

Effect of Polya's Problem-Solving Model on performance in Respiration Concept among Secondary School Students in Zamfara State, Nigeria

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Abstract

This study investigated the effect of Polya's problem-solving model on performance in respiration concept among secondary school students in Zamfara state, Nigeria. Two (2) research questions with their corresponding null hypotheses guided the study which adopted the quasi-experimental of the pretest-posttest control group research design. The population was 72, 534 students in 189 public senior secondary schools in the state. Multi-stage sampling was used in selecting 387 SS2 students during the 2024/2025 academic session as the sample using four (4) intact classes. Cellular Respiration Performance Test (CRPT) was the instrument used for data collection. Test-retest was adopted in determining the reliability of the instrument using the Pearson Product-Moment Correlation (PPMC) statistics which yielded a coefficient (r) of 0.82. The data collected were analyzed using descriptive statistics (Mean and Standard Deviation) and inferential statistics (One-Way Analysis of Covariance) at $p \leq .05$ significant level. The findings revealed that: the mean academic performance scores of the experimental group was significantly greater than that of the control group. Also, there were no statistically significant gender differences in the mean academic performance scores of the male and female students when taught cellular respiration using the Polya's Problem-Solving Model (PPSM). Hence, it was recommended that teachers should be encouraged to adopt the PPSM through re-trainings, seminars and workshops. Also, curriculum planners and policy makers should incorporate the PPSM in curriculum designs and policies so that it could widely be used at all levels of education.

Keyword: Polya's Problem-Solving Model, Performance, Biology

Introduction

Biology is the science that contributes to most of the major discoveries of 20th century and will continue to do so in the 21st century as emphasis moves towards understanding of biological approaches and more eco-friendly synthetic systems such as forensic, environmental, soil and water biology (Adekali, 2023). As a subject, biology has contributed tremendously to financial, physical and aesthetic benefits of mankind and to nation-building (Adekali, 2023). Despite the importance of biology, statistics of grades obtained by biology candidates in the West Africa Secondary School Certificate Examination (WASSCE) in 2019 have not been encouraging (WAEC Chief Examiner's Report, 2019). That is why biology is losing its might in academic performance of students in post-primary institutions (Ekineh & Otuturu, 2024). Biology is a wider branch of science with many branches like botany, zoology, microbiology, anatomy, physiology, genetics, biochemistry, cytology and cellular respiration.

Respiration is a biological concept which refers to the process by which complex food substances are broken down, in a stepwise series of reactions, in cells, to produce energy with carbon dioxide and water as waste products (Dam et al., 2019). Cellular or tissue respiration is the process by which cells convert glucose into energy in the form of adenosine triphosphates (ATP) which are molecular units for energy transfer in the body of organisms. Cellular respiration involves the chemical activities of the cells in which glucose is broken down by a series of reactions controlled by enzymes to release energy. It is very essential for the survival of living organisms, as it provides the energy needed to power cellular activities. Its main function is to synthesize biochemical energy (in the form of ATP) which is stored and used by all living cells for the various metabolic processes such as biosynthesis, locomotion, reproduction, nutrition, response, growth, excretion, gaseous exchange and transportation of molecules across membranes and so forth (Briggs et al., 2009 in Usman, 2021). Dam et al. (2019) explained the three main stages of cellular respiration: glycolysis, the citric acid cycle, and oxidative phosphorylation. Glycolysis is a process by which glucose is broken down into pyruvate in the cytosol, producing a small amount of ATP and NADH. Citric



