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Effects of a Contextual Approach Mediated by Digital Technology and Automation Literacy on Biology Achievement among Secondary School Students with Low, Medium and High-Ability Levels in Kaduna State, Nigeria

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Abstract

This study investigated the effect of the Contextual Approach on Biology achievement using digital technology and automation literacy among secondary school Biology students of varied ability levels in Kaduna State, Nigeria. As artificial intelligence and automation reshape the global workforce, digital literacy and automation skills are increasingly vital for STEM instruction. A quasi-experimental pretest-posttest control group design was employed with 172 Senior Secondary II students, randomly assigned to experimental and control groups and further classified into low, medium, and high ability levels. The Biology Achievement Test (BAT) was validated and pilot-tested, yielding reliability coefficients of 0.84 and 0.79. Instruction lasted six weeks, with the experimental group taught using digital sensors, mobile identification applications, and automated data-logging tools within the Contextual Approach, while the control group received conventional lecture-based teaching. Results revealed significant performance differences across all ability levels in favour of the experimental group. Findings suggest that embedding digital technology and automation literacy into contextual instruction enhances Biology achievement inclusively. It is recommended that teachers adopt this approach and that education authorities provide training and resources to support its implementation.

Keywords: contextual teaching and learning, biology achievement, digital technology literacy, automation literacy, varied ability

1 Introduction

The rapid advancement of artificial intelligence (AI) and automation is transforming the global workforce at an unprecedented pace, creating both new opportunities and significant challenges for educational systems worldwide. Education has long been recognized as an investment in national development, and Bichi (2019) affirmed that it guarantees economic growth, technological advancement, and equitable employment opportunities. Yet the growing presence of digital tools and automated systems in everyday life demands that STEM instruction itself be delivered using digital technology and automation literacy, so that students not only learn scientific content but also acquire the practical digital competencies that increasingly mediate scientific work. Nations across the globe, including Nigeria, recognize that no country can advance without a robust science education programme. The Federal Government of Nigeria, through its National Policy on Education (FRN, 2013), emphasizes science education goals that include producing scientists for national development, preparing students to observe and explore their environment, and developing critical and reflective thinking. These goals are increasingly achieved by embedding digital technology and automation literacy directly into instructional delivery, so that Biology achievement is built through, not merely about, digital tools. Biology education, as a gateway to medicine, biotechnology, bioinformatics, environmental science, and artificial intelligence applications in health, sits at the intersection of traditional science and the emerging digital economy.

However, Haruna (2021) noted that many Biology concepts remain difficult for students to grasp, and Kamar (2015) observed that Biology knowledge is foundational to national development yet consistently taught through passive, lecture-dominated methods ill-suited to a digitally mediated future. Benjamin and Emmanuel (2017) found that SS II students perceived several Biology topics as particularly difficult, including Environmental Pollution and Conservation of Natural Resources. These topics lend themselves naturally to instruction delivered using digital technology and automation literacy: for instance, mobile plant-identification applications, automated air- and water-quality sensors, and automated data-logging tools allow students to encounter these concepts as live, digitally mediated STEM practice rather than abstract lecture content.

Muchtar (2017) described the Contextual Approach as a pedagogical conception that helps teachers connect subject matter to real-world situations, motivating students to link knowledge with its applications in everyday life, including in the contexts of family, community, and work. When digital technology and automation literacy are used as the vehicle for this approach; for example, through digital sensors, mobile identification tools, and automated data-logging; the Contextual Approach becomes especially well-suited to building Biology achievement for an AI-age workforce, since its grounds learning in authentic, technology-mediated problems. Ekwue and Umukoro (2011) observed that students learn and retain knowledge more effectively when it is meaningfully connected to their lived experiences, while Kukliansky and Eshach (2013) underscored the importance of contextual reasoning in science education. Umar (2019) and Hassan (2020) identified over-reliance on the lecture method and poor student attitudes as key factors in Biology underperformance challenges. Yet much of this literature treats the Contextual Approach and digital or automation literacy as separate strands of inquiry: studies on contextual instruction (Ekwue & Umukoro, 2011; Kukliansky & Eshach, 2013) rarely employ digital or automated tools as the instructional medium, while studies on digital tools in science teaching rarely situate them within an explicit contextual pedagogy. Few, if any, Nigerian studies have examined digital technology and automation literacy as the operational vehicle of contextual instruction, and none appear to have done so across differentiated ability levels in Biology, a gap the present study sought to fill. Addressing this gap is particularly pressing given that digital-technology and automation-mediated contextual instruction is well positioned to address the underperformance challenges identified above.

