

Team -Pair- Solo, Computer Simulation, Guided Discovery Teaching Approaches and Secondary School Students' Academic Performance in Cell Structure in Biology

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Abstract: *This study examined the effects of the team-pair-solo, computer simulation, and guided discovery teaching approaches on students' academic performance in Biology in secondary schools in Mkpato Enin Local Government Area, Akwa Ibom State, Nigeria. Two research questions and two corresponding hypotheses were formulated to guide the study. A quasi-experimental, pretest-posttest, non-randomized design was adopted for the study. The study population comprised 1,964 Biology students enrolled in the 16 public secondary schools in Mkpato Enin Local Government Area during the 2023/2024 academic session. A sample of 267 Senior Secondary One students, from three intact classes, was selected using a multi-stage sampling technique. The instrument for data collection was the Biology Performance Test on Cell Structure. The reliability of the instrument was determined using the Kuder-Richardson formula-20, with a coefficient of 0.81. Data were analyzed using mean and standard deviation to answer the research questions, while analysis of covariance was used to test the hypotheses at a 0.05 level of significance. The findings showed a statistically significant difference in the mean performance scores of students taught the concept of cell structure across the three teaching approaches, with the team-pair-solo and computer simulation teaching approaches proving significantly more effective than guided discovery teaching approach. There was no significant difference in the performance mean scores between male and female students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches. Based on the findings, it is concluded that computer simulation teaching approach is the most effective in improving students' academic performance on the concept of cell structure in Biology, followed by the team-pair-solo and guided discovery teaching approaches. It is recommended, among others that Biology teachers should adopt computer simulation as well as team-pair-solo approaches in teaching the concept of cell structure in Biology in secondary schools.*

Keywords: Team-pair-solo teaching approach, computer simulation teaching approach, guided discovery teaching approach, cell structure, academic performance.

INTRODUCTION

Biology is the systematic study of plants, animals, and microorganisms, from the cellular level to the whole organism, and how they live and influence each other in the environment. It is the scientific study of life and living organisms, their structure, functions, characteristics, classification, distribution, and evolution. According to Reynolds (2022) and Urry (2020), Biology is the study of living organisms, their functions and the processes that govern life on earth. The study of Biology has contributed immensely to the improvement of our lives. It is one of the fundamental science subjects in the senior secondary school curriculum in Nigeria which is very important for individual well-being, development of good living environment and acquisition of functional scientific attitudes (Matazu, 2022). Since it is the study of life, learners get to understand the working of the various organs of their bodies, inform them about human health, disease prevention and the importance of nutrition. Biology provides a solid foundation for students who wish to pursue courses such as medicine, pharmacy, nursing, biochemistry, biotechnology and agriculture in the tertiary institutions. Every core science student requires a credit in Biology at the O' level to gain admission into the University to study these courses.

A sound knowledge of Biology is therefore of great importance to students in secondary schools to enable them gain deeper understanding of the living world, develop essential skills, address pressing global issues, such as pandemics, climate change, biodiversity loss and prepare them for a wide range of career opportunities. Despite the crucial role Biology plays in understanding life processes, students' academic performance in the subject has been poor and unsatisfactory (Bichi, Ibrahim & Ibrahim, 2019; Chukwu & Arokoyu, 2019). This poor performance of students in West African Secondary School Certificate Examination is of utmost concern to Biology educators, given the advantages and prospects of the study of Biology. Several factors have been attributed to students' poor performance in Biology in Nigerian secondary schools, some of which are due to the abstract nature of certain aspects of Biology, lack of understanding on the part of the students, insufficient laboratory practical, inadequate instructional resources, ineffective teaching methods, overcrowded classrooms, and students' attitudes towards the subject (Adekunle & Fem-Adeoye, 2016; Owoeye, 2016). Recent studies (Babalola & Omolafe, 2025; Manishimwe et al., 2023) emphasize that the persistent underperformance in science subjects calls for the integration of technology-driven and collaborative instructional strategies. Such strategies enhance visualization, motivation, and deeper conceptual understanding among learners.