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acid cycle (Krebs cycle) is the process by which pyruvate is converted into acetyl-CoA, which enters the citric acid cycle. This stage produces more ATP, NADH, and FADH₂ as byproducts. Oxidative phosphorylation refers to the process by which electrons from NADH and FADH₂ are passed through the electron transport chain, generating a proton gradient. This gradient is used to produce ATP through the process of chemiosmosis. Cellular respiration which is the main concept in this study is so wide with varied abstract contents or ideas that could best be taught using student-centered instructions and models like the Polya's problem-solving model. Polya's problem-solving model (PPSM) is a teaching model developed by George Polya in 1945. It is a problem-solving framework consisting of four stages: (i) understanding the problem; (ii) devising a plan; carrying out the plan; and looking back. This model guides learners in structured problem-solving, fostering critical thinking, and logical reasoning. Schoenfeld (2014) outlined how to effectively use the PPSM in teaching and learning. According to him, to apply the model in the classroom, teachers should: present a problem or scenario; guide learners through each stage; encourage active thinking and reflection; facilitate collaboration and discussion; and adapt the model to suit various subjects and levels. Studies and research findings in the use of PPSM in teaching learning processes show that the model enhances students' problem-solving skills (Schoenfeld, 2014). It improves critical thinking and logical reasoning (Nissenson et al., 2020). It develops mathematical literacy and supports science, technology, engineering and mathematics (STEM) education (Watson *et. al.*, 2020). It also fosters collaborative learning among diverse students (Kozma, 2019). Therefore, when effectively adopted by biology teachers in the class for teaching abstract and confusing biological concepts like cellular respiration, genetics and cell division, PPSM can significantly improve students' understanding and overall performance.

Performance refers to the measurement of academic achievement, progress, and accomplishment of students, teachers, and educational institution. Academic performance refers to how well a student performs in his/her educational pursuits. According to Obiakor et al. (2020), academic performance reflects a student's ability to understand and apply the knowledge, skills, and concepts taught in educational institutions. It may be used to refer to an expression used to present students' scholastic standing (Inekwe, 2002 in Salami, 2023). It is affected by many factors such as retention, student ability, the quality of secondary education received and teaching method (Usman, 2010 in Gachi, 2024). It has been observed (Nda, 2023) that the problem of students' under-performance in secondary schools in Nigeria has been a much-discussed educational issue. In solving any problem however, it is pertinent to understand the causes of such problems. Nda added that many causes or agents have been studied as the etiological starting point for investigating the phenomena of school failure or success. Olorundare (2014) in Oladehinde (2023) demonstrated that student's academic performance in senior secondary school certificate biology and other science subjects' examinations since eighties had remained poor. Adding that, a lot has been done to improve teaching of biology in secondary schools in Nigeria such as using different innovative teaching strategies, training and retraining of biology teachers, provision of laboratory equipment among others. In spite of that, students continue to perform poorly in biology. Oladehinde (2023) noted that this situation has created the need for more effective method and it then becomes necessary to explore the efficacy of alternative method of redressing this situation. Hence, this study intends to try PPSM to investigate its impacts on the students' understanding and overall academic performance. Gender could influence students' academic achievement in secondary school science subjects (Yuliskurnianati et al., 2019). It has been reported that there are sex differences in specific ability performance of students, that girls are better in spelling, writing and other knowledge. In contrast to this Okafor (2021) showed that females were not only under-represented but their levels of achievement in the fields of science and technology were low compared to the males'. Thus, the need to explore more on gender influence in education. That is why the researcher considers gender as one of the variables in the study.

Objectives of the Study

The aim of conducting this study was to investigate the Polya's problem-solving model on performance in respiration concept among secondary school students in Zamfara state, Nigeria. The specific objectives of the study were:

1. To find out the effect of Polya's problem-solving model on secondary school students' performance in respiration concept of biology; and
2. To determine the mean difference between male and female secondary school students' performance in respiration concept of biology when exposed to Polya's problem-solving model;

Research Questions

1. What is the mean difference in performance scores of students taught Respiration concept using Polya's model and those exposed to lecture method?
2. Is there any mean difference between male and female secondary school students' performance in respiration concept of biology when exposed to Polya's problem-solving model?