Ability grouping is another important dimension of effective STEM instruction. Lakpini (2006) categorised students into low (0–49%), medium (50–59%), and high (≥60%) ability levels. Understanding how digital technology and automation literacy, used within the Contextual Approach, interacts with these ability levels is critical for designing inclusive STEM education policies that leave no learner behind in an automation-driven world. This study, therefore, investigated the effects of the Contextual Approach on Biology achievement using digital technology and automation literacy among secondary school Biology students across ability levels in Kaduna State, Nigeria. Establishing whether this effect holds consistently for low-, medium-, and high-ability students is significant on two counts: theoretically, it extends the Contextual Approach literature by repositioning digital technology and automation literacy as an instructional medium rather than a standalone skill set; practically, it generates ability-level-specific evidence to guide Biology teachers, curriculum developers, and policymakers seeking to build an inclusive, AI-ready STEM workforce in which no ability group is left behind. The study was guided by the following research questions:

1. What is the difference in mean Biology achievement scores of low-ability students taught Biology using the Contextual Approach mediated by digital technology and automation literacy compared to those taught with the lecture method?
2. What is the difference in mean Biology achievement scores of medium-ability students taught Biology using the Contextual Approach mediated by digital technology and automation literacy compared to those taught with the lecture method?
3. What is the difference in mean Biology achievement scores of high-ability students taught Biology using the Contextual Approach mediated by digital technology and automation literacy compared to those taught with the lecture method?

Based on research questions stated, the following null hypotheses were formulated and tested at $P \leq 0.05$ level of significance:

H_{01}: There is no significant difference between the mean Biology achievement scores of low-ability students taught Biology using the Contextual Approach mediated by digital technology and automation literacy and those taught using the lecture method.

H_{02}: There is no significant difference between the mean Biology achievement scores of medium-ability students taught Biology using the Contextual Approach mediated by digital technology and automation literacy and those taught using the lecture method.

H_{03}: There is no significant difference between the mean Biology achievement scores of high-ability students taught Biology using the Contextual Approach mediated by digital technology and automation literacy and those taught using the lecture method.

2 Literature Review/Theoretical Framework

Several Nigerian and regional studies have examined the effect of contextual or context-based approaches on students' academic outcomes. Miyambo (2020) used a qualitative case-study design to investigate Biology teachers' context-based approach (CBA) knowledge in designing 'O' level Biology lessons in Kafue District, Zambia, sampling six teachers and 30 students across three schools; the study found that teachers demonstrated CBA knowledge in designing engaging lessons, using observation, interview, focus-group, and document-analysis instruments analysed thematically. Adamu (2020) employed a quasi-experimental pretest-posttest design with a sample of 49 SS III students across the Zaria and Giwa educational zones of Kaduna State to examine the effect of the Contextual Teaching-Learning approach on students' attitude to mathematics, using a validated Mathematics Attitude Questionnaire ($r = 0.94$) and t-test analysis; students exposed to the approach showed a significant positive attitude change. Similarly, Obikezie et al., (2021) used a quasi-experimental design with 130 students across six education zones in Anambra State to test the effect of the Contextual Teaching-Learning Approach (CTLA) on chemistry retention, using the Contextual Learning Chemistry Retention Test and t-test analysis, and found a significant positive effect on retention. Sunday and Audu (2021), using a quasi-experimental nonequivalent control-group design with 144 students in Katsina metropolis, similarly found that a contextual teaching strategy produced significantly higher geometry achievement scores than the conventional method.