Furthermore, Etobro and Fabinu (2017) attributed students' poor performance to the perceived difficulty of some Biology concepts such as water transport in plants, protein synthesis, respiration, photosynthesis, gaseous exchange, cell structure, hormonal regulation, genetics, mitosis and meiosis. These topics are often abstract and require high levels of cognitive engagement, which many secondary school students struggle with. The West African Examinations Council (WAEC) Chief Examiners' reports (2020-2024) have consistently identified students' weaknesses in answering questions related to these challenging areas. Common issues cited in the reports include misunderstanding of questions in these concepts, inaccurate biological drawings, misuse or misspelling of technical terms, poor definitions of scientific concepts, and a general lack of clarity in written explanations. These recurring

challenges suggest a need for more effective teaching strategies and learning support systems to enhance students' comprehension and performance in Biology.

Several researchers have reported that the difficulty in comprehension of some key biological concepts is linked to the prevailing teacher-centred, traditional teaching methods still dominant in many secondary schools (Babalola & Omolafe, 2025; Eden et al. (2023; Josiah, et al., 2019; Etobro & Fabinu, 2017). These methods which prioritize lectures and textbook-based instruction, tend to make abstract concepts difficult for student to visualize and internalize (Manishimwe et al., 2023; Umanah & Sunday, 2022). This approach often leads to students' lack of interest in the subject, negative attitude towards topics perceived as complex or difficult, lack of critical thinking or practical application of theoretical knowledge and consequently, poor academic performance in the subject (Umanah & Sunday, 2025). The overreliance on teacher-centered delivery marginalizes active students' participation, which is essential for deep learning. Biology educators therefore advocate for the use of innovative instructional strategies for deeper understanding of abstract concepts rather than the traditional lecture method, which encourages rote memorization of concepts without meaningful learning. Various innovative teaching methods and strategies that could be adopted in Biology instruction include guided inquiry, guided discovery, problem-based learning, collaborative learning, peer tutoring, computer simulations, team-pair-solo co-operative, to mention just few. This study therefore investigated the effects of team-pair-solo, computer simulation, and guided discovery teaching approaches on students' academic performance in cell structure in Biology.

Team-pair-solo teaching approach is a cooperative teaching approach in which students are grouped into teams to complete the same task or related task in three stages. In the team stage, students work in teams to complete a task, promoting collaboration and peer learning. They discuss, solve problems, and share knowledge together. In the pair stage, students work in pairs, building on what they learned in the team stage, collaborate with a partner to explore the topic further. In the solo stage, students work individually, reflecting on what they have learned in the previous stages to consolidate their understanding (Johnson & Johnson, 2018; Zamri & Bhavani, 2017). This approach helps to build student's self-confidence, self-motivation, promotes social learning, and develops problem-solving and leadership skills (Sojinu et al., 2025). It enhances student engagement and learning outcomes. Udumaabba (2020) reported that team-pair-solo instructional strategy significantly enhanced students' achievement and retention in Biology compared to those taught using the traditional method. Similarly, Joshiah and Shedow (2020) found that Physics students taught using team-pair-solo strategy outperformed those taught using conventional lecture method. These findings suggest that the strategy not only enhances academic performance but also promotes active engagement, collaborative skills, and learner autonomy qualities that are essential for 21st-century learning.

Computer simulation teaching approach refers to the pedagogical use of computer-generated models that replicate real-world or theoretical processes, allowing learners to interact with dynamic visual, auditory, and motion-based representations of concepts in a safe, controlled environment. It is an enriched instructional approach in which pictures, sound, and motion processes are synchronized and projected to enhance effective teaching and learning (Okolo & Oluwasegun, 2020). Computer simulation approach integrates synchronized pictures, sound, and motion, creating immersive learning experiences that bridge theoretical knowledge with practical application. This approach offers dynamic

and interactive models of complex systems, enabling students to manipulate variables, visualize intricate relationships, and test hypotheses in a risk-free environment (Seoane et al., 2020; Umoetuk & Akpan, 2023). Such experiential engagement promotes not only deeper conceptual understanding but also problem-solving and analytical thinking skills through direct interaction with simulated processes. Several researchers have reported the effectiveness of computer simulation in the teaching and learning of difficult and abstract concept in science subjects (Umanah & Atabang, 2025; Jere & Mpeta, 2024). Inyang (2021) reported a significant difference in the academic achievement of Biology students taught the concept of circulatory system using computer simulation, guided discovery and expository teaching strategies in favour of computer simulation. Akhigbe and Ogufere (2020) found out that computer simulation significantly improved the achievement of low ability learners when taught the concept of genetics. Atabang and Umanah (2024) have reported significant improvements in students' performance using computer-based instructional packages with animation and narration; Umoetuk et al. (2025) reported a positive effect of computer simulations on academic achievement in Basic Science. Sunday et al. (2025) opined that computer-based molecular modelling significantly enhanced students' understanding of chemical reaction mechanisms compared to traditional method. Despite these benefits, the effectiveness of computer simulation is often shaped by factors such as students' digital literacy, teachers' pedagogical competence, and the adequacy of technological infrastructure, which may limit its potential in certain educational contexts.