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Hypotheses

- Ho₁: There is no significant difference between the mean performance scores of students taught Respiration concept using Polya's model and those exposed to lecture method.
- Ho₂: There is no statistically significant gender difference in secondary school students' performance in respiration concept of biology when exposed to Polya's problem-solving model.

Methodology

The research design adopted in the study was the pretest, posttest and post-posttest non-equivalent control group Quasi-Experimental design. The design was suitable for the study because: it was not possible to conduct true experimental research due to lack of randomization of the groups; intact classes were used; and to avoid disruptions of the students' natural classroom settings in the schools. The design involves two groups (experimental and control). The total population of the study consisted of all the 72, 534 senior secondary school students for the 2024/2025 academic session in all the 189 public senior secondary schools in Zamfara state while the target population was all the 27,253 SS2 students (17, 132 males and 10,121 females). Multi-stage sampling technique was used in selecting the study's sample. In the first stage, simple random sampling by balloting was used to select one (1) educational zone out of the four educational zones in the state. This was Gusau educational zone. In the second stage, one (1) local government area was selected using simple random sampling by balloting from the selected educational zone. This was Gusau local government area. In the third stage, stratified-random sampling (based on gender) was used to select four (4) public senior secondary schools (two male and two female schools) in the selected local government. An intact class from each of the four (4) selected schools was finally selected using simple random sampling by balloting and assigned as experimental and control groups for the study. Hence, each group contained two intact classes (a male and a female class). These four (4) intact classes formed the study's sample size of 387 students. The techniques were appropriate for the study due to the facts that they are scientific and provide equal opportunities for all subjects and ensure objective selections with adequate number of subjects selected from the population. Also, the study involved gender as one of its variables and that the public senior secondary schools in the study area are all single-sex. The data collection instrument used in this study was Cellular Respiration Performance Test (CRPT). The CRPT was adapted from standardized WAEC (SSCE) question papers (2014-2024). It contained thirty (30) multiple choice questions (MCQs) in objective forms with four responses (options A–D) of which one was the correct answer while the remaining four were wrong answers. The CRPT was based on the revised Blooms' taxonomy of educational objectives Usman (2021). The CRPT was administered to the respondents during the pre-test, post-test and post-posttest and was answered within 30 minutes with the aim of testing their academic performance in the concept before the treatment and to determine the effect of the treatment respectively. The research instrument used in this study was validated by three (3) experts: two (2) from the Department of Science Education, Federal University Gusau, Zamfara state, Nigeria while the other one (1) was a secondary school biology teacher with ten (10) years teaching experience. The reliability of the CRPT was established by a pilot study carried out in Namoda Secondary School, Kaura Namoda which was part of the study area but not among the sample schools in the area through test-retest method. The two sets of scores obtained were correlated using the statistical tool of Pearson Product Moment Correlation (PPMC) to determine the reliability index of the CRPT as 0.82. The researcher used the two different methods (PPSM and CM) in teaching the two different groups the concept of cellular respiration for a period of four (4) weeks for both the experimental and control groups respectively during the normal biology periods in the sampled schools. Students in the experimental group were taught concept of cellular respiration with PPSM, adhering strictly to the steps specified in its lesson plans for four (4) weeks. The data collected in the study were analyzed using descriptive (Mean and Standard Deviation) and inferential (One-Way Analysis of Covariance (ANCOVA)) statistical tools. Specifically, all the research questions and the null hypotheses were restated whereby the research questions were answered using mean and standard deviation and all the hypotheses were tested using One-Way ANCOVA and z-test at $p \leq 0.05$ level of significance. ANCOVA was appropriate for the hypotheses testing due the presence of covariate (the pretest) in the study.

Presentation of Results

Research Question 1

What is the mean difference in performance scores of students taught Respiration concept using Polya's model and those exposed to lecture method? This research question was answered using mean and standard deviation as shown in Table 1.