Taken together, these four studies establish a consistent trend: across subjects as varied as Biology, mathematics, chemistry, and geometry, and across designs ranging from qualitative case studies to quasi-experiments, contextual and context-based approaches are consistently associated with improved academic attitude, retention, or achievement relative to conventional instruction. This convergence across subject areas strengthens the empirical case for the Contextual Approach adopted in the present study. However, none of these four studies examined Biology specifically at the Senior Secondary II level, none focused on the topic of environmental pollution and conservation of natural resources, and, most importantly, none operationalised the Contextual Approach through digital technology or automation literacy: in all four studies, contextual instruction was delivered through conventional classroom activity rather than through digital sensors, mobile identification tools, or automated data-logging. This is the first gap the present study addresses.

A good number of studies based in Kaduna have examined how varied instructional strategies interact with students' ability levels (low, medium, high). Ibrahim (2018) used a quasi-experimental pretest-posttest-post-posttest design with 110 pre-NCE Biology students, stratified by ability level after pretesting, to examine the 5E Teaching Cycle's effect on genetics retention (GAPT, $r = 0.79$), analysed using ANCOVA; students across all ability levels retained more under the 5E cycle than under the lecture method. Aliyu and Ibrahim (2019) used a quasi-experimental pretest-posttest design with 122 SS II students in Sabon Gari Local Government Area to test the Student Team Achievement Division (STAD) cooperative strategy on three-dimensional-shapes performance (TDBAT, $r = 0.95$), finding a significant performance advantage for STAD over the conventional method across ability groups. Maikano and Maikano (2020), working with 153 SS II students in the Sabon Tasha education zone, compared Computer-Assisted Instruction (CAI) and the Science Process Approach (SPA) against the Lecture Method (LM) on Biology performance (BPT, $r = 0.84$) across high, medium, and low-ability groups; using two-way ANOVA, they found that while CAI and SPA produced only slight mean-score differences across ability levels, the lecture method produced pronounced ability-based gaps, with high- and medium-ability students scoring markedly higher than low-ability students, leading the authors to recommend CAI and SPA as more equitable pedagogies. Mohammed, Omwirhirem, and Abubakar (2021), sampling 81 SS II chemistry students in the Zaria education zone, similarly found that the 5E Teaching Cycle improved mole-concept retention across all ability levels relative to the lecture method (MCRT, $r = 0.80$), with no significant gender difference.

These studies surface both a trend and an implicit debate relevant to the present study. The trend is that, across Biology, chemistry, and mathematics, activity-based and technology-assisted strategies (5E, STAD, CAI) consistently narrow the ability-based performance gap that the conventional lecture method tends to widen, as Maikano and Maikano's (2020) ANOVA results most starkly illustrate. The implicit debate concerns which specific ingredient drives this equity effect, structured activity sequencing as in the 5E cycle, cooperative peer interaction as in STAD, or computer-based delivery as in CAI, since the studies reviewed here do not disentangle these mechanisms: none combined a contextual pedagogy with digital or automated instructional tools within a single treatment. This is a second, and more critical, gap: while ability-differentiated studies in Kaduna State confirm that technology- and activity-based methods narrow ability gaps, and contextual and context-based studies confirm that contextual pedagogy improves retention, and achievement, no identified study has combined the two, that is, examined the Contextual Approach specifically as mediated by digital technology and automation literacy, on Biology achievement, across low, medium, and high-ability SS II students.

The literature reviewed above therefore converges on two established but so far unconnected findings: contextual pedagogy reliably improves academic outcomes, and technology-assisted, activity-based instruction reliably narrows ability-based performance gaps. The present study is positioned at the intersection of these two literatures, testing whether a Contextual Approach that is itself delivered through digital technology and automation literacy, specifically mobile plant-identification applications and automated data-logging tools, produces the combined benefit that neither literature has yet demonstrated on its own: subject-specific Biology achievement gains together with equitable outcomes across ability levels.

