



Efficacy of Individualized and Collaborative Virtual Biology Instruction on Secondary School Students' Academic Achievement in Biology

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Abstract

This study investigated the efficacy of individualized and collaborative virtual biology instruction on secondary school students' academic achievement in Biology. The study was guided by three research questions and three null hypotheses. Quasi experimental research design was adopted. The study was conducted in Obollo-Afor education zone of Enugu state. The population of the study comprised 2406 SS 2 Biology students in the zone. The sample size for the study comprised of 144 Biology students, from four intact SSS 2 classes, sampled through multistage sampling procedure. The instruments used for data collection are Biology Achievement Test (BAT) and Standardized Ability Test (SAT). The instruments were validated by two lecturers in Biology Education, one in measurement and evaluation unit, one senior secondary school Biology teacher and one academic staff from the Department of Computer Science. The reliability indices of the BAT as determined using Cronbach Alpha respectively and they yielded internal consistency reliability index of 0.87. The experimental lasted six weeks and students were assigned to individualized and collaborative virtual Biology instruction groups. Data collected were analysed using SPSS version 25. Mean and standard deviation were used to answer the research questions while Analysis of Covariance (ANCOVA) was used to test the hypotheses. Results revealed a significant difference in the mean academic achievement scores of Biology students taught with individualized and collaborative virtual biology instruction, in favour of students taught with collaborative virtual Biology instruction; the influence of cognitive ability level on academic achievement of Biology students is not significant. Based on the findings, the study recommends among others that collaborative and individualized virtual Biology instruction be adopted by teachers to improve students learning outcomes in Biology, and teachers should monitor the academic achievement of their students in Biology.

Keywords: Individualized Virtual Biology Instruction, Collaborative Virtual Biology Instruction, Academic Achievement, Biology, Cognitive Ability.

Introduction

The increasing complexity of contemporary education has created a growing need for instructional approaches that address the diverse learning needs of secondary school students. In science education, students are expected not only to acquire scientific knowledge but also to understand complex concepts, interpret scientific information and apply what they have learnt to real-life situations. Biology, in particular, requires

students to understand abstract processes, interpret diagrams, conduct practical investigations and establish relationships among living organisms and their environment. However, the abstract nature of some biological concepts and the difficulties students encounter in understanding them can make effective instruction challenging (Adam et al., 2024; Adewumi et al., 2024). Consequently, improving students' academic achievement in

Biology remains an important concern for educators and researchers, particularly in the search for instructional approaches that promote meaningful learning.

Biology is a fundamental science subject that provides students with knowledge of living organisms, their structures, functions, interactions and relationships with the environment. Its importance extends beyond the classroom, as knowledge of Biology contributes to understanding human health, environmental conservation, agriculture and biotechnology. Academic achievement in Biology reflects the extent to which students have acquired and can demonstrate the knowledge and skills specified in the curriculum. However, achieving satisfactory learning outcomes requires students to understand and retain biological concepts rather than merely memorise facts and definitions. Recent research has identified abstractness, conceptual complexity, inadequate instructional materials and limited practical experiences as factors that can make some Biology topics difficult for secondary school students (Adam et al., 2024; Adeyanju & Sam-Kayode, 2024). These difficulties may affect students' understanding and retention of biological concepts, making the choice of appropriate instructional strategies particularly important for improving academic achievement.

The growing use of digital technologies in education has created opportunities for teachers to present scientific concepts through virtual learning environments. Virtual instruction involves the use of digital platforms, computer-based resources and interactive technologies to deliver learning experiences beyond conventional classroom teaching. In Biology, virtual instruction can incorporate animations, simulations, virtual laboratories, videos, diagrams and interactive learning materials to represent biological structures and processes. These resources can help students visualise complex concepts, manipulate virtual objects and explore processes that may be difficult to demonstrate using conventional instructional materials. In a study of Nigerian secondary school students, the use of audiovisual technological aids was associated with higher achievement in Biology than

instruction without these resources (2019). Similarly, research on computer-animated simulations among secondary school students in Cross River State reported significantly higher academic performance among students exposed to simulation-based instruction than those taught using conventional methods (Ashiwere et al., 2025). Such findings indicate the potential of technology-supported instruction to improve students' understanding of biological concepts, although the learning outcomes may depend on how the resources are organised and used.

