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Effect of AI-Enhanced Inquiry-Based Learning on Scientific Reasoning Ability and Achievement in Photosynthesis among Basic Science Students in Zaria, Kaduna-State

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Abstract

The study investigated the effect of AI-Enhanced Inquiry-Based Learning on scientific reasoning ability and academic performance of Basic Science students in Photosynthesis concept in Zaria, Kaduna State, Nigeria. A quasi-experimental, pre-test-post-test design with non-equivalent control group was employed with two intact classes of 156 students from a population of 30,840 students from public secondary schools in Zaria Local Government Area. A total of 79 students in the experimental group were taught Photosynthesis using the AI-Enhanced Inquiry Based Learning platform, while 77 students in the control group were taught the same topic using conventional lecture method. Two validated instruments; the Scientific Reasoning Test (SRT) and the Photosynthesis Achievement Test (PAT) were used for data collection. Reliability was determined using test re-test method and data was analyzed using Pearson's product Moment Correlation Coefficient statistics (PPMC), yielding a reliability coefficient of 0.79 and 0.82 respectively. Data were analyzed using mean, standard deviation, t-test and 2 × 2 factorial ANCOVA, with pre-test scores as covariates. Results obtained, showed that the treatment effect on students' scientific reasoning ability was statistically significant ($p = 0.01$), there was a statistically significant treatment effect on students' achievement in photosynthesis ($p = 0.01$) and the main effect of gender is not significant for scientific reasoning, $F(1, 153) = 0.15$, $p = 0.70$. The study concluded that AI-enhanced IBL has effect on developing students' reasoning ability in photosynthesis and achievement and it is gender friendly. It was recommended that basic science teachers should adopt AI-enhanced IBL in teaching photosynthesis and by implication, other difficult basic science concepts.

Keywords: AI-Enhanced Inquiry-Based Learning, Photosynthesis, Scientific Reasoning, Achievement, Basic Science.

1 Introduction

Science is a dynamic human activity concerned with understanding the workings of our world. It is a systematic and evidence-based approach to understanding the natural world through observation, experimentation and analysis. According to Martins-Omole (2022) Science is the systematic study of natural phenomena. The field of science encompasses various discipline and as such it is required that it foundation should be laid early on in an individuals' life. Thus, the genesis for Basic science. Basic science curriculum is a broad field curriculum in which subject matter from different areas of discipline like biology, chemistry, physics, technology, geography, geology, astronomy and environment are synthesized to provide a holistic and unified nature of science (Federal Republic of Nigeria [FRN], 2013 & Project store, 2025). The Federal Republic of Nigeria (2018) assert that science education is for the development of the individual and the Nation. It stressed that the aim is to produce scientifically and technology literate citizens that can relate with the environment and understand scientific information. Basic science is a tree-years subject at the Junior Secondary School (JSS) level in Nigeria, that aimed to teach students from JS1-JS3 what science is and how scientist work. Thus, Photosynthesis as a variable in this study, is an important concept in the Basic Science curriculum taught in the junior secondary schools in Nigeria. It is a natural phenomenon whereby plants manufactured their own food in the presence of sunlight, using carbon dioxide and water as raw materials to make glucose and give up oxygen as a byproduct. It can be deduced that plants have the ability to convert light energy into chemical energy and stored it as glucose. The concept of photosynthesis is essential in the study of energy flow in ecosystems, food chains, global carbon

cycle and agricultural productivity in a country like Nigeria that is predominantly an agricultural society (Nduji et al, 2020; Oyewole, & Khalil, 2023).

However, Photosynthesis is found to be one of the most difficult topics prone to misconceptions among junior secondary school students. Olotu et al.,(2024) reported that students have conceptual problems in understanding the role of photosynthesis in plant nutrition; the physiological role of chlorophyll; the difference between light dependent and light independent reactions and the nature of raw materials in photosynthesis. Ahiakwo and Oko-Jaja (2024) and Aprianti et al., (2025). observed that students also have misconceptions about the transformation of energy, food production and gaseous exchange in the process of photosynthesis. Therefore, this basic science concept 'photosynthesis' needs to be taught not just theoretically but practically using AI-enhance approach like 5E's model specifically, for it to be functional and to lay the basic foundation needed for scientific and technological development among students. Thus, basic science students find the concepts very challenging and difficult to understand the whole process due to misconceptions leading to contradictions regarding the biological processes and sometimes could be due to alternative conceptions, such as having the idea that plants get their food from the roots. Researchers like Nduji et-al, (2020) and Onwunali et-al, (2026) linked the students' challenges in learning the concepts to pedagogy. They observed that conventional method has failed to create an adequate conceptual understanding of the topic. Aprianti et-al, (2025). Opined that, students can recite and write photosynthesis equation while holding alternative conception of where the plants gets their food. Demonstrating poor reasoning ability of the students, that is reflected in their low achievement.

