Relative Effectiveness of Polya's Problem Solving and Algebraic Games Methods on Secondary School Students' Achievement in Algebra in Onitsha Education Zone

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Abstract
The study investigated the relative effectiveness of Polya's problem solving and algebraic games methods on secondary school students' achievement in algebra in Anambra state. Two research questions and three hypotheses guided the study. Quasi-experimental design was adopted. The population of the study comprised 5,562 senior secondary two (SS2) students offering mathematics in Onitsha Education Zone, from which 102 students were drawn using purposive and random sampling techniques. The instruments for data collection were Mathematics Achievement Test on Algebra (MATA) validated by three experts. The reliability of MATA was established using Kuder-Richardson Formula 20 which yielded a coefficient of internal consistency of 0.77. Research questions were answered using mean and standard deviation whereas analysis of covariance was used to test the null hypotheses. The findings from the results of the study showed that; students taught algebra using PPSM had higher mean gain achievement scores than those taught using AGM and the observed difference in their mean gain score was significant. It was therefore recommended among others that seminars and workshops should be organised for secondary school mathematics teachers by school administrators on the instructional methods of polya's problem solving method (PPSM) and algebraic games method (AGM) with a view to have them master their usage in teaching mathematics.

Keywords: *Algebra, Polya, games, Achievement, Problem-solving*

Introduction

Mathematics provides an efficient means of building mental discipline and it supports logical reasoning and mental rigor. It encourages logical and critical thinking, innovative ideas, abstract or spatial intelligence, problem-solving ability, and effective corporate communication. Despite the importance of Mathematics, students' achievements in the subject over the years have not improved significantly. This is evident in the Chief Examiners reports of most external examinations written in Nigeria of which the West African Senior School Certificate Examination (WASSCE) is the most prominent. Analysis of WASSCE in 2015 and 2016, revealed that 38.68% and 52.97% of students registered, correspondingly passed Mathematics at credit level, while 59.22% of students passed Mathematics in 2017. The percentage of students who passed dropped significantly in 2018, given that 49.98 passed the examination as compared to the 59.22% candidates who passed the examination

in 2017. There was a considerable increase in the number of students (64.18%) who passes Mathematics at a credit level or higher in 2019. By 2020, there was another significant drop, where only 39.82% of the students passed Mathematics at a credit level. However, in 2021, 81.7% of the candidates passed at credits level and above.

Many reasons have been advanced for students' inconsistent performances and poor achievement in internal and external Mathematics examinations. The reasons, according to Woji and Charles-Organ (2022) include a shortage of Mathematics teachers, students' attitudes toward the subject, Mathematics phobia, lack of teaching and learning tools, and inexperienced teachers. Students' attitudes, teachers' attitudes, teaching methods, classroom environment, gender stereotypes, and parental influences have all been found to influence students' achievement in Mathematics (Njoku and Okigbo, 2020). Yet, to Ogoke and Okigbo (2021), the main reasons for Mathematics being a challenging subject for students is because students lack the prerequisite knowledge for studding the subject and are always afraid of it. Students' reluctance to seek help from others, inattention in the classroom, and a lack of motivation were also cited as factors in students' difficulty in learning Mathematics (Okeke and Okigbo, 2021).

Certain areas in mathematics appear difficult for students due to its abstract nature and complexity of calculations associated with it. Some of those concepts include: Circle theorem, longitude and latitude, logarithm, probability and word problems in mathematics. Okigbo and Ejikeme (2017) also identified algebra as one of the areas which Mathematics teachers and students find difficult to teach and learn respectively. According to WAEC Chief Examiner's (2021), students lack proper understanding of the concept of algebra branch of Mathematics. Algebra, according to Jesy (2022) is a branch of Mathematics that deals with symbols or variables and uses arithmetic operations to find the unknown quantities represented by these variables. It is a branch of Mathematics dealing with symbols and the rules for manipulating those symbols. The basics of algebra according to Okeke and Okigbo (2021) include numbers, variables, constants, expressions, equations, linear equations, quadratic equations. Further, it involves the basic arithmetic operations of addition, subtraction, multiplication, and division within the algebraic expressions.