Two instructional approaches that can be implemented through virtual learning environments are individualized and collaborative virtual Biology instruction. Individualized virtual instruction allows students to engage with digital learning materials independently and progress at a pace that suits their learning needs. It can provide opportunities for students to revisit difficult concepts, repeat learning activities and receive immediate feedback without depending entirely on the pace of the class. This approach may be particularly useful in Biology, where students differ in their prior knowledge, comprehension and ability to understand complex concepts. By allowing learners to control aspects of their learning, individualized virtual instruction may support independent knowledge acquisition and give students more time to master challenging biological concepts. However, its effectiveness may depend on students' ability to regulate their learning, maintain concentration and use the available resources independently.

Collaborative virtual Biology instruction, in contrast, involves students working together through digital platforms to achieve shared learning objectives. Students may participate in virtual discussions, group assignments, shared simulations and other interactive activities that require them to exchange ideas, explain concepts and solve problems collectively. This approach provides opportunities for learners to benefit from one another's knowledge and perspectives while developing a shared understanding of biological concepts. Adejimi et al. (2021) found that collaborative instructional strategies improved secondary school students' achievement in

Biology, with cooperative reflective journal writing producing higher achievement than consensus group instruction. Similarly, Kingdom-Aaron et al. (2019) reported that secondary school students taught Biology using cooperative learning achieved significantly higher scores than those taught using conventional lecture methods. Although these studies examined collaborative learning in conventional classroom settings, their findings provide a basis for investigating whether similar benefits can be achieved when collaboration takes place in virtual learning environments.

The effectiveness of individualized and collaborative virtual instruction may differ because the two approaches provide distinct learning experiences. Individualized instruction gives students greater control over their learning pace and opportunities for independent practice, whereas collaborative instruction emphasises interaction, shared problem-solving and the exchange of ideas. While independent learning may allow students to concentrate on concepts they find difficult, collaboration may help them clarify misunderstandings through discussion and explanations from their peers. Evidence from Freeman et al. (2014), although predating the specified literature period, established the wider relevance of active learning in science education. More recent evidence from a meta-analysis by Theobald et al. (2020) also demonstrated that active learning can improve student performance in undergraduate STEM education, although its findings do not directly establish the comparative effectiveness of individualized and collaborative virtual Biology instruction among secondary school students. These distinctions make it necessary to examine the two approaches within the same study rather than assume that they produce identical learning outcomes.

In Nigeria, the integration of digital technologies into secondary school Biology instruction presents opportunities to address some of the limitations of conventional teaching. Ibe and Abamuche (2019) found that senior secondary school students taught Biology using audiovisual technological resources achieved higher scores than students taught without those resources. Similarly, Ashiwere et

al. (2025) reported that computer-animated simulation significantly improved secondary school students' academic performance in Biology in Cross River State. These findings demonstrate the potential of technology-supported instruction to improve Biology achievement. However, the use of digital resources alone does not determine how students engage with learning materials. The manner in which virtual instruction is organised, whether students work independently or collaboratively, may also influence their learning outcomes. Thus, examining different modes of virtual instruction is important for understanding how digital technologies can be used effectively in secondary school Biology.

Despite the growing use of virtual technologies in education, important questions remain about how the organisation of virtual instruction influences students' academic achievement in Biology. Existing studies have examined the effects of virtual laboratories, computer simulations and collaborative learning, but relatively few have directly compared individualized and collaborative modes of virtual instruction among secondary school students. For example, Ibe and Abamuche (2019) investigated audiovisual technological instruction, while Adejimi et al. (2021) examined collaborative instructional strategies in conventional classroom settings. Although these studies provide useful evidence on technology-supported and collaborative learning, they do not establish how individualized and collaborative virtual Biology instruction compare in their effects on students' achievement. This gap highlights the need for further empirical investigation into the two approaches, particularly in the context of secondary school Biology.