This study was anchored on Constructivism, as advanced by Piaget (1975), Vygotsky (1978), and Ausubel (1968). Constructivism holds that learners actively construct their own understanding of the world through experience and reflection, rather than passively absorbing information transmitted by a teacher. Its key constructs include prior knowledge, learners interpret new information through their existing conceptions; active engagement, learners build knowledge through experimenting, questioning, and problem-solving; and social and environmental mediation, Vygotsky's emphasis on scaffolding and guided interaction as a bridge between a learner's current and potential understanding. Its central assumption is that meaningful, durable learning occurs when learners are given authentic tasks that let them reconcile new information with what they already know, with the teacher acting as a facilitator who diagnoses learners' pre-existing conceptions and structures activities accordingly, rather than as a transmitter of ready-made facts. Constructivism therefore transforms students from passive recipients of information into active participants in the learning process.

Constructivism is directly relevant to the present study because both the Contextual Approach and digital-technology-and-automation-mediated instruction are constructivist in character: the Contextual Approach operationalizes constructivism by situating Biology concepts, such as environmental pollution, in real-world problems that learners can question and explore, while digital tools such as mobile plant-identification applications and automated data-logging sensors serve as the scaffolds through which students actively construct STEM understanding rather than receive it passively. This theory directly informs three elements of the present study's design. First, the Contextual Approach, mediated by digital technology and automation literacy, as the treatment variable, justifies the constructivist premise that authentic, technology-supported experience produces more durable learning than lecture-transmitted facts. Second, it justifies the study's attention to ability level (low, medium, high) as a moderating variable, since constructivism holds that learners construct knowledge from their existing conceptions, which differ systematically by ability. Third, it shapes the interpretation of Biology achievement gains as evidence of active knowledge construction rather than of rote memorization, since constructivist theory predicts that instruction anchored in real, technology-mediated experience should produce more durable and transferable learning than passive reception of content.

3 Methodology

The study employed a quasi-experimental design, specifically a pretest-posttest, non-equivalent control group design using intact classes. This design was considered appropriate because it permits comparison of an experimental and a control group under natural classroom conditions while controlling pre-existing differences through the pretest. The study was conducted in Kaduna north education zone, Kaduna State, Nigeria. The population of the study comprised 7,954 Senior Secondary II (SS II) Biology students drawn from 24 public secondary schools within the zone. To guard against pre-existing school-level differences in Biology achievement, four schools within the zone (Labelled as school A, B, C and D) were first screened for pretest homogeneity using the BAT; a one-way ANOVA followed by Scheffe post hoc comparison showed that School A, B, and D formed a single homogeneous subset, while school D differed significantly and was excluded. From the three homogeneous schools, School A and B were selected by simple random sampling (balloting) and randomly assigned to the Experimental Group (EG) and the Control Group (CG) respectively. One intact SS II Biology class was used in each school.

Students in both groups were subsequently classified into low, medium, and high ability levels using a composite of each student's BAT pretest score and their average score on the two Biology terminal examinations immediately preceding the study, banded according to Lakpini's (2006) classification (low = 0–49%, medium = 50–59%, high ≥ 60%). Because this composite naturally sorts students unevenly across the three bands, the ability-level cells are of unequal size within each group; the modest difference in overall EG/CG size (94 vs. 78) similarly reflects the difference in intact class size between the two schools at pretest (100 at GSS Badarawa vs. 72 at Rafin Guza), consistent with the use of intact classes in a quasi-experimental design. Applying this classification yielded a total sample of 172 students: EG = 94 students (low 28, medium 50, high 16); CG = 78 students (low 19, medium 46, high 13).

The research instrument used for data collection was the Biology Achievement Test (BAT), consisting of 50 multiple-choice items drawn from WASCE past questions on Environmental Pollution and Conservation of Natural Resources. Items assessed general Biology achievement while embedding scenarios delivered using digital technology and automation literacy, including mobile plant-identification applications, automated water, soil, and air quality sensors, automated noise-pollution monitoring, and automated conservation data-logging systems. The face and content validity of the BAT were established by two Science Education specialists at Ahmadu Bello University, Zaria, who reviewed the instrument for clarity, alignment with the WASCE Biology curriculum, and the appropriateness of the embedded digital-technology scenarios, and whose observations were used to revise the final version of the instrument. The reliability of the instrument was established through a pilot test administered to students outside the main sample, using the test-retest method at a two-week interval; the resulting scores yielded a Pearson Product Moment Correlation Coefficient of $r = 0.84$, indicating strong reliability.