Guided discovery teaching approach is an instructional approach in which learners actively engage in the process of discovering or constructing knowledge with the guidance and support of a teacher or facilitator. Rather than being directly provided with information or answers, learners are encouraged to explore, investigate, and make connections independently, fostering deeper understanding of the concepts (Bustos, 2020). In this method, the instructor designs a sequence of prompts either in the form of statements or questions that systematically guide learners toward a predetermined goal. The teacher initiates a stimulus, and the learners respond through active inquiry, ultimately discovering the appropriate concepts or solutions (Omiko, 2017). The teacher's role in guided discovery teaching approach is primarily that of a facilitator, encouraging students to take responsibility for their learning, think autonomously, and construct their own understanding of each concept. This approach enhances students' interest, creativity, and problem-solving abilities, thereby improving their academic performance. Many researchers have affirmed the effectiveness of guided discovery teaching approach in teaching complex or abstract concepts in science (Bileya & Achor, 2021). Tofi, Achor, and Eje (2022) reported that students taught Biology using guided discovery method achieved significantly higher than those taught using the traditional lecture method. The study therefore examined the comparative effectiveness of team-pair-solo, computer simulation and guided discovery teaching approaches on students' academic performance in the concept of cell structure in Biology.

Gender is one of the factors that may influence students' academic performance in secondary schools in Nigeria. Gender refers to the range of attributes, roles, expectations, and behaviors that a society assigns to individuals based on their perceived identity as male or female (Umanah & Akpan, 2024). Research findings have shown varying differences in academic performance between male and female students across different subjects. According to Oscar, Luis and Lopez (2018) reported that gender disparity exists on students' academic achievement, with some indicating an advantage for males and others showing better outcomes for females under specific teaching conditions. Esseine-Aloja (2021)

found that male students who participated in the school organized extra-mural classes in Biology outperformed their female counterparts. Rahama et al. (2024) examined students' academic performance in Chemistry and found that male students outperformed their female counterparts. A number of studies have also elucidated that gender has no significant influence on students' academic performance (Umanah & Akpan, 2025; Cleopas & Igbojinwaekwu, 2023; Umanah & Sunday, 2022). Furthermore, other research reports indicate that well-designed interactive teaching strategies such as computer simulations and computer-based packages can narrow or even eliminate performance gaps, between male and female thereby fostering equitable participation and inclusive classrooms (Akpan et al., 2025; Umanah, 2024). This persistent gap in students' academic achievement in Biology between male and female and the limited comparative evidence on the relative effectiveness of these innovative teaching approaches necessitated the search for effective, and inclusive teaching approaches that could be used in teaching Biology in secondary schools in Nigeria in order to close the gender gap. Hence, this study investigated the influence of gender on students' academic performance when taught the concept of cell structure in Biology using team-pair-solo, computer simulation, and guided discovery teaching approaches.

Statement of the Problem

Despite the important role of Biology in addressing global issues and its significant contribution to national development, students' academic performance in the subject in West African Senior School Certificate Examination (WASSCE) has been poor and unsatisfactory. This poor performance is a major concern to Biology educators. Data from recent WAEC Chief Examiners' Reports consistently highlight students' poor performance, particularly in questions that require a deep understanding of abstract concepts and processes. Students often struggle with topics that are not easily observable, and the microscopic nature of cell structure falls squarely into this category. The reports frequently point to a lack of conceptual understanding, reliance on rote memorization, and an inability to apply knowledge to new scenarios as major contributing factors. This difficulty in comprehension is often linked to the prevailing teacher-centered, traditional teaching methods still dominant in many secondary schools. These methods, which prioritize lectures and textbook-based instruction, tend to make abstract concepts like cell structure difficult for students to visualize and internalize. This approach often leads to low achievement, a lack of interest in the subject, and a negative attitude towards topics perceived as complex or difficult. Students may be able to label a diagram of a cell but fail to grasp the dynamic, interconnected functions of its organelles, thus hindering their ability to build on this foundational knowledge.