Considering the importance of Biology and the growing opportunities provided by digital technologies, there is a need to establish how different modes of virtual instruction can support students' academic achievement. Comparing individualized and collaborative virtual instruction may provide evidence on the learning benefits and limitations of each approach and inform decisions about their use in secondary school Biology. The findings may

also provide useful guidance for Biology teachers, curriculum planners and educational stakeholders seeking to integrate technology into teaching. Against this background, the present study examined the efficacy of individualized and collaborative virtual Biology instruction on secondary school students' academic achievement in Biology.

Research Questions

The following research questions guided the study;

1. What is the efficacy of individualized and collaborative virtual Biology instruction on students' mean academic achievement score in Biology?
2. What is the influence of cognitive ability levels on students' mean academic achievement score in Biology?
3. What is the interaction effect of modes of virtual Biology instruction and cognitive ability levels on students' academic achievement in Biology?

Hypotheses

The following null hypotheses were formulated for the study and tested at a 0.05 level of significance.

- Ho₁: There is no significant difference in the mean academic achievement score of students taught Biology using individualized and collaborative virtual Biology instruction.
- Ho₂: The influence of cognitive ability levels on students' mean academic achievement score in Biology is not significant.
- Ho₃: There is no significant interaction effect of modes of virtual Biology instruction and cognitive ability levels on students' academic achievement score in Biology.

Methods

The study adopted quasi experimental research design, specifically the non-equivalent control group design. The study was conducted in Obollo-Afor education zone of Enugu state. The population of this study comprised of 2,406 Senior Secondary School 2 (SSS2) students studying Biology in 43 public co-educational

secondary schools in Obollo-Afor Education Zone. This population comprises of 1038 male students and 1,757 female students. The sample size for the study consists of 144 (51 female and 93 males) senior secondary school two (SSS 2) Biology students, from four intact SSS 2 classes. Multistage sampling procedure used to select the secondary schools which were used for the study. First, simple random sampling technique (balloting without replacement) was used to select two LGAs out of the three LGAs in Obollo-Afor education zone. Then, purposive sampling technique was used to sample two senior secondary schools from each of the selected LGAs. The criteria for purposiveness include that the schools must have a functioning Biology laboratory, and have Biology teachers with adequate qualification for teaching Biology (a minimum of Nigerian Certificate in Education, NCE, in Biology). The schools must also possess a functional computer laboratory to allow the researcher host the instructional packages. Finally, one stream of SSS 2 class studying Biology, were then be selected from each of the four sampled schools, using simple random sampling technique. Two classes were then be assigned to the individualized virtual Biology instruction group, and the remaining two were be assigned to the collaborative virtual Biology instruction group. The number of students in these four intact classes made up the sample for the study.

The instruments for data collection are Biology Achievement Test (BAT) and Standardized Ability Test (SAT). A treatment instrument called Virtual Biology Instruction (VBI) was also developed for the study and stimulus instruments (lesson plans were also used). The instruments were validated by three experts in the University of Nigeria Nsukka, and trial-tested on 20 SS2 students of Community Secondary School, Obukpa. The experimental procedure spanned 6 weeks, covering training of research assistants, administration of pretests, instructional phase where sampled student groups were taught using individualized and collaborative virtual biology instruction, and administration of post-tests. Measures were adopted to control the following extraneous variables: experimental bias, school variable,

initial group difference, variability of instructional situation, teacher variable, subject interaction and effect of pre-test on post-test. The data collected from the study was analyzed using SPSS version 25. Mean and standard deviation was used to answer the research

questions posed for the study because these statistics measure average value, coverage and spread of the data. Analysis of Covariance (ANCOVA) with pretest as covariate was used to test the hypotheses formulated for the study at 0.05 level of significance.

Results

Findings from this study are presented in tables in line with the research questions and corresponding hypotheses which guided the study.

Table 1: Mean achievement scores and standard deviation of students exposed to individualized and collaborative virtual Biology instruction.

Group	N	Pre-Test X	SD	Post-Test X	SD	Adjusted Mean
Individualized	70	19.91	6.29	35.53	12.13	15.62
Collaborative	74	21.81	6.03	42.97	9.33	21.16

Results on Table 1 shows that the students exposed to collaborative virtual Biology instruction achieved higher than those exposed to individualized Biology instruction. The post-test standard deviation scores of 12.13 and 9.33 for students taught Biology using

individualized and collaborative virtual instruction indicates that the mean achievement score of students with individualized VBI varied more from their group mean than those of their counterparts taught with collaborative VBI.