Data collection followed a systematic sequence. Permission to conduct the study was obtained from Kaduna State Ministry of Education and Kaduna North Education zone and from the authorities of the two selected schools. The regular Biology teachers in both schools were briefed and trained by the researcher on the procedures to assist while the researcher deliver their respective treatments, the Contextual Approach mediated by digital technology and automation literacy tools for the experimental group, and the conventional lecture method for the control group. The BAT was administered as a pretest to both groups before the commencement of treatment, to establish baseline equivalence between the groups, then both groups were taught for six weeks: the experimental group received instruction via the Contextual Approach, delivered using digital technology and automation literacy tools, including a mobile plant-identification application (PlantNet) and automated data-logging devices, to situate Biology concepts within authentic, technology-mediated, real-world scenarios; the control group was taught the same content using the conventional lecture method, without these digital tools. At the end of the six weeks, a parallel form of the BAT was re-administered to both groups as a posttest, under the same test conditions as the pretest. Finally, scripts were marked by the researcher using a uniform marking scheme, and scores were coded and entered for statistical analysis. Research questions were answered using descriptive statistics, mean, standard deviation, and mean difference, while the three null hypotheses were tested using independent-samples t-test at the 0.05 level of significance, with the aid of the Statistical Package for Social Sciences (SPSS).

4 Results

4.1 Baseline (Pretest) Equivalence

Before the six-week intervention began, the BAT was administered as a pretest to the intact SS II Biology classes at both selected schools, (the Experimental Group and the Control Group), to establish baseline equivalence. Table 1 reports the descriptive pretest statistics and Table 2 reports the independent-samples t-test comparing the two groups at pretest.

Table **1**

Pretest Mean and Standard Deviation of BAT Scores for the Experimental and Control Groups (Prior to Ability Grouping)

Group	N	Mean	STD	Mean difference
EG	94	23.82	2.64	
				-0.29
CG	78	24.11	3.00	

Table 1 shows pretest means of 23.82 (SD = 2.64, N = 98) for (EG) and 24.11 (SD = 3.00, N = 76) for (CG), a mean difference of only 0.29 points, indicating that the two groups entered the study with closely comparable Biology achievement.

Table **2**

Independent-Samples t-Test of Pretest BAT Scores for the Experimental and Control Groups

Group	N	Mean	STD	Mean diff.	Df	t-value	p	R
EG	94	23.82	2.64					
				-0.29	170	-0.67	0.50	NS

CG	78	24.11	3.00

An independent-samples t-test confirmed that the pretest difference between the two groups was not statistically significant, $t(170) = -0.67$, $p = .50$, $d = -0.10$ (a negligible effect), indicating that the Experimental and Control groups were statistically equivalent in Biology achievement before treatment began. This baseline equivalence supports attributing the significant posttest differences reported below to the treatment rather than to pre-existing group differences. As a further check on the comparability of the sampled schools, a one-way ANOVA was conducted on pretest BAT scores across the four schools initially considered within the zone (School A, B, C, and D) $F (3, 284) = 106.75$, $p < .001$. A Scheffe post hoc test showed that School A, B and D formed a single statistically homogeneous subset (Sig. = .827), whereas School C scored significantly higher than the other three schools ($p < .001$) and was therefore not selected for the study. School A and B, both members of the homogeneous subset, were subsequently selected by balloting and randomly assigned to the Experimental and Control conditions respectively, providing further assurance that the two groups were drawn from populations of comparable prior Biology achievement.

Research Question One

What is the difference in mean Biology achievement scores of low-ability students taught Biology using the Contextual Approach mediated by digital technology and automation literacy and those taught with the lecture method?

Table **3**

Mean and Standard Deviation of Posttest BAT Scores for Low-Ability Students

Group	**N**	**Mean**	**STD**	**Mean difference**
Exp. (Digital-Technology-Mediated Contextual Approach)	28	33.10	2.08	10.58
Control (Conventional Lecture Method)	19	22.53	3.20	

Table 3 revealed mean Biology achievement scores of 33.10 (SD = 2.08) and 22.53 (SD = 3.20) for the experimental and control groups respectively, yielding a mean difference of 10.58 in favour of the group taught using digital technology and automation literacy within the Contextual Approach.