In response to these challenges, innovative teaching approaches such as team-pair-solo cooperative learning, computer simulations, and guided discovery approaches which foster collaboration, critical thinking, and active participation, thereby enhancing student achievement and engagement could be used in teaching Biology in secondary schools. However, a significant gap exists in the literature, particularly within the Nigerian context. While the individual efficacy of student-centered methods is established, there is a critical dearth of empirical research on the comparative effectiveness of team-pair-solo, computer simulation, and guided discovery teaching approaches in mitigating the documented learning difficulties associated with a highly abstract, foundational Biology concept like cell structure at the secondary school level. Consequently, Biology educators lack clear, comparative, and context-specific data to inform the optimal pedagogical choice. It remains unclear which of these

student-centered teaching approaches is empirically the most potent and equitable in improving academic performance in this specific subject area for Nigerian students. Understanding these gaps and persistent performance challenges provides the rationale for the present study. Therefore, this study sought to fill this gap by investigating the comparative effectiveness of team-pair-solo, computer simulation, and guided discovery teaching approaches on secondary school students' academic performance in cell structure in Biology.

Purpose of the Study

The purpose of this study was to investigate the effects of team-pair-solo, computer simulation, and guided discovery teaching approaches on students' academic performance in cell structure in Biology. Specifically, the study sought to:

1. Compare the difference in the mean performance scores of Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches.
2. Compare the difference in the mean performance scores between male and female Biology students taught the concept of cell structure.

Research Questions

The following research questions shall guide the study:

1. What is the difference in the mean performance scores of Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches?
2. What difference exists in the mean performance scores between male and female Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches?

Hypotheses

1. There is no significant difference in the mean performance scores of Biology students taught the concept of cell structure using Team-Pair-Solo, Computer simulation and Guided discovery teaching approaches.
2. There is no significant difference in the mean performance scores between male and female Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches.

RESEARCH METHOD

This study adopted a quasi-experimental, pretest-posttest, non-randomized design. The study was conducted in the Mkpato Enin Local Government Area of Akwa Ibom State, Nigeria. The population consisted of all 1,964 Senior Secondary one (SS1) Biology students from the 16 public co-educational secondary schools in the study area during the 2023/2024 academic session. A sample of 267 SS1 students was selected using a multistage sampling technique. In the first stage, the 16 public co-educational secondary schools were stratified into urban and rural schools based on geographical location. In the second stage, purposive sampling technique was used to select a total of six schools; three from the urban schools and three from the rural schools with adequate classroom facilities to implement the instructional approaches. In the third stage, one intact class of SS1 from each of the six sampled schools was used for the study. Thus, two schools each from urban and two schools each from

the rural strata were assigned to Team-pair-solo group, Computer simulation group, and Guided discovery group respectively using simple random sampling technique.

The instrument used for data collection was the Biology Performance Test on Cell Structure (BPTCS). To ensure face and content validity, the instrument was submitted to three independent assessors, two content experts in Biology education and one expert in Research Measurement and Evaluation, all in the Faculty of Education, Akwa Ibom State University, Mkpato Enin. The reliability of the BPTCS was determined using the Kuder-Richardson formula - 20 (KR-20), with a reliability coefficient of 0.81. Mean and standard deviation were used to answer the research questions, while analysis of covariance was used to test the hypotheses at a 0.05 level of significance. Additionally, a post-hoc test was conducted to determine the specific direction of significance among the three teaching approaches.

RESULTS

Research Question One

What is the difference in the mean performance scores of Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches?