The conventional method of teaching photosynthesis in most secondary schools in Nigeria is teacher-centered that consists of explanations, drawing of diagrams on the chalkboard, and memorizing of photosynthesis equations. This method appears weak for junior level science education. Because students at this stage are still in their exploration stage, full of energy and curiosity, as such conventional method would be boring for learning an abstract concept like photosynthesis. Hence, it become a pedagogical challenge in learning process. Interesting learning would require students to visualize the process and actively participate using AI assistance that would feed their curiosity and boost understanding like AI-enhanced Inquiry Based Learning (IBL). Because it is a teaching model that has been widely tested and successfully used in science learning that is based on constructivist and socio-cognitive learning theory (Moemeke, et al. 2025; Zhang, & Jamaludin, 2025). The studies of Alé et al. (2025) and Nogot (2025) demonstrated the effectiveness of AI-IBL in science classrooms by utilizing AI-supported tools to facilitate students to engage with scientific practices to enhance learning in various content areas. Thus, when AI tools are combined with IBL, an AI-Enhanced IBL environment is created that include features such as personalised feedback, real-time data visualization, and simulation-based investigation that can make abstract biological processes like photosynthesis come to life and observable for students (Holmes et al., 2019). Constructivist believed that AI-enhanced IBL has the capacity to trigger and stimulate cognitive processes that influence reasoning ability in learning process.

1.1 Statement of the Problem

In many Nigerian secondary schools, students often hold misconceptions about photosynthesis, leading to contradictions regarding basic biological processes. This issue is widespread and exacerbated by overreliance on conventional teaching methods that focus on lectures and memorization. These methods do not foster the development of the scientific thinking skills necessary to correct misunderstandings. The 2024 BECE chief examiners' report identified several weaknesses among students, including their inability to accurately articulate scientific concepts due to poor reasoning skills. The report recommends that teachers engage students in practical and outdoor (inquiry) activities to enhance their understanding of these concepts. The conventional lecture-based teaching method limits students' opportunities to hypothesize, test variables, and reason from evidence, which hinders their development of scientific reasoning skills and achievement. Meanwhile, the use of AI-enhanced teaching strategies is on the rise and holds great potential for transforming Basic Science education. Therefore, in this study by leveraging AI, students would obtain personalized feedback and visualize the process of photosynthesis adequately.

1.2 Objectives of the Study

The objectives of this study are to:

1. Determine the effect of AI-enhanced IBL on students' scientific reasoning ability in learning Basic Science.
2. Ascertain the effect of AI-enhanced IBL on students' achievement in Photosynthesis.

3. Find out the gender interaction effect of AI-enhanced IBL on students' scientific reasoning ability.

1.3 Research Questions

The following research questions guided the study:

1. What is the difference in the level of scientific reasoning ability of students taught with AI-enhanced IBL and those taught using conventional lecture method?
2. What is the difference in the achievement scores of students taught with AI-enhanced IBL group and those in the conventional instruction group?
3. Is there any gender interaction effect of AI-enhanced IBL on students scientific reasoning ability?

1.4 Null Hypotheses

The following hypothesis were formulated and tested at $\alpha = 0.05$ level of significance

H_{01}: There is no significant difference in the level of scientific reasoning ability of students taught with AI-enhanced IBL and those taught with conventional lecture method.

H_{02}: There is no significant difference in the Photosynthesis achievement scores of students taught with AI-enhanced IBL and those taught with conventional method.

H_{03}: There is no significant gender interaction effect of AI-enhanced IBL on students scientific reasoning ability.