The importance of the concept of algebra to Mathematics learning cannot be over-emphasized. This is because, algebra is not just a mathematical concept, but a skill that all of us use in our daily life without even realizing it (Iyoke, 2015). Understanding algebra as a concept is more important than solving equations and finding the right answer, as it is useful in all the other topics of Mathematics that students will learn in the future or have already learnt in the past. The arithmetic operations of addition, subtraction, multiplication, and division help us solve mathematical problems. Algebra according to Jesy (2022) deals with these concepts and can be considered as generalized arithmetic. Thus, students' poor understanding of the algebra and its broad areas and application could be a contributory factor to their poor academic achievement in general Mathematics. To address these problems therefore, there is need to adopt instructional strategies like problem-solving approach and games methods that facilitate proper understanding of the concepts and ensure students' active engagement during learning process.

There are different strategies of problem solving such as Justin (2014) problem-solving strategy, and Wood (1975) problem solving strategy and Polya's problem solving among others which has been shown to be effective. However secondary school teachers do not these specific problem-solving strategies especially the Polya's problem solving which is a type of problem solving strategy that may be very suitable for teaching and learning of algebraic concepts. Polya's problem-solving method was created by George Polya in 1945 and was designed as a four-step method to solve all kinds of problems. The steps are that students need to: (i) understand the problem, (ii) make a plan, (iii) execute the plan, and (iv) look back and reflect. Understanding the problem, Okafor (2019) noted, requires that the teacher uses some questions to guide the students into understanding

the problem they are to solve. Making a plan, is to develop strategies or steps or procedures required to solve the problem. Executing the plan requires that students apply the plans in solving the problem while looking back and reflecting on the plans, as a necessary check to errors that may arise from using it (Okafor, 2019). Because the method is simple and generalizes well, it has become a common problem solving strategy adopted by teachers in many subject areas including mathematics. Although, studies and literatures have established the positive effect of the method on students' achievement, there is no in-depth understanding of its effects on secondary school students' academic achievement in algebra specifically, which can be taught using game-based method.

. Game-based method, according to Asanre, Abiodun, Odupe and Ogendeji (2021) is a kind of instructional activity, which integrates games into teaching for instructional goals. There are several games method of teaching such as board games, card games, words games, video games, simulations, role-play games and puzzles. One of the advantages of using games, as a teaching strategy, is that students have the opportunity for immediate feedback, through the discussion of correct answers and their rationales. However, the games method also have a disadvantages which include distraction to the students, and those who could not engage in the critical thinking required in games may switch to rote learning and may not be actively engaged in the learning process and this effect could happen across the students' gender. Although, there have continued to be discrepancies in research findings on influence of gender on achievement, in some studies, significant differences in mathematics achievement were found between male and female students (Abonyi, Maduagwuna and Ugama, 2014).

In some other studies however, no significant difference was found in male and female Mathematics achievement (Nneji, 2013; Chiakwelu and Okigbo, 2020; Chiakwelu, 2021). Specifically in algebra, Okpube and Anugwo (2016) and Ali (2015) found significant differences in male and female students' achievement whereas Iyoke and Anaeche (2019) found no significant differences. There are barely any studies however, that have established conclusively the gender differences and gaps as regards secondary school students' achievement in specific Mathematics concepts like algebra.

Purpose of the Study

The purpose of the study was to determine the relative effectiveness of polya's problem-solving and algebraic games methods on secondary school students' achievement in algebra in Onitsha Education Zone. Specifically, the study sought to determine the:

1. mean achievement scores of students taught algebra using Polya's problem solving method (PPSM) and those taught using algebraic games method (AGM).
2. mean achievement scores of male and female students taught algebra using PPSM and AGM.
3. Interaction effect of instructional methods (PPSM, AGM) and gender on students' achievement in algebra.