Hypothesis One: Independent Sample t-Test

Table **4**

Independent Sample t-Test of Posttest BAT Scores for Low-Ability Students

Group	**N**	**Mean**	**STD**	**Mean diff.**	**Df**	**t-value**	**p**	**R**
Exp.(Digital-Technology-Mediated Contextual Approach)	28	33.10	2.08	10.58	45	13.76	0.00	Sig
Control (Conventional Method)	19	22.53	3.20					

*Significant at $P \leq 0.05$ level.

An independent-samples t-test showed a statistically significant difference between the two groups, $t(45) = 13.76$, $p < .001$, $d = 4.09$ (95% CI approx. 3.2–5.0), a very large effect size by conventional benchmarks. Null Hypothesis One is therefore rejected.

Research Question Two: Medium-Ability Students

Table **5**

Mean and Standard Deviation of Posttest BAT Scores for Medium-Ability Students

Group	N	Mean	STD	Mean difference
Exp. (Digital-Technology-Mediated Contextual Approach)	50	33.06	2.01	
				10.69
Control(Conventional Lecture Method)	46	22.37	3.14	

Table 5 revealed mean Biology achievement scores of 33.06 (SD = 2.01) and 22.37 (SD = 3.14) for the experimental and control groups respectively, yielding a mean difference of 10.69 in favour of the group taught using digital technology and automation literacy within the Contextual Approach.

Hypothesis Two: Independent Sample t-Test

Table **6**

Independent Sample t-Test of Posttest BAT Scores Medium-Ability Students

Group	N	Mean	STD	Mean diff.	df	t-value	p-value	R
Exp. (Digital-Technology-Mediated Contextual Approach)	50	33.06	2.01					
				10.69	94	19.99	0.00	Sig
Control (Conventional Method)	46	22.37	3.14					

*Significant at $P \leq 0.05$ level.

An independent-samples t-test showed a statistically significant difference between the two groups, $t(94) = 19.99$, $p < .001$, $d = 4.09$ (95% CI approx. 3.5–4.7), a very large effect size. Null Hypothesis Two is therefore rejected.

Research Question Three: High-Ability Students

Table 7

Mean and Standard Deviation of Posttest BAT Scores High-Ability Students

Group	N	Mean	STD	Mean difference
Exp (Digital-Technology-Mediated Contextual Approach)	16	32.88	2.55	
				9.26
Control (Conventional Lecture Method)	13	23.62	2.96	

Table 7 revealed mean Biology achievement scores of 32.88 (SD = 2.55) and 23.62 (SD = 2.96) for the experimental and control groups respectively, yielding a mean difference of 9.26 in favour of the experimental group.

Hypothesis Three: Independent Sample t-Test

Table **8**

Independent Sample t-Test of Posttest BAT Scores — High-Ability Students

Group	N	Mean	STD	Mean diff.	Df	t-value	P	R
Exp. (Digital-Technology-Mediated Contextual Approach)	16	32.88	2.55	9.26	27	9.05	0.00	Sig
Control (Conventional Lecture Method)	13	23.62	2.96					

*Significant at P ≤ 0.05 level.

An independent-samples t-test showed a statistically significant difference between the two groups, t(27) = 9.05, p < .001, d = 3.38 (95% CI approx. 2.4–4.3), a very large effect size. Null Hypothesis Three is therefore rejected.

5 Discussions

Across all three ability levels, students taught using the Contextual Approach delivered via digital technology and automation literacy recorded significantly higher posttest Biology achievement scores than those taught using conventional lecture instruction, with very large effect sizes (d = 3.4–4.1). Because the Experimental and Control groups were shown to be statistically equivalent at pretest (t(170) = -0.67, p = .50), these posttest gains can reasonably be attributed to the treatment rather than to pre-existing differences between the groups. For low-ability students, learning mediated by digital tools such as mobile identification applications and automated sensors appears to bridge the gap between abstract biological concepts and tangible, technology-mediated experience. When students use automated tools to identify plants, log environmental data, and interpret automatically generated readings, they engage cognitively in ways the lecture method does not facilitate. These findings align with Suleiman et al. (2015) and Omeiza (2019), and contrast with Williams and Akpan (2017), whose null result reflect differences in concept selection and student ability profiles.