2 Literature Review/Theoretical Framework

Scientific reasoning as a variable of the study are cognitive skills for asking questions, testing ideas based on evidence, controlling variables and drawing conclusions. Akpan, (2025). Assert that Scientific reasoning are cognitive skills that students develop in order to make hypotheses, control variables, interpret data, and make logical conclusions during the scientific inquiry process. Therefore, when scientific reasoning is intentionally developed and practiced through AI-enhanced IBL, students would improve beyond memorization and achieve higher. Bao et al., (2018), affirms that, the Lawson Classroom Test of Scientific Reasoning (LCTSR), first developed in 1978 and revised in 2000, continues to be the most widely used measurement of this construct that has been used internationally across biology, physics, chemistry and astronomy classrooms, including undergraduate biology courses and secondary teacher professional development programmes. Its framework considers concrete operational thinking and formal operational thinking. However, Concrete operational thinking is when learners rely on observable patterns and formal operational is when learners can manipulate abstract variables, systematically test hypotheses, and reason proportionally and probabilistically (Lawson et al., 1978).

The role of LCTSR in scientific reasoning and achievement has been investigated and reported in various studies within and outside Nigeria. Wu et al., (2025) in their study titled ‘The role of light in regulating plant growth, development and sugar metabolism’ revealed that the majority of students in Indonesian junior secondary school were still in the concrete-operational level with proportional reasoning consistently being the weakest skill, which limits students' ability to grasp abstract processes in the biological world, for example when light energy is converted to chemical energy. In its specific context, another study conducted in Lagos State with senior secondary Biology students revealed that students' epistemic beliefs had a significant influence on their conceptual understanding and scientific reasoning performance, with naive epistemic beliefs correlated with poor performance on both (Oladipo & Awofala, 2026). This highlights the fact that students' poor reasoning abilities are not just a lack of content knowledge but are deficiencies in the way the learner is able to develop, test, and modify scientific explanations and are not adequately taught by conventional approaches that rely on lectures. Thus, as earlier stated, when scientific reasoning is intentionally and objectively developed and practiced via modified inquiry method like AI-enhance IBL, students can develop beyond memorization to form hypotheses, manipulate variables and analyze evidence which are skills that are directly applicable to understanding the interrelated variables of light, carbon dioxide, water, and chlorophyll that affect the process of photosynthesis. Moreover, in a systematic review; Selvam (2024) and Ng et al., (2024) concluded that the use of AI systems reduces students' cognitive load and enhances conceptual understanding, especially in the domain of self-regulated learning for students with a solid scientific background. The shift from the traditional to simulation-based teaching is an effective strategy to improve

students' reasoning skills on complex biological concepts and systems. Darling-Hammond, et al. (2020) assert that, a multi-parameter dynamic AI-generated simulation, was found to be much more readily accessible to students, than a diagram of these parameters on a static chalkboard. Hence, learning about complex physiological processes like photosynthesis, where a number of variables are changing at the same time, like light intensity, carbon dioxide concentration and temperature, students rely particularly on visualizing moving feedback loops to understand the process. As it relates to this study, Previous studies examining the impact of using technology to enhance learning in science education have demonstrated that the addition of intelligent guidance and interactive simulations was more effective in delivering pre-to-post-test gains in conceptual and reasoning skills than lecture methods (Shofiyah, et al., 2025; Kotsis, 2025; Doğan, et al., 2026).

In line with the current study, Previous Nigerian studies have investigated inquiry based learning (IBL), cooperative learning (CL) and digital learning (DL) independently. However, no study has investigated AI-enhanced inquiry based learning (IBL) for improving scientific reasoning and achievement in photosynthesis among Nigerian Junior Secondary Students (JSS). Thus, Tyagi, (2025). Laments that the process may not be feasible in classrooms in Nigeria that lack the necessary resources. However, this was what prompted the study, because different researchers have tried to provide solution to this problem in learning photosynthesis. This gap highlighted the importance of the present study as it has been established from the existing literature that AI- enhanced IBL will be effective in solving conceptual challenges that students experience due to the limited resources available to them in the Science classrooms (Alé et al., 2025; Awofala, 2026). This study therefore investigated the effect of AI-Enhanced Inquiry Based Learning (IBL) on the scientific reasoning ability and achievement among basic science students in Zaria, Kaduna-state, Nigeria.

