondary schools (4 from thirty-six in Ibadan North, 4 from thirteen in Ibadan North West and 4 from thirty in Ibadan South West) with an intact class from the arms of classes of SS 2 Mathematics students were selected from each school. In all, a total of five hundred and twenty (520) students formed the sample of the study.

Two instruments were used for collection of data: Problem-Solving Skills Test (PSST) and Mathematics Achievement Test (MAT). The PSST was developed to elicit information from the students on their level of solving economic problems using simulated real life situations from different sectors of the economy: oil and gas, financial, health, agriculture and other service- rendering sectors. A total of 20 items were selected for the study from the pool of 25 items developed. The instrument consists of two sections A and B. Section A sought students' demographic data on school, location and gender. Section B has 20 items which has to do with themes/topics learnt in SS 2 Mathematics and the use of its skills to solve real life problems in immediate environment. The section has option format where students are expected to indicate the topic from which each item (problem) is drawn and the procedure with which the item (problem) can be solved. Content validity was ensured by drawing up a table of specification using the topics covered in the SS 2 Mathematics curriculum that are related to real life situations using scenarios. It was also given to mathematics teachers who are SSCE examiners and experts in scale development to ascertain the face validity. The instrument was thereafter trial-tested on a smaller sample of students that were similar but not part of those used for the study to establish its psychometric properties using difficulty index ($0.3 \leq P \leq 0.5$) and discrimination index of ($D \geq 0.3$). This was also used to determine the good/bad items. The reliability of the items internal consistency was estimated using Kuder Richardson (KR_{20}) which yielded $r = 0.70$.

The MAT is an achievement test used to quantify the performance of students in identifying and grasping the fundamental notions required to learn and apply mathematics concepts and procedures. The instrument was developed by the researcher with a pool of 60 initial items with four options lettered A, B, C and D drawn from the topics in the SS 2 mathematics curriculum. This gave a total of forty (40) multiple-choice items for the final instrument. The instrument consists of two sections, A and B. Section A sought students' demographic data on school, location and gender while section B consists of items that determined the extent of students' knowledge of concepts learnt in SS 2 mathematics topics. To ensure the validity of the instrument, it was given to mathematics teachers who are SSCE examiners to and experts in scale development ascertain the face validity. Content validity was ensured by drawing up a table of specification using the SSS 2 topics. The instrument was thereafter trial-tested on a

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smaller sample of students that were similar but not part of those used for this study to establish its psychometric properties using difficulty index ($0.3 \leq P \leq 0.6$) and discrimination index of ($D \geq 0.3$). This was also used to determine the good/bad items. The reliability of the items internal consistency was estimated using Kuder Richardson (KR_{20}) which yielded r = 0.72.

The approval to conduct the research was sought and obtained from the relevant secondary school heads in Ibadan. Informed consent of the participants was also sought (by informing them the purpose of the study) before the administration of the instruments. The administration lasted for 4 weeks after which the instruments were retrieved for analysis. Data was analysed using linear discriminant analysis package in R.2.2 and Rstudio 12.0. This technique is more appropriate because of its ability to discriminate correctly using continuous variables to predict two or more categorical dependent groups.

Results

Research Question 1: Which of the predictor variables do male and female significantly discriminated?

Table 1: Box's M Test for Homogeneity of Group Means

Box's M: Chi-Sq (approx.) = 16.864 df1 = 3 Sig. = 0.001					
Tests of Equality of Group Means					
	Wilks' Lambda	F	df1	df2	Sig.
Achievement in Mathematics	0.367	894.503	1	518	0.000
Problem Solving Skills	0.999	0.735	1	518	0.392

Box's M Test for equality of covariance matrices examine the assumptions of linearity and test of equality of group mean of predictor variables obtained from the discriminant analysis. The result of Box's M test presented in Table 1 shows that the data meet the linearity assumptions and that there is equal variance between the groups with Box's M value of Chi-Sq (approxi.) = 16.864; p value = 0.001. This implies that the groups are homogenous and analysis can be carried out. Also, the equality of group mean of the predictor variables in Table 1 shows that at the df = 1, 518, the F-ratios and p-values revealed that achievement in Mathematics (F = 894.503, p = 0.000, λ = 0.367) differ significantly in the mean score between male and female while problem-solving skills does not differ significantly in the mean score between male and female (F = 0.735, p = 0.392, λ = 0.999). This was also evident as problem-solving skills value of Wilk's Lambda is closer to 1. This implies that the achievement in Mathematics discriminates between male and female significantly.

Research Question 2: Do Mathematics achievement and problem-solving skills reliably discriminate between male and female students?