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Table 1: Summary of the Result of Students’ Posttest Scores Means and Standard Deviations in both Experimental and Control Groups

Group	N	Mean (\bar{X})	SD	MD	Remarks
Experimental	199	17.26	3.72		
Control	188	11.17	1.98	6.09	Difference Exists
Total	387				

Source: Author’s Fieldwork 2024

Table 1 showed that the posttest mean scores and standard deviation of the experimental group were 17.26 and 3.72 respectively while those of the control group were 11.17 and 1.98 respectively. Hence, the mean difference between the groups was 6.09 and this result clearly indicated that the students taught using Polya’s problem-solving model had higher mean performance score than those taught using the conventional method. That is, the experimental group performed better than the control group. However, by their respective standard deviations, the students’ scores in the control group were more closely around the mean compared to those of the experimental group.

Research Question 2

Is there any mean difference between male and female secondary school students’ performance in respiration concept of biology when exposed to Polya’s problem-solving model? This research question was answered using mean and standard deviation and the result is presented in Table 2.

Table 2: Summary of the Result of Students’ Posttest Scores Means and Standard Deviations in the Experimental Group by Gender

Gender	N	Mean (\bar{X})	SD	MD	Remarks
Males	107	15.35	2.57		
Females	92	16.21	2.27	0.86	Difference Exists
Total	199				

Source: Author’s Fieldwork 2024

Table 3 showed that the posttest scores means and standard deviations of male students in the experimental group were 15.35 and 2.57 respectively while those of the female students were 16.21 and 2.27 respectively. Hence, the mean difference between the male and female students’ performance scores was 0.86. Likewise, in terms of standard deviations, the scores of the female students were more closely around the mean compared to those of the male students.

Hypothesis 1

There is no significant difference between the mean performance scores of students taught Respiration concept using Polya’s model and those exposed to lecture method. This null hypothesis was tested with One-Way ANCOVA at $p \leq .05$ alpha level using the pretest as covariate as shown in Table 3.

Table 3: Summary of One-Way Analysis of Covariance (ANCOVA) of Students’ Academic Performance Scores in CRPT

Source	Sum of Squares	DF	Mean Squares	F	Sig.	Decision
Corrected Model	15245.594	4	3811.398	30.777*	.000	
Intercept	45302.745	1	45302.745	365.815*	.000	
Pre-test	31.0 12	1	31.012	0.250	.618	Not Sign.
Inst. Strategy	14469.023	1	14469.023	116.836*	.000	Sign.
Error	13993.974	113	123.840			
Total	424685.000	118				
Corrected Total	29239.568	117				

Source: Author’s Fieldwork 2024

* Significant ($P < 0.05$)



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Table 3 revealed that Polya’s problem-solving model has statistically significant effect on students' academic performance in the cellular respiration contents studied. This is because as seen from the table, the instructional strategy is statistically significant at P -value of .000 and therefore it is also statistically significant at a higher P -value of .05. This led to the rejection of the null hypothesis that Polya’s problem-solving model has no statistically significant effect on secondary school students’ performance in respiration concept of biology. Thus, there is a statistically significant difference between the mean academic performance scores of secondary school students taught cellular respiration concepts using Polya’s problem-solving model and those taught using conventional method of teaching in favour of the experimental group ($F = 116.836^*$, $df = 1$ and $p = .000 < .05$).

Hypothesis 2

There is no statistically significant gender difference in secondary school students’ performance in respiration concept of biology when exposed to Polya’s problem-solving model. This null hypothesis, One-Way ANCOVA at $p \leq .05$ level of significance was used and the result is displayed in Table 4.