Research Questions

1. What are the mean achievement scores of students taught algebra using Polya's problem solving method (PPSM) and those taught using algebraic games method (AGM))?
2. What are the mean achievement scores of male and female students taught algebra using PPSM and AGM?

Hypotheses

1. There is no significant difference between the mean achievement scores of students taught algebra using Polya's problem solving method (PPSM) and those taught using algebraic games method (AGM).
2. There is no significant difference between the mean achievement scores of male and female students taught algebra using PPSM and AGM.

Method

The study was conducted using quasi-experimental design, specifically with the pretest-posttest non-randomized control group design. The area for the study was Onitsha Education Zone of Anambra state, Nigeria. The study is made up of 5,561 (2,448 males, 3,113 females) SS2 students offering Mathematics in the Onitsha Education. The sample size for the study is 99 SS2 students offering Mathematics in Onitsha Education Zone of Anambra State. The sample was obtained using a multi-stage sampling procedure. In the first stage random sampling was used to select two local government area in Onitsha Education zone. Two co-educational schools were selected purposively in each of the two local government areas to take care of the gender variables and to prevent subject contamination. Secondly, using random sampling (balloting without replacement), the two selected schools is assigned to experimental groups one and experimental group two. In the third stage which is the final stage, one intact class of SS2 students offering Mathematics is chosen in each of the schools using simple random sampling. The experimental group one has 52 students (23 males and 29 females) and experimental group two has 47 students (22 males and 25 females).

MATA comprised of 50 objective test items drawn from the concept of algebra in Mathematics. It has four response options lettered A-D. The questions were taken from past West African Examination Council (WAEC) question papers from 2012-2022 in order to make sure that they are standardized. In order to ensure that adequate number of questions is covered from each unit area taught, a Table of specification was used to determine the number of questions from each unit area. Each question correctly answered will earn the student 2 marks. Lesson plans for the two experimental groups on the two different methods (PPSM and AGM) were developed by the researcher.

Experts from the Department of Science Education, and Department of Educational Foundations (Measurement and evaluation), Nnamdi Azikiwe University, Awka and Department of Science (Mathematics option), Federal College of Education (Technical), Umunze validated MATA. The reliability of MATA was established using Kuder-Richardson Formula 20 (KR-20). KR-20 was chosen for MATA because it is suitable for determining the internal consistency of dichotomously scored instruments in objective format. KR-20 yielded a coefficient of internal consistency of 0.77.

In the PPSM group, the teachers introduced the lessons first and further proceeded to teaching the students by solving problems related to the introduced topic and have students solve the similar problem by following four general steps. The steps required students to identify the main idea, details, and process used, as well as solve for a calculation. The purpose of the first step is that students understand the problem. In this step, the student is a reader, a thinker, and an analyzer. First, the student reads over the problem and finds or establishes what the problem is under the guidance of the teacher. Students were allowed to ask as many questions as possible to clear any confusion and to see if the question now makes sense. When the student identifies the main idea, they were required by the teacher to write it down, using mathematical notation or words or phrases that helps them best describe what is to be solved. The teacher asked such questions as: What is the main idea in the question of this problem?; What are we looking for? x or y?; What do we want to find out?

In the second step, the teacher led the students to read the problem again, slowly and carefully in order to identify and records any details, using numbers, words, and phrases and determine reasonable ways to solve the problems. The teacher guided the student to look for extra information, that is, facts that do not figure into the answer. The student were required also to look for hidden numbers, notations, exponents, letters, equal to signs which may be indicated but not clearly expressed. The teacher asked the students the following kinds of questions: What are the details needed to answer the question?; What are the important details?; What is going on that can help me answer the question?; What details do you need?

The teacher modelled and guided the students to chose a mathematical strategy to find a solution to the problem and uses that strategy or plan to find the answer/solve the problem. In order to carry out the plans in the strategy found out, the teacher required the students to do the following: use or draw a picture; look for a pattern such as similar letters (x, y, xy); write a number sentence; use actions (operations) such as add, subtract, multiply, divide; make or use a table; make or use a list; work a simpler problem; work backwards to solve a problem; and recall the laws of indices. The teacher further asked questions such as: What are we going to do to solve this problem?; What is our strategy?; and What can we do with the details to get the answer?