Table 2: Descriptive Statistics of Mean and Standard Deviation of Mathematics Achievement and problem-solving skills by Gender

Predictor Variables	Male		Female		Total		Remark
	Mean	SD	Mean	SD	Mean	SD	
Achievement in Mathematics	15.25	2.86	23.65	3.51	19.45	5.28	**
Problem Solving Skills	15.73	1.71	15.81	0.99	15.77	1.07	*

*N for male = 261 (50.2%); N for female = 259 (49.8%); N for total = 520; *= Not reliably discriminate; **= reliably discriminate*

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Table 2 presents the descriptive statistics of mean and standard deviation of the predictors of male and female students. Below the table are the frequency and percentage distribution of the study sample which shows that there are more males (N= 261; 50.2%) than females (N= 259; 49.8%) from the study sample. Comparing the means of the predictor variable (achievement in Mathematics), it is very clear that there are mean differences in the predictor variable under the categories (male and female) as well as the total average mean. The means of the achievement in Mathematics were ($\bar{x}$= 15.25, 23.65 and 19.45 for male and female and the overall total respectively. The finding implies that the means of the two groups are reliable to discriminate between the two groups as their means are greater or lower than the overall average mean. In other words, the ability of a predictor variable to discriminate between the two groups is denoted by double asterisks (**). Hence, achievement in Mathematics is a reliable discriminator of gender in favour of female students.

Moreover, comparing the means of the predictor variable (problem solving skills), it could be observed that there were no convincing means differences in the predictor variable under the categories (male and female) as well as the total average mean. The means of the problem solving skills were ($\bar{x}$ = 15.73, 15.81 and 15.77 for male and female and the overall total respectively. The finding shows that the comparison of the two group means was not really greater or lower than the overall mean. In the remark column, the asterisk * denotes that the predictor variable does not reliably discriminate between the two groups. This result implies that problem-solving skills cannot be used to reliably discriminate between male and female students in Mathematics.

Discussion of Findings

The finding from this study revealed that achievement in Mathematics was found in this study to be the strongest and reliable predictor that can discriminate between male and female students in Mathematics. This finding contradicts that of Fatokun and Omenesa (2015), who found no significant relationship between gender differences and academic achievement. They based their findings on the assertion that students can perform better academically regardless of gender status and that girls were less engaged in classroom interactions during teaching and learning than boys. The results of this study also contradict those of Christine (2015), who discovered that boys are more engaged in the teaching and learning process in the classroom than girls due to gender prejudice. Similarly, this study's results contradict those of Eshetu (2015), who claimed that there was no statistically significant difference between male and female students' regional examination results in terms of average score and subject-specific analysis. According to Goni et al. (2015), it was found that there is no noticeable gender gap in the academic achievement of the pupils. In their study, Faisal et al. (2017) discovered no statistically significant variation in the academic achievement of gender for both multiple choice and short essay problems.

It could be that these studies have not really adopted the appropriate statistical techniques that could sufficiently revealed the group that is significant in relation to Mathematics achievement of male and female as abilities of the group differs. Although the finding of this study corroborates that of Nnamani and Oyibe (2016) who demonstrated that in post-primary school, male learners mean academic achievement scores were lower than those of female learners. Considering the sample differences between the study and this present study, using discriminant analysis could make this directional and in favour of the appropriate group.

The finding from this study on proble-solving skills revealed that problem-solving skills do not reliably discriminate or predict between male and female students in Mathematics. This finding could be revealing an obvious fact because having a high or low problem solving skills might influence achievement of male and female students but this might not really imply that male or female student who does not possess sufficient problem solving skills would not perform better in Mathematics but could only

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lack the abilit to transfer such skills to other fields. The finding of the study agrees with Omoniyi (2016) who found that there was no significant difference in the performance of female and male students after being exposed to problem solving approach of teaching students the mole concept. Similarly, the finding of this study corroborates Sinaga et. al. (2023) who found that gender has no influence on students' mathematics problem-solving understanding. However, the finding of this study negates that of Yuyun et. al. (2020) who found that average result of male students was less than the female student problem-solving skill in the test. The finding also disagrees with Özeren (2023) whose study found that problem-solving and 21st-century skill levels of secondary school students differ significantly by gender. It would be of essence to also use discriminant analysis to predict group difference if the focus is on categorical dependent variable as it gives a reliable discriminating results.

Implications of the Study

This study has found out that achievement in Mathematics can predict reliably the differences between male and female students while problem-solving skills do not. This has shown that for researchers to accurately measure group differences, the use of discriminant analysis is apt.

Conclusion

This study on the using of discriminant analysis has shown that one might have proper understanding of the predictor variables that can reliably discriminate between categorical dependent variables. The result of this study revealed that achievement in Mathematics reliably discriminate or categorically predict gender difference in the subject in favour of female students. It was also found that problem-solving skills are not a potent predictor between male and female students.

Recommendations

The study recommends that:

1. Researchers should use discriminant analysis for studies that involve prediction of two or more categorical dependent variables.
2. Cognitive scales should not be categorised and used for categorical dependent variable if the focus is on discriminant analysis.

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