Table 4: Summary of One-Way Analysis of Covariance (ANCOVA) of Students’ Academic Performance Scores in CRPT by Gender

Source	Sum of Squares	DF	Mean Squares	F	Sig.	Decision
Corrected Model	15245.594	4	3811.398	30.777*	.000	
Intercept	45302.745	1	45302.745	365.815*	.000	
Pre-test	31.012	1	31.012	0.250	.618	Not Sign.
Gender	260.389	1	260.389	2.103	.150	Not Sign.
Error	13993.974	113	123.840			
Total	424685.000	118				
Corrected Total	29239.568	117				

Source: Author’s Fieldwork 2024

* Significant ($P < 0.05$)

Table 4 revealed that the computed F -ratio for the effect of gender on academic performance of students in the cellular respiration concept taught was 2.103 which is not statistically significant at P -value of .05. Hence, the null hypothesis which states that there is no statistically significant gender difference in secondary school students’ performance in respiration concept of biology when exposed to Polya’s problem-solving model was accepted being that the derived significant level is greater than the p -value (F -ratio = 2.103, $df = 1$ and $p = .150 > .05$). Therefore, there is no statistically significant gender difference in the mean academic performance scores of the secondary school students when taught cellular respiration concept using the Polya’s problem-solving model. Hence, it is a gender-friendly teaching strategy.

Discussion of Findings

This study investigated the effect of Polya’s problem-solving model on secondary school students’ performance and retention in respiration concept of biology in Zamfara state, Nigeria where four research questions and four research hypotheses were respectively answered and tested to obtain these results as the main findings discussed here. The findings revealed that there was difference between the mean academic performance scores of the students taught cellular respiration using the PPSM and those taught using the conventional method in favour of those taught using the PPSM and the difference was statistically significant. This was indicated by the groups’ mean difference and the result of the one-way ANCOVA analysis on the mean academic performance scores of the secondary school students taught using the PPSM in learning cellular respiration and those taught using the conventional method. This implies that exposing students to the PPSM as an instructional strategy helps students learn and comprehend even the erroneously misconceived cellular respiration concept more easily than using the conventional method. This could simply be attributed to the PPSM intervention in the study. This finding is in line with the findings of Abuh *et. al.* (2024), Ekinch and Otuturu (2024) and Salami (2023). On gender and academic performance, the findings revealed also that there was no statistically significant difference in the mean academic performance in cellular respiration between male and female students exposed to the PPSM in learning cellular respiration. This was shown by their respective mean academic performance and the result of the one-way ANCOVA analysis on the academic performance scores of the male and female students taught using PPSM. Thus, the strategy is generally found to be gender-friendly and very suitable for both male and female students with varying intellectual abilities, learning styles and interests. This is owing to the fact that the strategy gives room for all students to actively participate and engage in the lesson irrespective of their gender. This finding is in line with the findings of Abuh *et. al.* (2024), Adekali (2023) and Usman (2021) who reported similar results in their



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respective studies. However, Ekineh and Otuturu (2024) Odagboyi (2015) contradicted the above findings when they all revealed that boys achieved significantly higher than girls in their various findings. The findings of the study also revealed that students taught using PPSM had higher retention ability in cellular respiration than those students taught using conventional method. This indicated that the positive effect of PPSM is not only on academic performance of students but also on their retention abilities. This can be attributed to the fact that PPSM is a student-centred teaching model which paves way for the students to best grasp the ways solutions to various problems are arrived at through the problem-solving activities during the instruction. This finding is in line with the findings of Usman (2019).

Conclusion

In accordance with the findings of the study, the following conclusions were drawn:

1. PPSM significantly improves students' academic performance in learning cellular respiration concept as indicated by the statistically significant mean difference between the students in the experimental and control groups.
2. PPSM could generally be regarded as gender-friendly teaching strategy suitable for teaching both sexes as the mean difference between male and female students in the experimental group was not statistically significant.

Recommendations

By the objectives and findings of this study, the researcher recommended that:-

1. Teachers should be encouraged to adopt the PPSM through re-trainings, seminars and workshops as it greatly improves students' academic performance.
2. Stakeholders (governments, professional bodies and school administrators) should encourage biology and other science teachers to use PPSM in teaching all categories of students being it gender-friendly. This could be done right from the teacher training institutions and in-service programs and team-teaching.

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