To make sure that their answer is reasonable and that they understood the process clearly, the teacher requested the students to use words or phrases to describe how they solved the problem. This is to ensure that students look again at the solutions and make corrections where necessary and confirm its correctness. The teacher asked the students such questions as the following: How did you solve the problem?; What strategy did you use?; and What were the steps? In this step, students explained the solution strategy they have selected. They provided reasons for and offer proof of the soundness of their strategy. This step gave students the opportunity to communicate their understanding of Mathematics concepts and Mathematics vocabulary represented in the problem they solved and to justify their thinking.

In AGM group, students in the classroom were clustered in groups of fives. The teacher first introduced the lesson, solve one or two problems. The teacher shuffled a pack of cards containing algebraic expressions which are the step by step solutions to questions. The teacher gave to each group a set of cards at random. When a question is posed by the teacher, she calls on each group at random to find a card that is a correct answer to the step in the solution of the question being solved. Group members were required to first solve the question and find from their cards each step to the solution, so that when called, they can easily present the step. The teacher at the end of each lesson presented a general summary of all the important points of the lesson and gave students class exercise to solve individually as a mean of evaluating the objectives of the instruction.

MATA and MIIA were given to students in the first week before treatment. The students did not receive any feedback or revisions. After four weeks of treatment, MATA and MIIA were administered as a post-treatment test on a different colour of paper with reshuffled serial numbering. The researcher graded the students' performance and organized the scores for data analysis. The research questions were answered using mean and standard deviation. The null hypotheses will be tested using Analysis of Covariance (ANCOVA) at 0.05 alpha level. The null hypothesis was rejected if the probability value (p-value) is less than or equal to the significant value of 0.05 ($P \leq 0.05$), while the null hypothesis was not rejected where P-value is greater than 0.05 ($P > 0.05$).

Results

Research Question 1: What are the mean achievement scores of students taught algebra using Polya's problem solving method (PPSM) and those taught using algebraic games method (AGM)?

Table 1: Mean Achievement Scores of Students taught Mathematics using Polya's Problem Solving Method (PPSM) and Algebraic Games Method (AGM)

Group	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Gained Mean
PPSM	52	30.98	8.83	68.31	13.73	37.33
AGM	47	29.57	11.37	63.43	11.03	33.86

Table 1 shows that students taught Mathematics using Polya's Problem Solving Method (PPSM) had higher gained mean achievement score of 37.33 than those taught using AGM with mean gained achievement score of 33.86.

Research Question 2: What are the mean achievement scores of male and female students taught algebra using PPSM and AGM?

Table 2: Mean Achievement Scores of Students Male and Female Students taught Mathematics using PPSM and AGM

Method	Gender	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Gained Mean
PPSM	Male	23	30.61	7.04	74.57	10.65	43.96
	Female	29	31.28	10.15	63.34	14.01	32.06
AGM	Male	22	30.00	12.26	59.55	8.12	29.55
	Female	25	29.20	10.77	66.84	12.23	37.64

Table 2 shows that the male students taught Mathematics using PPSM had higher gain in mean achievement scores (43.96) than the females with gain in mean achievement scores of 32.06. Table 2 also reveals that the male students taught Mathematics using AGM had low gain in mean achievement scores (29.55) when compared to the female students with gain in mean achievement scores of 37.64.

Hypothesis 1: There is no significant difference between the mean achievement scores of students taught algebra using Polya's problem solving method (PPSM) and those taught using algebraic games method (AGM).