Table 2: Summary of Analysis of Covariance (ANCOVA) for the mean achievement scores of students taught Biology using individualized and collaborative virtual Biology instruction.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4499.674	12	374.973	3.506	.000	.243
Intercept	10900.742	1	10900.742	101.918	.000	.438
Pre-Test	549.214	1	549.214	5.135	.025	.038
Treatment	454.974	1	454.974	4.254	.041	.031
Cognitive Ability	28.248	2	14.124	.132	.876	.002
Treatment * CA	366.602	2	183.301	1.714	.184	.025
Error	14011.263	131	106.956			
Total	241531.000	144				
Corrected Total	18510.938	143				

The result presented on Table 2 shows that there is a significant difference in the mean achievement scores of students taught Biology using individualized and collaborative virtual Biology instruction, $F(1,131) = 4.254$, $p = .041$, $\eta^2 p = .031$. This is because the associated probability (sig) value of 0.041 is less than 0.05 level of significance the hypothesis was formulated. Hence, the null hypothesis which

stated that there is significance difference in the mean achievement scores of students taught with individualized and collaborative virtual Biology instruction is rejected. Moreover, the effect size difference ($\eta^2 p = .031$) indicates that 3.1% variance exists between the mean achievement scores of students taught using two modes of virtual Biology instruction.



Table 3: Mean achievement scores and standard deviation of high, moderate and low cognitive ability students exposed to individualized and collaborative virtual Biology instruction.

Group	Pre-Test			Post-Test		Adjusted Mean
	N	X	SD	X	SD	
High	39	21.77	6.38	40.08	10.10	18.31
Moderate	81	20.38	6.21	40.11	12.07	19.73
Low	24	21.17	6.00	35.63	10.56	14.46

Results on Table 3 shows that cognitive ability level influenced the achievement of students with those moderate cognitive level having the highest achievement, followed by high and then low. The post-test standard deviation scores of 10.10, 12.07, and 10.56 for students with high, moderate and low cognitive ability levels taught Biology using individualized virtual instruction indicates that the mean achievement scores of students with moderate ability level varied more from their group mean than those of their counterparts.

The result presented on Table 2 also shows that the influence of cognitive ability

levels on students' mean achievement in Biology is not significant, $F(2,131) = .132$, $p = .876$, $\eta^2 p = .002$. This is because the associated probability (sig) value of 0.876 is greater than 0.05 level of significance. Hence, the null hypothesis which stated that the influence of cognitive ability levels on students' mean achievement in Biology is not significant is not rejected. Moreover, the effect size difference ($\eta^2 p = .002$) indicates that 0.2% variance exists between the mean achievement score of students with high, moderate and low ability levels taught using two modes of virtual Biology instruction.

Table 4: Mean achievement scores and standard deviation of students with high, moderate and low cognitive ability levels taught Biology using two modes of virtual Biology instruction.

Group	Gender	Pre-Test			Post-Test		Adjusted Mean
		N	X	SD	X	SD	
Individualized Virtual Instruction	High	8	17.75	4.06	36.88	13.61	19.13
	Moderate	43	19.65	6.58	35.95	12.68	16.3
	Low	19	21.42	6.29	34.00	10.66	12.58
Collaborative Virtual Instruction	High	31	22.81	6.50	40.90	9.09	18.09
	Moderate	38	21.21	5.75	44.82	9.49	23.61
	Low	5	20.20	5.26	41.80	8.35	21.6

The results showed that students' academic achievement in Biology improved across all cognitive ability levels following both individualised and collaborative virtual instruction. Under individualised instruction, students with high cognitive ability recorded the highest mean gain (19.13), followed by those with moderate (16.30) and low (12.58) cognitive ability. However, under collaborative instruction, students with moderate cognitive

ability recorded the highest mean gain (23.61), followed by those with low (21.60) and high (18.09) cognitive ability. These results indicate that collaborative virtual instruction produced greater improvements in achievement among students with moderate and low cognitive ability, while individualised virtual instruction produced a slightly higher mean gain among students with high cognitive ability.