For medium-ability students, instruction delivered using digital technology and automation literacy connects academic content to the everyday technological realities these learners are already navigating. This is critical in Nigerian public schools where awareness of digital tools is growing but formal STEM engagement remains limited. As Ahmad (2017) and Miyambo (2020) found, context-based approaches meaningfully improve secondary school Biology achievement, particularly when digital tools make the relevance of STEM content to students' own futures more visible; this is also broadly consistent with Adamu (2020), who reported a significant positive shift in Kaduna State students' attitude following contextual instruction, suggesting that the performance gain observed here may be reinforced by a parallel improvement in attitude toward the subject.

Among high-ability students, digital-technology and automation-mediated contextual instruction not only maintained their performance advantage but amplified it, encouraging deeper engagement, cross-disciplinary STEM reasoning, and the kind of self-directed inquiry that will be essential in AI-age careers in biotechnology, environmental data analytics, and computational biology, corroborating Sunday and Audu (2021) and Obikezie, Abumchukwu and Chikendu (2021). The mean difference recorded for high-ability students (9.26) was the smallest of the three ability groups, compared with 10.58 for low-ability and 10.69 for medium-ability students. This was not anticipated given that high-ability students are typically expected to derive the greatest benefit from an enriched instructional method. A plausible explanation could be that the high-ability control group already recorded the highest control-group mean of the three ability levels (23.62), leaving comparatively less room for improvement than the low- and medium-ability control groups. Smaller gains among high-ability students does not indicate a weaker effect of the treatment itself but rather reflects the more limited headroom available for further gain among students already performing relatively well under conventional instruction. The consistency of results across ability groups underscores the equity dimension of this approach: using digital technology and automation literacy to teach STEM does not merely benefit the academically advantage but raises the floor for all learners.

Theoretically, these findings extend the Constructivist framework underpinning this study by showing that digital and automated tools can function as the concrete, manipulable scaffolds through which learners at every ability level actively construct STEM knowledge, rather than as a supplementary layer added to an otherwise unchanged lecture method. The consistent, statistically significant gains recorded across all three ability groups support the constructivist premise that authentic, technology-mediated experience produces more durable learning than passive reception of ready-made facts and extend the Contextual Approach literature specifically by demonstrating that digital technology and automation literacy can serve as its operational medium rather than as a standalone skill set. Practically, the findings offer Biology teachers, curriculum developers, and policymakers' ability-level-specific evidence that a digitally mediated Contextual Approach can be adopted as a single, inclusive instructional strategy rather than requiring separate interventions for lower and higher performing students, which is of particular relevance to under-resourced Nigerian public secondary schools seeking a cost-effective route to building an AI-ready STEM workforce.

This study is not without limitations. The six-week intervention period, while sufficient to detect a significant short-term effect, cannot speak to whether the performance gains reported here are sustained over a longer period. The study was restricted to a single topic, Environmental Pollution and Conservation of Natural Resources, within a single subject and geographic zone, which may limit the generalization of the findings to other Biology topics, other STEM subjects, or other parts of Nigeria. Fourth, Biology achievement was measured solely through a multiple-choice instrument (the BAT); this captures conceptual and applied knowledge but does not directly assess students' hands-on digital or automation literacy skills, such as their competence in operating the mobile identification applications or data-logging tools themselves. One further limitation should be acknowledged: although the BAT items embed scenarios delivered using digital tools, the instrument is fundamentally a convergent-response Biology content-knowledge test; it does not itself measure students' ability to use digital technology or interpret automated data, and the outcome variable is accordingly reported here as Biology achievement rather than as a direct measure of digital or automation literacy. Future research should therefore consider school administrative structures permit, extend the intervention period to assess the durability of performance gains, and replicate the study across other Biology topics, other STEM subjects, and other Nigerian states to test the generalization of these findings. Future studies should also incorporate performance-based assessments of students' digital and automation literacy skills alongside conceptual Biology achievement tests and might usefully examine teacher digital competence as a potential moderating variable, given that the effectiveness of a digitally mediated Contextual Approach is likely to depend in part on how confidently and consistently individual teachers use the underlying digital tools.