Table 3: ANCOVA Test of Significance of Difference between the Mean Achievement Scores of Students taught Mathematics using PPSM and AGM

Source	SS	df	MS	F	Sig.	Decision
Corrected Model	2912.445[a]	4	728.111	5.314	.001	
Intercept	46248.357	1	46248.357	337.513	.000	
Pretest	86.474	1	86.474	.631	.429	
Methods	844.742	1	844.742	6.165	.015	Sig.
Gender	94.909	1	94.909	.693	.407	Not Sig.
Methods * Gender	2064.058	1	2064.058	15.063	.000	Sig.
Error	12880.545	94	137.027			
Total	446905.000	99				
Corrected Total	15792.990	98				

Table 3 shows that there is a significant main effect of the treatment on students' achievement in Mathematics, $F(1, 94) = 6.165$, $P < 0.05$. Therefore, the null hypothesis is rejected meaning that there is a significant difference between the mean achievement scores of students taught algebra using Polya's problem solving method (PPSM) and those taught using algebraic games method (AGM) in favour of those taught using PPSM.

Hypothesis 2: There is no significant difference between the mean achievement scores of male and female students taught algebra using PPSM and AGM.

Table 3 shows that there is no significant main influence of gender on students' achievement in Mathematics, $F(1, 94) = 0.693$, $P > 0.05$. Therefore, the null hypothesis was not rejected meaning that there is no significant difference between the mean achievement scores of male and female students taught algebra using PPSM and AGM.

Hypothesis 3: There is no interaction effect of instructional methods (PPSM, AGM) and gender on students' achievement in algebra.
Table 3 also shows that there is a significant interaction effect of instructional methods and gender on students' achievement in algebra, F (1, 94) = 15.063, P < 0.05. Therefore, the null hypothesis was not rejected meaning that there is a significant interaction effect of instructional methods (PPSM, AGM) and gender on students' achievement in algebra.

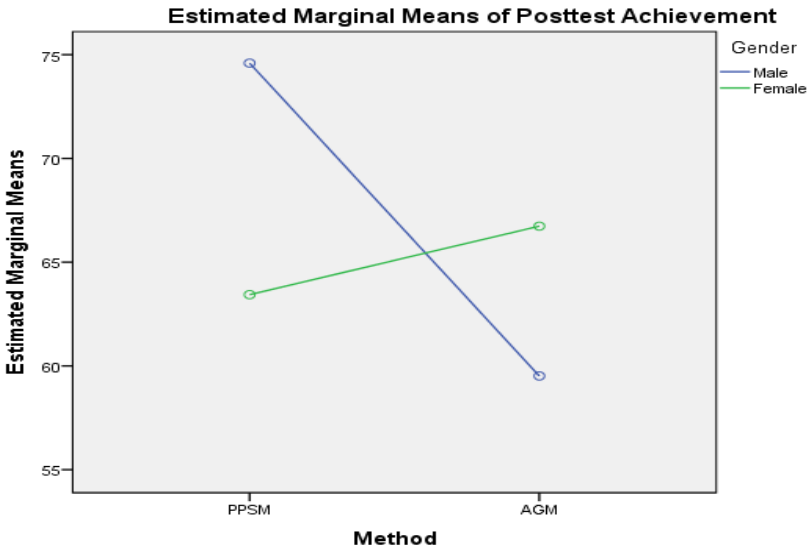

Figure 3: Plot of interaction effect of instructional methods (PPSM and AGM) and gender on students' achievement in Mathematics

The plot of interaction effect of instructional methods and gender on students' achievement in Mathematics is significant and disordinal. This shows that the instructional methods had different effect with respect to gender and are therefore gender sensitive. Male students taught Mathematics using PPSM had higher mean achievement score than female students whereas male students taught using AGM had a lesser mean achievement score than the female students.

Discussion

The findings of the study showed that students taught algebra using Polya's problem solving method (PPSM) had significantly higher achievement than those taught using AGM. The better effectiveness of PPSM was obvious, particularly due to its dual role in fostering logical thinking skills and providing students with a meaningful framework for acquiring mathematical information. The utilisation of this PPSM facilitated the application of acquired skills to unknown algebraic problems, while also possessing inherent aesthetic qualities. Additionally, the use of Polya's four-step procedure for problem solving aided students in maintaining an awareness of the inherent logical reasoning involved in mathematics and the resolution of mathematical problems. By using these steps, students were able to employ their existing reasoning capabilities to overcome obstacles that they may have previously perceived as impossible to overcome when solving mathematic problem.