The result presented on Table 2 shows that there is no significant interaction effect of modes of virtual Biology instruction and cognitive ability levels on students' mean achievement scores in Biology, $F(2,131) = 1.714$, $p = .184$, $\eta^2p = .025$. This is because the associated probability (sig) value of 0.184 is greater than 0.05 level of significance. Hence, the null hypothesis which stated that there is no significant interaction effect of modes of virtual Biology instruction and cognitive ability levels on students' mean achievement scores in

Biology is not rejected. Moreover, the effect size difference ($\eta^2p = .025$) indicates that 2.5% variance exists between the mean achievement scores of students with high, moderate and low ability level taught Biology using two modes of virtual Biology instruction. The interaction graph below shows that cognitive ability levels (high, moderate and low) plots against teaching strategy for Biology students' achievement scores does intercept, indicating that there is an interaction effect but it is not significant as indicated by the p-value.

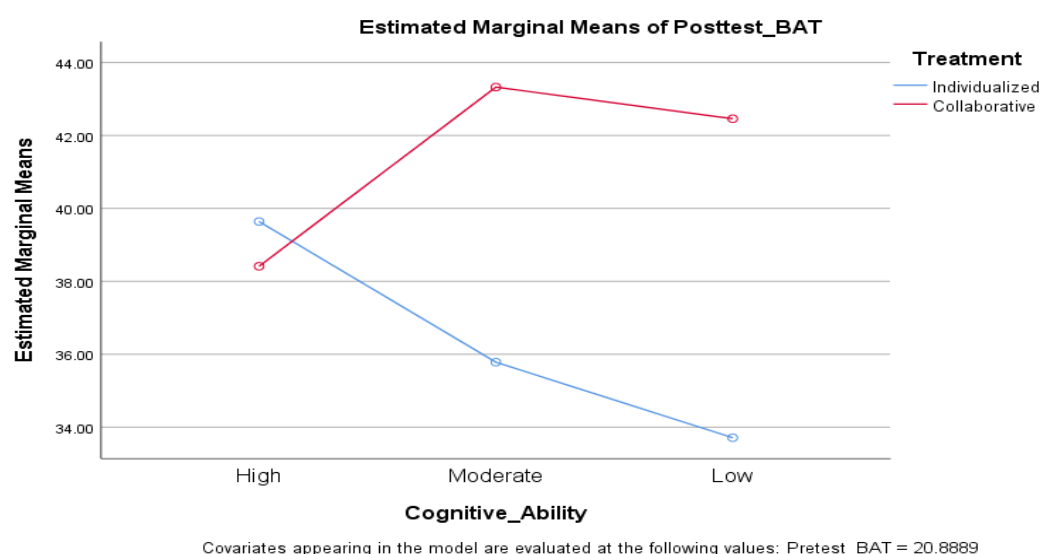


Figure 1: Graph showing the interaction effect for teaching strategies and cognitive ability levels on Biology students' achievement.

Discussion of Findings

The findings revealed that students taught Biology through collaborative virtual instruction achieved higher post-test mean scores than those taught through individualised virtual instruction, indicating that collaborative instruction was more effective in improving students' academic achievement. This may be attributed to the opportunities for peer interaction, knowledge sharing, group discussions and immediate feedback provided by collaborative learning. Through these activities, students can clarify difficult biological concepts, correct misconceptions and develop a better understanding of lesson content. The findings suggest that collaborative virtual instruction can support students' academic achievement by promoting active participation and shared knowledge

construction. The findings revealed that students taught Biology through collaborative virtual instruction achieved higher post-test mean scores than those taught through individualised virtual instruction, indicating that collaborative instruction was more effective in improving students' academic achievement. This may be attributed to opportunities for peer interaction, knowledge sharing, group discussions and immediate feedback, which enable students to clarify difficult concepts, correct misconceptions and develop a better understanding of Biology. This finding is supported by Driessen et al. (2024), whose meta-analysis of 91 studies found that group work significantly improved academic performance in Biology. Similarly, Tian and Zheng (2024) found that online collaborative problem-solving had a positive effect on

students' learning performance. These findings suggest that collaborative virtual instruction can improve students' academic achievement by promoting active participation and shared knowledge construction.