Table 1: Mean and standard deviation of difference in the mean performance scores of Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches

Teaching approaches	N	Pretest		Posttest		Mean Difference
		Mean	SD	Mean	SD	
Team pair solo	80	31.00	8.58	61.36	14.56	30.36
Computer simulation	86	30.56	6.59	64.66	15.60	34.10
Guided discovery	101	30.97	8.39	53.54	13.51	22.57

The result in Table 1 shows that the pretest–posttest mean difference of 34.10 obtained by the students taught the concept of cell structure using computer simulation was greater than that of 30.36 obtained by those taught using the team pair solo which was in turn greater than that of 22.57 obtained by those taught using the guided discovery teaching approach. The result in Table 1 also indicated that the pretest and posttest standard deviation scores of 8.58 and 14.56, 6.59 and 15.60, as well as 8.39 and 13.51 obtained by the students taught using team pair solo, computer simulation and guided discovery approaches respectively showed that, although the students taught using computer simulation had the highest mean score difference, the scattering of the raw scores from the mean was also higher in the computer simulation group, followed by those in the team pair solo and those in the guided discovery group. This means that there is difference in mean performance scores of Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches.

Research Question Two

What is the difference in mean performance scores of male and female Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches?

Table 2: Mean and standard deviation of difference in the mean performance scores of male and female Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches

Teaching approaches	Gender	N	Pretest		Posttest		Mean Difference
			Mean	SD	Mean	SD	
Team pair solo	Male	39	31.03	7.79	60.44	14.85	29.41
	Female	41	30.98	9.37	62.24	14.41	31.26
Computer simulation	Male	30	30.33	6.81	65.33	14.40	35.00
	Female	56	30.68	6.52	64.30	16.33	33.62
Guided discovery	Male	44	30.18	8.06	53.43	14.93	23.25
	Female	57	31.59	8.67	53.61	12.44	22.02

The result in Table 2 shows that the pretest–posttest mean difference in the academic performance scores of male and female Biology students taught the concept of cell structure using team pair solo were 29.41 and 31.26 while that of the male and female students taught with the computer simulation were 31.26 and 33.62 and that of male and female Biology students taught the concept of cell structure using guided discovery approach were 23.25 and 22.02. Although there were slight differences in performance between male and female students across the three teaching approaches, these differences were not substantial. The standard deviation scores also showed some variations in the spread of scores indicating that, though male students taught using computer simulation had the highest mean score difference, the female students in the computer simulation group however exhibited the highest variability in their scores. This implies that there is no difference in mean performance scores of male and female Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches.

Hypothesis One

There is no significant difference in mean performance scores of Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches.

Table 3: Summary of analysis of variance of the difference in mean performance scores of Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6219.88 ^a	3	2073.29	9.80	.00
Intercept	62033.81	1	62033.81	293.29	.00
Pretest	56.31	1	56.31	.27	.61
Teaching_approaches	6140.70	2	3070.35	14.52	.00
Error	55626.53	263	211.51		
Total	1005963.00	267			
Corrected Total	61846.41	266			

The result in Table 3 shows the F-value of 14.52 and the corresponding probability level of significance of .00 alpha at 2 and 263 degrees of freedom. This level of significance is less than .05 in which the decision is based. With this result, the null hypothesis was rejected. This implies that there is significant difference in mean performance score of Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches.

Table 4 Summary of Scheffe's Post-hoc pairwise comparison of students' posttest scores classified by teaching approaches

(I) Teaching_approaches	(J) Teaching_approaches	Mean Difference (I-J)	Std. Error	Sig.
Team pair solo	Computer simulation	-3.30	2.26	.34
	Guided discovery	7.83*	2.17	.00
Computer simulation	Team pair solo	3.30	2.26	.34
	Guided discovery	11.13*	2.13	.00
Guided discovery	Team pair solo	-7.83*	2.17	.00
	Computer simulation	-11.13*	2.13	.00

The result in Table 4 using Scheffe's Post-hoc shows that the mean performance scores of students taught the concept of cell structure using team-pair-solo did not differ significantly with those taught using computer simulation ($p=.34$). However, the mean performance scores of students taught the concept of cell structure using team-pair-solo differ significantly with those taught using guided discovery teaching approach ($p=.00$) in favor of team-pair-solo. On the other hand, the mean performance scores of students taught using computer simulation significantly differs from those taught using guided discovery at ($p=.000$) in favor of computer simulation. Hence, it could be generalized that both team-pair-solo and computer simulation were significantly more effective than the guided discovery approach in improving students' academic performance.

Hypothesis Two

There is no significant difference in mean performance scores between male and female Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches.