The implementation of the PSSM also facilitated students' acquisition of knowledge through a process that involves both successes and failures. This approach enabled students to actively engage in their own learning, leading to a deeper understanding of algebra. The implementation of the PPSM helped students in organising and categorising factual information or data, while also instilling in them the inclination to seek logical solutions or identify suitable patterns that can aid in problem-

solving. This suggests that the approach fostered independent thinking among students, leading them to have a more profound comprehension of problem-solving. In essence, while the employment of AGM provided fun-filled learning experience for students, the use of PPSM facilitated the learner's independent exploration of solutions to specific problems that arise within their academic pursuits. Moreover, students were encouraged to engage in reasoning and critical thinking in order to arrive at a logical resolution for the algebraic problems given all through the lessons.

The comprehension of the procedural steps in PPSM, as opposed to the AGM problem, facilitated the students' ability to elucidate and discern the data derived from the problem. The implementation of strategic planning facilitated the engagement of students in the process of problem-solving within the realm of mathematics. The process of students identifying and selecting a strategy was found to enhance the ease of learning and foster the development of self-confidence in their abilities and talents for independent learning and critical thinking. By retrospectively analysing past experiences, individuals were able to anticipate and determine the most effective approach to address forthcoming challenges. Through the implementation of PPSM within their instructional practises, the teacher facilitated the students' achievement of two significant objectives within the mathematics curriculum. Firstly, the students were able to develop their abilities to identify and solve problems, while engaging in critical and creative thinking. Secondly, they were able to apply their acquired knowledge and skills in mathematics to effectively solve problems.

The findings of the study support the findings of Okafor (2019) hat student taught with Polya's problem solving technique performed better than those taught with conventional problem-solving technique. The findings of Yusha and Muhammad and Usman (2020) that that there was significant difference between performance of students in experimental group taught word problem using Polya's Problem Solving Instructional Model and control group taught word problem using Discussion Method supports the finding of the present study. The findings of the study are also in line with the findings of Idoko and Agbudu (2021) that Polya problem solving strategy has significant effect on students' performance in geometry. The findings of the study however contradicted the finding of Ojukwu (2012) that Polya's technique did not have significant effect on the students' achievement.

The findings of the study revealed that there were no significant difference in the mean achievement scores of students taught using PPSM and Again, significant interaction effect of gender and instructional methods was observed on students' on students' achievement in algebra. The insignificant difference in the students' achievement arises out of the fact that both strategies of instruction actively engaged the students. However, while PPSM favoured more of the male students, AGM was especially more favourable to female students in their achievement.

The finding of the study is in line with the findings of Nwigwe and Osuafor (2019) that the influence of gender on the students' achievement was not significant. However, the findings of Nwigwe and Osuafor (2019) contradicts the finding of the study when they reported that the interaction effect of gender and teaching methods on students' achievement were also not significant. The findings of the study on achievement supports the findings of Chiakwelu and Okigbo (2020) and Chiakwelu (2021) that no significant difference was observed between the mean achievement scores of male and female students in Mathematics.

Conclusion

The findings of this study showed that students taught Mathematics using PPSM had significantly higher achievement scores than those taught using AGM. It is concluded therefore, that despite AGM being an effective instructional method for teaching mathematics, PPSM is a more effective instructional method for teaching and improving students' achievement in Mathematics than AGM.

Recommendations

1. Seminars and workshops should be organised for secondary school mathematics teachers by school administrators on the instructional methods of polya's problem solving method (PPSM) and algebraic games method (AGM) with a view to have them master their usage in teaching mathematics.
2. Secondary school mathematics teachers should employ more often, the use of PPSM than AGM in order to ensure a better mathematics achievement.

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