The findings revealed that cognitive ability had no statistically significant influence on students' academic achievement in Biology. Although students with high, moderate and low cognitive ability levels improved their achievement following the instructional intervention, those with high cognitive ability recorded the greatest mean gain. This suggests that students' cognitive ability may be associated with differences in the extent of improvement, even when the overall differences are not statistically significant. The findings also indicate that both collaborative and individualised virtual instruction can improve academic achievement across different cognitive ability levels. This highlights the importance of using instructional approaches that accommodate students' varying learning abilities and provide equal opportunities for academic improvement. The findings revealed that cognitive ability had no statistically significant influence on students' academic achievement in Biology. Although students with high, moderate and low cognitive ability recorded improvements following the instructional intervention, those with high cognitive ability achieved the greatest mean gain. This suggests that cognitive ability may be associated with differences in students' academic achievement, even though the observed differences were not statistically significant. The findings also indicate that both collaborative and individualised virtual instruction can improve academic achievement across different cognitive ability levels. This is consistent with Peng and Kievit (2020), who found that cognitive abilities and academic achievement are related, with the strength of this relationship varying across developmental stages. Their findings also suggest that effective instruction can contribute to the development of cognitive abilities. The present study therefore highlights the importance of adopting instructional strategies that support students with different cognitive ability levels and

provide opportunities for academic improvement.

The findings revealed no significant interaction effect of teaching strategy and cognitive ability on students' academic achievement in Biology. This indicates that the effectiveness of collaborative and individualised virtual instruction did not differ significantly across students with high, moderate and low cognitive ability levels. Both instructional approaches supported improvements in students' academic achievement, irrespective of their cognitive ability. Although students may differ in their ability to process and understand information, the findings suggest that these differences did not significantly influence the effectiveness of the instructional strategies. Collaborative virtual instruction may provide opportunities for peer discussion, knowledge sharing and clarification of difficult concepts, while individualised instruction allows students to learn at their own pace. The findings revealed no significant interaction effect of teaching strategy and cognitive ability on students' academic achievement in Biology. This indicates that the effectiveness of collaborative and individualised virtual instruction did not differ significantly across students with high, moderate and low cognitive ability levels. Both instructional approaches supported improvements in academic achievement, irrespective of students' cognitive ability. This finding is consistent with Adewumi and Adeoye (2022), who investigated the interaction between instructional strategies and students' mental ability in Biology. Their study provides relevant evidence on how instructional approaches and students' abilities relate to academic achievement. The present finding suggests that collaborative and individualised virtual instruction can support students with different cognitive ability levels without one group having a statistically significant advantage arising from the interaction between teaching strategy and cognitive ability.

Conclusion

The study concluded that collaborative and individualised virtual Biology instruction improved students' academic achievement

across different cognitive ability levels. Although students with high cognitive ability recorded greater mean gains under individualised instruction, those with moderate and low cognitive ability benefited more from collaborative instruction. However, cognitive ability had no significant influence on students' academic achievement, and there was no significant interaction effect between teaching strategy and cognitive ability. These findings suggest that both instructional approaches can support Biology learning among students with different cognitive ability levels and should be considered in planning and delivering Biology lessons.

Recommendations

The following recommendations are made:

1. Biology teachers should adopt collaborative virtual instruction to improve students' academic achievement, particularly by encouraging peer discussions, group activities and knowledge sharing during Biology lessons.
2. Biology teachers should use both collaborative and individualised virtual instruction to accommodate students with different cognitive ability levels and provide varied learning experiences.
3. Biology teachers should provide equal learning opportunities for students with high, moderate and low cognitive ability by designing instructional activities that encourage active participation and support individual learning needs.
4. School administrators and educational authorities should provide adequate ICT facilities and internet access to support the effective implementation of collaborative and individualised virtual Biology instruction in secondary schools.
5. The Ministry of Education and curriculum planners should organise professional development programmes to equip Biology teachers with the skills required to design and implement virtual instructional activities that improve

students' academic achievement across different cognitive ability levels.

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