3 Materials and Methods

This study used a quasi-experimental, pre-test/post-test, non-equivalent control group design. The population consisted of 30,840 JSS basic science students in Zaria, Kaduna State (2024/2025 academic session), as photosynthesis falls under the plant nutrition theme of the NERDC (2025) curriculum. Two public secondary schools, Kofar Gayan Secondary School and GJSS Tudun-Jukun, were purposively selected based on internet-equipped classrooms. From each school, an intact JSS II class was randomly assigned by coin toss to the experimental (AI-enhanced IBL) and control (conventional method) group, yielding a total sample of 156 students (80 male, 76 female). Permission from the ministry of education, informed consent from school authorities and students' consent were obtained beforehand, with confidentiality and voluntary participation explained. Two instruments were used for data collection: the 20-item Scientific Reasoning Test (SRT) adapted from Lawson (2000) and the 20-item Photosynthesis Achievement Test (PAT) which was developed across the five bloom's taxonomy levels (knowledge, comprehension, application, analysis, synthesis/evaluation). Content validity was assessed for both instruments by science education experts and reliability was done with test re-test method, and it was conducted between two weeks' interval. where the first test was administered, data was collected and after two weeks the second test as retest was administered and data was collected. The data collected were analyzed using Pearson's Product Moment Correlation Coefficient statistics (PPMC) yielding a reliability coefficient of 0.79 and 0.82 respectively. The instruments were found to be reliable and thus viable for the study, because an instrument is considered reliable when it calculated reliability falls between 0.5 - 1.0 (Mustapha, 2018). The experimental group underwent a six-week AI-enhanced IBL intervention based on a five-phase AI-Enhanced inquiry cycle (engage, explore, explain, elaborate and evaluate), adapted from Bybee's (1997) 5E model, in which students worked in small groups to create AI-generated videos on photosynthesis concepts using locally contextualized scenarios (e.g., greenhouse tomato farming, observing the process of hypothesis under different environmental conditions; like presence and absent of light, different light intensity; testing different variables of photosynthesis like raw materials involved etc), followed by presentation and critique. The control group received conventional method instruction with textbook diagrams over the same period. Both groups completed the SRT and PAT as pre-tests in week 1 and post-tests in week 6. Research questions were answered using Mean and standard deviation, while hypothesis were tested using t-test and a 2×2 factorial ANCOVA at $\alpha = 0.05$.

4 Results

Prior to testing the stated hypotheses, an independent samples t-test was conducted to confirm difference between the experimental and control groups. Results of analyses are presented as follows:

Table **1**

Descriptive Statistics for SRT and PAT by Group

Instrument	Group	N	Pre-test Mean (SD)	Post-test Mean (SD)	Mean Difference
SRT	Experimental	79	13.80 (3.50)	24.52 (4.05)	6.64
	Control	77	13.75 (3.40)	17.88 (3.85)	
PAT	Experimental	79	21.60 (4.28)	36.55 (4.80)	7.77
	Control	77	21.50 (4.45)	28.78 (4.58)	

Table 1 presents the pre-test and post-test mean scores of students in the experimental and control groups on the Scientific Reasoning Test (SRT) and the Photosynthesis Achievement Test (PAT). For the SRT, the experimental group recorded a post-test mean of 24.52 (SD = 4.05), while the control group recorded a post-test mean of 17.88 (SD = 3.85), yielding a mean difference of 6.64 in favour of the experimental group indicating improvement in scientific reasoning ability among students exposed to the AI-enhanced IBL instructional approach. For PAT analysis, the experimental group recorded a post-test mean of 36.55 (SD = 4.80), while the control group recorded a post-test mean of 28.78 (SD = 4.58), yielding a mean difference of 7.77 suggesting that the AI-enhanced IBL approach improved achievement. The results in Table 1 indicated that while both groups began the study at comparable levels, the experimental group outperformed the control group on both instruments. These preliminary findings were analysed further with t-test and presented in Tables 2 and 3.

Table **2**

Summary of t-test Analysis of SRT for both Groups.

Group	**N**	**Mean**	**SD**	**Df**	**t-value**	**p-value**	**Remark**
Experimental	79	24.52	4.05				
				154	10.49	0.01	Significant
Control	77	17.88	3.85				

Significant at P ≤0.05

The data presented in Table 2 shows an independent samples t-test comparison between the experimental and control groups on the SRT. The calculated t-value is 10.49 and p-value is 0.01 is less than the alpha level of 0.05, indicating the result is statistically significant. Hence, the null hypothesis was rejected.