Table 5: Summary of ANCOVA analysis of the difference in mean performance score of male and female Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6306.65 ^a	6	1051.11	4.92	.00
Intercept	61959.64	1	61959.64	290.05	.00
Pretest	56.19	1	56.19	.26	.61
Teaching_approaches	6008.13	2	3004.07	14.06	.00
Gender	7.92	1	7.92	.04	.85
Teaching_approaches * Gender	78.60	2	39.30	.18	.83
Error	55539.77	260	213.61		
Total	1005963.00	267			
Corrected Total	61846.41	266			

The result in Table 5 shows the F-value of .18 and the corresponding probability level of significance of .00 alpha at 2 and 260 degrees of freedom. This level of significance is greater than .05 in which the decision is based. With this result, the null hypothesis was rejected. This implies that there is no significant difference in mean performance score of male and female Biology students taught the concept of cell structure using team-pair-solo, computer simulation and guided discovery teaching approaches.

DISCUSSION OF FINDINGS

The findings indicated a significant difference in the academic performance of Biology students when taught the concept of cell structure using team-pair-solo, computer simulation, and guided discovery approaches. This outcome can be attributed to the fact that these innovative approaches directly address the complexities of the subject matter. The effectiveness of computer simulations is likely due to their interactive features and immediate feedback, which allow students to learn at their own pace and correct misconceptions on the spot. This personalized learning experience improves comprehension and helps students achieve mastery of the concept. Similarly, in the team-pair-solo approach, the progressive structure, which moves students from collaborative group work to individual problem-solving, fosters peer learning, critical thinking, and a sense of autonomy. While this structure builds confidence and reinforces learning, it may be less effective for visualizing microscopic structures compared to computer simulation. These findings are consistent with Udumaabba (2020) and Joshiah and Shedow (2020) who found that students taught with the team-pair-solo method performed better than those taught with traditional lecture methods. Inyang (2021) also reported a significant difference in the academic achievement of Biology students taught with computer simulation, guided discovery, and expository teaching methods. Furthermore, the results are supported by other studies that have shown the positive impact of technology-based instruction. Atabang and Umanah (2024), Umoetuk et al. (2025), and Sunday et al. (2025) all documented a significant improvement in students'

performance using computer simulation and molecular modelling compared to conventional teaching methods.

The analysis of the difference in the mean performance scores between male and female Biology students taught the concept of cell structure using the team-pair-solo, computer simulation, and guided discovery approaches indicated no statistically significant difference between gender. This outcome may be attributed to the inherently interactive, inclusive, and student-centered nature of these teaching approaches, which emphasize active participation, collaboration, and individualized learning benefiting all learners regardless of gender. This finding aligns with the reports of Cleopas and Igbojinwaekwu (2023); Akpan et al. (2025), Umoetuk et al. (2025) and Tofi et al. (2022), who similarly found no significant gender-based differences in the performance of science students. However, the findings of this study contradict that of Rahama et al. (2024) and Esseine-Aloja (2021) who reported that male students outperformed the female students in science.

CONCLUSION

This study provides empirical evidence that both computer simulation and team-pair-solo approaches are effective learner-centered strategies for improving students' understanding of abstract biological concepts such as cell structure. The findings are novel in that they directly compare three innovative strategies team-pair-solo, computer simulation, and guided discovery within a single experimental framework, thereby addressing a notable research gap in the Nigerian context. The implications of these findings are twofold: first, they reinforce the centrality of technology-driven and cooperative learning pedagogies in 21st-century science education; and second, they demonstrate that equitable gender outcomes can be achieved when instruction is inclusive and interactive. Future research could extend this study across other Biology topics or related science subjects such as Chemistry and Physics to test the generalizability of the findings. Longitudinal studies are also recommended to examine the lasting retention and motivational impacts of these innovative instructional strategies across varied educational settings.

Recommendations

Based on the findings of the study, the following recommendations were made:

Biology teachers should use computer simulation and team-pair-solo teaching approaches, as both proved equally effective and significantly superior to guided discovery in enhancing students' academic performance.

Teacher education programmes and in-service training workshops should incorporate team-pair-solo and computer simulation into their instructional methodology modules, in order to equip prospective and practising teachers with the skills to implement these teaching approaches effectively in the classroom.

Curriculum planners should integrate technology-driven and collaborative learning approaches like computer simulation and team-pair-solo into the senior secondary school Biology curriculum to

replace or complement less effective traditional methods, thereby aligning instructional practices with 21st-century learning demands.

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