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Effectiveness of the 5E Learning Cycle in teaching respiration in secondary school biology: a quasi-experimental study on enhancing conceptual understanding and student engagement

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Abstract. This quasi-experimental study explored the effectiveness of the 5E Learning Cycle instructional model in enhancing Form Three students' conceptual understanding and engagement in the topic of respiration in secondary school biology. Conducted in four public secondary schools in Morogoro Municipality, Tanzania, the study involved 208 students, divided into an experimental (n = 101) and a control (n = 107) group. The experimental group was taught using the 5E model (Engage, Explore, Explain, Elaborate, Evaluate), while the control group received traditional lecture-based instruction. Data were collected using the Respiration Concept Test (RCT), a Student Engagement Checklist, and a Student Perception Questionnaire. Results revealed that the experimental group achieved significantly greater conceptual gains (mean gain = 6.6, $p < 0.001$) than the control group (mean gain = 2.2, $p < 0.001$). Observations indicated higher levels of engagement among experimental group students, particularly in questioning, collaboration, and participation in practical activities. Additionally, students in this group reported more positive perceptions of the learning experience, including increased motivation, enjoyment, and confidence in learning biology. The findings underscore the pedagogical value of the 5E model in supporting deeper learning and student engagement. The study recommends its broader adoption and integration into teacher training programs to strengthen science education in Tanzanian secondary schools.

Keywords: 5E Learning Cycle, student engagement, conceptual understanding, biology education, respiration, inquiry-based learning

1. Introduction

1.1. Background and context

The teaching of biology in secondary schools plays a critical role in equipping students with essential scientific knowledge and practical skills to understand the structure, function, and diversity of the living world. Biology provides the foundation for many disciplines in the natural sciences and contributes to the development of students' analytical and problem-solving abilities [26, 30]. Among the various topics taught, respiration stands out as a fundamental biological process. It is central to understanding how cells convert biochemical energy from nutrients into adenosine triphosphate (ATP), which fuels other cellular activities [2]. Thus, respiration not only explains how organisms obtain and use energy but also provides a gateway to understanding complex physiological systems. Despite its significance, many secondary school students struggle to grasp the concept, indicating a need for more effective pedagogical approaches [13, 38].

One of the core topics in the Ordinary Level Biology curriculum in Tanzania is respiration, typically introduced in Form Three [42]. However, the methods used to teach

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this topic often rely heavily on conventional teacher-centred techniques, particularly the lecture method. While lectures may efficiently cover large portions of content within a limited time, they do not always foster deep conceptual understanding [23, 27]. This is especially true for abstract topics such as aerobic and anaerobic respiration, which involve microscopic cellular processes and intricate biochemical reactions that students cannot observe directly [22]. Consequently, learners tend to memorise definitions and sequences without fully understanding the underlying principles. This limited grasp becomes evident in their poor performance on respiration-related questions in both classroom assessments and national examinations administered by the National Examination Council of Tanzania [39].

Given the persistent challenges of traditional instruction, educational reformers and science educators have increasingly advocated a shift toward student-centred, inquiry-based teaching strategies. These approaches actively involve learners in the construction of knowledge through exploration, collaboration, and reflection [16, 28]. A prominent model within this category is the 5E Learning Cycle, developed by Bybee et al. [10]. The 5E model breaks down the learning process into five sequential and interconnected phases: Engage, Explore, Explain, Elaborate, and Evaluate. The Engage phase captures students' interest and activates prior knowledge. The Explore phase encourages hands-on investigations and inquiry. During the Explain phase, students construct and share conceptual explanations. The Elaborate phase extends knowledge to new contexts, and the Evaluate phase assesses understanding. The model is rooted in constructivist learning theory, which posits that learners build new ideas from prior experiences and actively restructure their understanding through social and individual meaning-making [33, 43].

The effectiveness of the 5E Learning Cycle in science education has been well documented across international contexts. Research has shown that it enhances students' academic achievement, improves critical thinking skills, and increases motivation and engagement in science classrooms [8, 9, 14]. In studies conducted in diverse educational settings, the model has been linked to improved conceptual change and reduced misconceptions in topics such as photosynthesis, digestion, and respiration [24, 29]. However, there is limited empirical evidence from Sub-Saharan African countries, including Tanzania, regarding the application of the 5E model in teaching specific biology topics such as respiration. Most local studies have focused on general curriculum implementation or teacher competence [35, 40], leaving a gap in topic-specific instructional research. This study addressed that gap by exploring whether a 5E-based instructional approach can lead to significant improvements in students' understanding of respiration and foster higher levels of engagement in biology lessons in the Tanzanian secondary school context.