6 Conclusion

This study set out to examine the effects of the Contextual Approach on Biology achievement, using digital technology and automation literacy as the instructional medium, among low, medium, and high ability Senior Secondary Biology students in Kaduna State, Nigeria. This objective was achieved: across all three ability levels, students taught using the digital-technology-and-automation-mediated Contextual Approach recorded significantly higher Biology achievement scores than those taught using the conventional lecture method, and all three null hypotheses were accordingly rejected. The study's principal contribution to theory is to extend the Constructivist and Contextual Approach literature by demonstrating that digital and automated tools, rather than being taught as an isolated skill set, can themselves serve as the operational medium through which learners at every ability level actively construct STEM knowledge. Its principal contribution to practice is to show that this single, digitally mediated instructional strategy narrows rather than widens the ability-based performance gap, offering Biology teachers and curriculum developers concrete, ability-level-specific evidence for adopting the Contextual Approach as an inclusive route to STEM competence for an AI-driven workforce.

Taken together, these findings suggest that embedding digital technology and automation literacy within everyday classroom pedagogy, rather than treating it as supplementary content, is a viable and equitable strategy for preparing Nigerian secondary school students, across the full range of academic ability, for a future defined by automation. Detailed recommendations for classroom practice and teacher training are presented below, while replication of other Biology topics, other STEM subjects, and larger, multi-zone samples remains a priority for future research.

1. Secondary school Biology teachers should integrate digital technology and automation literacy as instructional tools within the Contextual Approach, especially for concepts with direct applications in environmental monitoring and automated scientific work.
2. Biology teachers should design contextual learning activities that use digital technology and automation literacy such as mobile identification applications and automated data-logging tools to build Biology achievement through real-world problem-solving.
3. The Ministry of Education, Kaduna State, should institutionalise regular teacher training through seminars, workshops, and conferences, specifically focused on delivering contextual instruction using digital technology and automation literacy.
4. School administrators should support Biology departments in acquiring and utilising appropriate digital tools and automated instructional resources to facilitate contextual, hands-on STEM learning environments.
5. Curriculum developers should revise the Senior Secondary Biology curriculum to explicitly incorporate digital technology and automation literacy as instructional media for building Biology achievement, rather than as standalone content.

7 Declaration

Ethical Considerations: The study observed standard ethical procedures for research involving minors. Introductory letter was collected from the Ahmadu Bello University, an acceptance letter from Kaduna north education zone and principals of the two selected schools. Written permission was obtained from the school authorities prior to data collection. Because participants were minors, informed consent was sought from school authority, in addition to the assent of the students themselves. Participation was entirely voluntary, and students were informed of their right to withdraw from the study at any point without penalty. Student anonymity was protected through the use of coded identifiers in place of names, and all data collected were stored securely and used strictly for the purposes of this research. To address the ethical concern of instructional disadvantage, the control group continued to receive standard Biology instruction throughout the study, and the researcher offered to share the Contextual Approach materials with the control group's teacher after data collection was completed.

Conflict of Interest: The authors declare no financial or non-financial conflicts of interest.

Author Contributions: HYH (Dr. Hassan Hadiza Yakubu), as the lead researcher, conceived and designed the study, secured permissions, supervised data collection, conducted the statistical analysis, and drafted the manuscript. IAU (Professor I. A. Usman) provided overall supervision of the study, contributed to its conceptualization and theoretical framing, and critically reviewed and revised the manuscript for important intellectual content. ASU (Dr. Umar Amina Salihu), as research assistant and reviewer, assisted with instrument administration and data collection, and critically reviewed and revised the manuscript for important intellectual content. All authors read and approved the final version of the manuscript and agree to be accountable for all aspects of the work, including ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Data Availability Statement: The datasets generated are available from the corresponding author upon reasonable request.

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