Table **3**

Summary of t-test analysis of PAT for both Groups

Group	**N**	**Mean**	**SD**	**Df**	**t-value**	**p-value**	**Remark**
Experimental	79	36.55	4.80				
				154	10.34	0.01	Significant
Control	77	28.78	4.58				

Significant at P ≤0.05

The results presented in Table 3 is the independent samples t-test results comparing the academic achievement of the experimental and control groups in the PAT. The experimental group obtained a mean achievement score of 36.55 with a standard deviation of 4.80, while the control group maintained a mean score of 28.78 with a standard deviation of 4.58. The t-value (t-cal) of 10.34 at 154 degrees of freedom, and p-value of 0.01 indicated a significance difference between the two groups. Therefore, the null hypothesis was rejected.

Table **4**

Summary of Sampled Students in both groups by Gender

SN	Group	Male	Female	Total
1	Experimental	41	38	79
2	Control	35	42	77
	Total	80	76	156

Table **5**

Summary of ANCOVA Analysis for Experimental Group

Source	Sum of Squares	df	Mean Square	F	Sig.	Remark
Corrected Model	1858.62	4	464.66	29.39	0.01	S
Intercept	4125.40	1	4125.40	260.94	0.01	S
Pre-test (Covariate)	122.35	1	122.35	7.74	0.06	NS
Method	1731.85	1	1731.85	109.54	0.01	S
Gender	2.30	1	2.30	0.15	0.70	NS
Method x Gender (interaction)	2.12	1	2.12	0.13	0.72	NS
Error	2387.00	153	15.81			
Total	74162.00	155				
Corrected total	4245.62	155				

Significant at p ≤0.05

The results from Table 5 indicate that gender had no significant interaction effect on the AI-enhanced IBL method, F (1,153) = 0.15, p = 0.70. This indicates that the teaching approach didn't have a significant impact on the students' scientific reasoning ability and achievement in the photosynthesis topic regardless of gender. Therefore, the null hypothesis was retained or not rejected.

5 Discussion

Table 1 presented the descriptive analysis of SRT and PAT for both experimental and control groups. The mean difference of 6.64 in favour of the experimental group indicate improvement in scientific reasoning ability among students exposed to the AI-enhanced IBL instructional approach. For PAT, the mean difference of 7.77 in favour of the experimental group indicate improvement in achievement among students exposed to AI-enhanced IBL instructional approach.

The results shown in Table 2 indicate that there was a significant difference between the students' scientific reasoning ability, $p = 0.01 < 0.05$. The result suggests that AI-enhanced IBL yielded significantly better scientific reasoning ability level than the conventional method indicating that the treatment was effective in helping students to develop scientific reasoning skill as they were able to analyse evidence, explain the phenomenon, evaluate scientific claims, and make logical inferences about photosynthesis. Hypothesis one which states that there is no significant difference in the scientific reasoning ability of students taught with AI-enhanced IBL and those taught with conventional lecture method was rejected. Result confirms the view of Lawson et al. (2000) that scientific reasoning is a product of hands-on experiences in inquiry-based learning. It also validates Bao et al.'s (2018) claims that scientific reasoning is sensitive to specific instructional interventions that can elicit higher-order thinking. The discovery also agrees with the findings of Zhang and Jamaludin (2025)**,** who discovered that AI-enhanced IBL instructional framework significantly enhances students' conceptual understanding and their thinking as scientists in learning biology. The finding was in line with the views of Moemeke et-al (2025) who contended that science inquiry has strong theoretical foundation which promotes student autonomy, analysis and conceptual exploration. As it relates to the study, Ojo and Ige (2025) concluded that scientific reasoning is a predictor for achievement in challenging topics of biology like photosynthesis. This corroboration has helped to confirm the hypothesis that the intervention positively contributed to the students' achievement in photosynthesis; in part because of the improvement in their scientific reasoning skills.