1.2. Problem statement

As established in the preceding section, secondary school students widely struggle with respiration concepts, and Tanzanian classrooms face particular challenges due to the continued dominance of teacher-centred instruction. This underperformance undermines not only students' achievement in biology but also their preparedness for advanced science courses and careers in health and life sciences.

Biology teachers in Tanzania face compounding difficulties in adopting student-centred pedagogies, including large class sizes, inadequate laboratory facilities, limited professional development, and insufficient training opportunities [23, 27, 35]. As a result, many continue to rely on traditional teaching methods that hinder active learning, particularly when teaching abstract topics such as respiration.

Although the 5E Learning Cycle has demonstrated promising results in international science education, its application in African and resource-constrained contexts remains largely unexplored [37]. This study was therefore undertaken to determine whether the 5E Learning Cycle model can improve the teaching and learning of respiration in Tanzanian secondary schools. It further aimed to assess the applicability of findings from other contexts to Sub-Saharan Africa, thereby generating both local and comparative insights for science education.

1.3. Objectives of the study

The primary objective of this study was to investigate the effectiveness of the 5E Learning Cycle model in enhancing students' conceptual understanding and engagement when learning respiration in secondary school biology. Specifically, the study aimed to:

1. Evaluate the impact of the 5E Learning Cycle on students' understanding of key biological concepts related to respiration compared to conventional lecture-based instruction.
2. Assess the level of student engagement during lessons on respiration when taught using the 5E Learning Cycle versus traditional teaching methods.
3. Explore students' perceptions of the teaching approaches used and their perceived interest and understanding of respiration content.

1.4. Theoretical background

This study was guided by the constructivist theory of learning, which holds that learners actively construct knowledge through interactions with the environment, prior experiences, and social engagement. Constructivist theory has been significantly shaped by the contributions of Piaget and Inhelder [33] and Vygotsky [43]. According to Piaget, learning occurs as individuals assimilate new information into existing cognitive frameworks or accommodate their frameworks to incorporate new experiences. Vygotsky emphasised the importance of social interaction and introduced the concept of the Zone of Proximal Development (ZPD), suggesting that learners can achieve higher levels of understanding when supported by more knowledgeable others.

In alignment with these theoretical perspectives, the study employed the 5E Learning Cycle model [10] as its instructional framework. Each of the model's five phases serves a distinct pedagogical function grounded in constructivist principles: activating prior knowledge (Engage), facilitating hands-on inquiry (Explore), supporting conceptual explanation and scaffolding (Explain), enabling knowledge application and transfer (Elaborate), and assessing understanding (Evaluate).

The choice of this model is theoretically justified as it aligns with the principles of constructivist pedagogy, which emphasises active participation, inquiry, and the social construction of knowledge. Previous studies have demonstrated that the 5E Learning Cycle improves students' understanding of scientific concepts, enhances engagement, and reduces misconceptions [1, 8]. Given the abstract nature of respiration, which involves microscopic processes and complex biochemical reactions, the 5E model is considered an appropriate and effective approach for promoting deep conceptual learning, as summarised in table 1.

1.5. Significance of the study

This study is of considerable significance to multiple stakeholders within the Tanzanian education system. Primarily, it provides robust empirical evidence for integrating inquiry-based instructional models in science education, thereby addressing existing pedagogical gaps. By focusing on the teaching of complex and often abstract biological processes, specifically respiration, this research provides a well-structured and practical framework that educators can adopt to enhance student comprehension and retention. Furthermore, the study's outcomes have direct implications for teachers,

Table 1
Theory-to-practice alignment in the study.

Constructivist principle / theoretical concept	Theorist(s)	5E model phase	Practical application in the study
Learning builds on prior knowledge	Piaget and Inhelder [33]	**Engage**	Students were introduced to respiration by discussing everyday experiences (e.g., breathing after running) to activate prior knowledge and misconceptions.
Active learning through exploration	Piaget and Inhelder [33]; Vygotsky [43]	**Explore**	Learners conducted simple respiration experiments (e.g., limewater test for CO_2) to discover concepts independently.
Social interaction enhances learning	Vygotsky [43]	**Explore / Explain**	Group discussions and peer explanations were facilitated to support collaborative knowledge construction.
Learners construct knowledge individually	Piaget and Inhelder [33]	**Explain**	Students explained observations from activities, linked findings to biological concepts, and received teacher scaffolding.
Transfer and application of knowledge	National Research Council [28]	**Elaborate**	Students applied respiration knowledge to new scenarios, such as comparing aerobic and anaerobic respiration in plants and animals.
Continuous assessment improves understanding	Black and Wiliam [7]	**Evaluate**	Students completed formative assessments and reflection questions to assess their conceptual progress and clarify misconceptions.
Zone of Proximal Development (ZPD)	Vygotsky [43]	All phases (especially Explain)	The teacher scaffolded learning throughout the 5E phases by guiding students from what they knew to what they could learn with support.