Findings in Table 3 revealed there was also significant difference of instructional methods on students' achievement in p = .01 < 0.05. The scores for the students who were taught using AI-enhanced IBL were found to be significantly higher than the scores of the students who were taught with the conventional lecture method. Hypothesis two which states that there is no significant difference in the Photosynthesis Achievement Tests of students taught with AI-enhanced IBL and those taught with conventional method was also rejected. The result validates the efficiency of supporting inquiry processes with the help of AI tools to improve scientific reasoning skills achievement. The outcome is consistent with the findings of Zhang and Jamaludin (2025), which discovered that students learning in an AI-enhanced IBL environment achieved better results in biology. It also agrees with the findings of Mamman (2025), Alé et al. (2025), Fayzullina et al. (2025) and Nogot (2025) where results showed that learner centered learning models like AI-enhanced IBL are able to create better academic results than conventional learning models. The results in the current study support Oladipo and Awofala (2026), who proposed that scientific reasoning skills is an essential element to conceptual understanding in the study of biological sciences. The present intervention helped students to develop their scientific reasoning skills which helped them in the understanding of photosynthesis related to basic science concepts.

The ANCOVA results in Table 5 revealed that, after adjusting pre-test scores, instructional method had a statistically significant effect on students' scientific reasoning skills**,** $F(1,153) = 109.54$, $p < .01$, indicating that students taught using AI-enhanced inquiry-based learning achieved significantly higher adjusted post-test scores than those taught using the conventional method. The covariate (pre-test score) was also not significant**,** $F(1,153) = 7.74$, $p = .06$, indicating that pre-test performance significantly predicted post-test scores. However, the main effect of gender was not statistically significant, $F(1,153) = 0.15$, $p = .70$, suggesting that male and female students performed similarly. Likewise, the interaction between instructional method and gender was not statistically significant**,** $F(1,153) = 0.13$, $p = .72$**,** indicating that the effectiveness of AI-enhanced inquiry-based learning did not differ between male and female students. Therefore, Hypothesis 3, which posits that there is no significant gender interaction effect of AI-enhanced IBL on students' scientific reasoning abilities, was retained. This finding aligns with the study conducted by Yediarani et al. (2019), which suggested that the development of scientific reasoning skills is not dependent on gender but rather influenced by the quality of instruction. Thus, Technology-based learning environments enhance the accessibility of science education, providing all learners with equal opportunities for interaction, feedback, and exploration. Consequently, this study supports the findings of Oyewole and Khalil (2023), which indicated that classroom management with regard to using the right pedagogy has a greater impact on learners' outcomes than demographic factors such as gender.

6 Conclusion

Based on the findings of the study it was concluded that AI-enhanced IBL has effect on students' scientific reasoning abilities and achievement in photosynthesis at junior secondary school level and it is gender friendly. It is inferred and deduced that shifting from conventional teacher-centered practices to an engaging, technology-driven approach significantly enhanced Basic Science education in Junior Secondary Schools. This was by incorporating real-time diagnostic feedback and interactive simulations that stimulate and provide vital cognitive support and processes, as students actively engage in learning using AI-enhanced IBL strategy.

7 Recommendations

Based on the study the following recommendations were made:

1. Basic Science teachers should adopt AI-enhanced IBL in teaching photosynthesis and by implication other difficult basic science concepts.
2. Government and education stakeholders should sponsor and provide ICT facilities and learning tools equipped with AI features to facilitate workshop to train and teach the effective application of AI-IBL approach for public junior secondary school basic science teachers.
3. Teachers should create awareness among Basic Science students to enable them endeavor to appreciate and value the AI-enhanced IBL method of learning.

8 Declarations

Ethical statements: Ethical approval for this study was obtained from the Kaduna State Ministry of Education, Zaria Zone. Informed consent was secured from school authorities, participating teachers, and the students' parents or legal guardians, while voluntary participation and confidentiality were strictly maintained throughout the research.

Conflict of Interest: The authors declare that there are no financial, commercial, or other relationships that could be perceived as a potential conflict of interest regarding the publication of this work.

Author Contributions: U.H.A. conceived the study, designed the instructional intervention, collected the data, and drafted the initial manuscript. Y.A. participated in experimental design, supervised the classroom implementation, and contributed to the literature review. N.R.A. supervised the overall research design, performed the statistical data analyses, and critically revised and proofread the manuscript for intellectual content. All authors have read and agreed to the final version of the manuscript.

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Data Availability Statement: The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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