curriculum developers, and educational policymakers. Insights derived from the findings can guide the design and implementation of more effective biology instruction strategies that align with Tanzania's ongoing competency-based curriculum reforms. This alignment is critical to ensuring that instructional methods not only meet curriculum standards but also foster deeper conceptual understanding among learners. Ultimately, the study is expected to contribute to improved academic performance in science subjects and to heightened learner engagement and interest in biology. These outcomes resonate with the broader educational and developmental objectives articulated by the Ministry of Education, Science and Technology [41], supporting Tanzania's national vision for quality education and scientific literacy.

2. Methodology

2.1. Research design

This study employed a *quasi-experimental design* featuring a *non-equivalent control group pre-test–post-test structure*. This design was chosen because of the practical constraints of implementing random assignment in actual classroom settings, which are often the case in educational research. To accommodate these limitations, two intact Form Three biology classes from two public secondary schools were purposively selected and assigned to the experimental or control group (figure 1). The *experimental group* received instruction on respiration using the 5E Learning Cycle instructional model. In contrast, the *control group* was taught the same content using conventional lecture-based methods, including teacher explanations, note-taking, and textbook readings, without learner-centred experimentation. This research design facilitated a comparative analysis of learning outcomes and engagement. It allowed the researcher to (i) assess changes in students' conceptual understanding of respiration before and after the intervention within each group, (ii) compare learning gains between the experimental and control groups, and (iii) evaluate the extent of student engagement and perception under the two instructional approaches. Although the design lacked true randomisation, its *quasi-experimental nature* ensured that meaningful and rigorous comparisons could still be drawn under natural classroom conditions.

Experimental group (n = 101)	**Control group (n = 107)**
Pre-test (Respiration Concept Test – RCT)	Pre-test (RCT)
↓	↓
5E Learning Cycle instruction	Traditional lecture method
↓	↓
Post-test (RCT)	Post-test (RCT)
↓	↓
Student Engagement Checklist and Student Perception Questionnaire	Student Engagement Checklist Student Perception Questionnaire

Figure 1: Flow diagram of the quasi-experimental design used in the study.

2.2. Participants and setting

The study involved 208 Form Three students from four public secondary schools in Morogoro Municipality: Tushikamane, Tubuyu, Nanenane, and Kihonda. These schools were purposively selected to represent typical urban government secondary schools. Students from Tushikamane and Tubuyu formed the experimental group and were taught using the 5E Learning Cycle instructional model. Students from Nanenane and Kihonda served as the control group and received instruction through traditional lecture-based methods. Table 2 presents the distribution of participants by sex and school for both groups.

Table 2

Distribution of participants by school and sex.

Group	**School**	**Male**	**Female**	**Total**
Experimental	Tushikamane	25	28	53
	Tubuyu	23	25	48
Subtotal		**48**	**53**	**101**
Control	Nanenane	24	28	52
	Kihonda	28	27	55
Subtotal		**52**	**55**	**107**
Total		100	108	208

This demographic information ensured gender inclusivity and a balanced representation across the selected schools.

2.3. Sampling procedures

Purposive sampling was used to select the schools and intact classes to maintain natural classroom conditions and to ensure comparable academic levels and class sizes [15]. This sampling approach also facilitated the practical implementation of the intervention without disrupting the regular school timetable.

2.4. Intervention procedure

The intervention spanned four weeks, covering six instructional periods on key subtopics of respiration, including introduction to respiration, aerobic versus anaerobic respiration, respiration in plants and animals, the role of mitochondria in energy production, and practical experiments such as the CO_2 test with limewater and yeast respiration. The experimental group received instruction through a 5E Learning Cycle module developed by the researcher [10]. The control group was taught the same content through conventional lecture-based methods, emphasising note-taking and teacher explanations without hands-on activities [19, 34].

2.5. Teacher effect and classroom conditions

To minimise teacher-related bias, the study ensured that the same biology teacher conducted lessons for both the control and experimental groups within each participating school. All participating teachers held at least a bachelor's degree in science education and had at least 3 years of classroom teaching experience. Prior to the intervention, they received structured training on the 5E Learning Cycle model to ensure consistent and accurate implementation across the schools.

The study was carried out under typical Tanzanian secondary school conditions. Class sizes ranged between 45 and 60 students, reflecting the realities of overcrowded classrooms in the country's public education system. Laboratory facilities were available in some schools but often lacked modern equipment and adequate teaching aids. Where ICT resources, such as projectors and digital animations, were available, they were used to supplement instruction. In schools with limited ICT access, teachers relied on printed materials, chalkboard explanations, and locally improvised models. These variations provided a realistic picture of how the 5E Learning Cycle can be implemented in resource-constrained environments.

2.6. Research instruments

Data were collected using three instruments, each described in the following subsections.

2.6.1. Respiration Concept Test (RCT)

The RCT was designed to measure students' conceptual understanding of key respiration concepts, including aerobic and anaerobic respiration, cellular processes, mitochondrial functions, ATP production, and gas exchange. The test comprised 20 multiple-choice questions (MCQs), each with one correct answer and three plausible distractors. Items were developed based on the Tanzanian Ordinary Level Biology syllabus and informed by existing literature highlighting common student misconceptions in respiration [13, 38]. The questions assessed both factual knowledge recall and higher-order cognitive skills, such as conceptual clarity and application. Content validity was ensured through expert review by two university biology education lecturers who assessed item relevance, clarity, and alignment with learning objectives. A pilot test was conducted with 20 Form Three students from a comparable school not included in the main study to refine ambiguous items and estimate reliability. Reliability was determined using the Kuder-Richardson Formula 20 (KR-20), yielding a coefficient of 0.78, indicating acceptable internal consistency. The RCT was administered as a pre-test before the intervention and as a post-test immediately after its completion to both groups.

2.6.2. Student Engagement Checklist

This checklist was employed to observe and quantify students' behavioural engagement during biology lessons on respiration. It comprised observable indicators such as participation in discussions, attentiveness, question-asking, cooperative group work, and responsiveness during lessons. Items were adapted from established student engagement frameworks [18] to fit the Tanzanian classroom context. Education experts reviewed the checklist to ensure appropriateness and clarity. Research assistants were trained to use the checklist consistently to minimise observer bias. Observations were conducted during each lesson throughout the four-week intervention period. Engagement indicators were scored either as frequency counts or using Likert-scale ratings.

2.6.3. Student Perception Questionnaire

This instrument collected students' subjective perceptions of the instructional methods, their interest in the respiration topic, and their perceived understanding of the topic. The questionnaire consisted of 1 to 5 Likert-scale items (ranging from "strongly disagree" to "strongly agree") covering aspects such as teaching effectiveness, clarity, motivation, enjoyment, and confidence in the topic. Items were drawn from relevant literature on student perceptions of science instruction [12] and tailored to reflect experiences with the 5E Learning Cycle and conventional teaching approaches. Expert review ensured content validity. A pilot test was conducted to refine item wording and structure. The questionnaire was administered once after the intervention to both groups.

2.7. Data analysis

Data from the three instruments were analysed using both descriptive and inferential statistical methods.

2.7.1. Analysis of Respiration Concept Test data

Pre-test and post-test scores were analysed to assess changes in conceptual understanding. Descriptive statistics such as means and standard deviations summarised overall group performance at each testing stage. Paired sample t-tests were used within each group to determine whether there were statistically significant improvements from pre-test to post-test. Independent samples t-tests compared post-test scores between the experimental and control groups to examine differences attributable to the instructional approach. Effect sizes (Cohen's d) were calculated to evaluate the practical significance of observed differences. The significance level was set at $p < 0.05$.

2.7.2. Analysis of Student Engagement Checklist data

Frequencies and percentages of specific engagement indicators were computed for each lesson and averaged across the four-week intervention period. To compare engagement levels between groups, nonparametric tests (e.g., the Mann-Whitney U) were used when the data did not meet parametric assumptions. Trends in engagement over time were also examined to identify patterns or changes in students' behavioural participation throughout the intervention.

2.7.3. Analysis of Student Perception Questionnaire data

Likert-scale responses were coded numerically and analysed using descriptive statistics, including means and standard deviations, for each item within both groups. Independent samples t-tests were performed to evaluate statistically significant differences between groups on key perception measures. The questionnaire's internal consistency was assessed using Cronbach's alpha to ensure reliability. Additionally, any qualitative feedback from students was thematically analysed to complement and deepen the quantitative findings.

2.8. Research ethics

This study was conducted in accordance with established ethical standards for educational research. Ethical clearance was obtained from the Sokoine University of Agriculture Research Ethics Committee. Permission to conduct the study was also sought from school authorities at the district and institutional levels. Informed consent was obtained from all participating teachers, students, and their parents or guardians. Participation in the study was voluntary, and students were assured of the right to withdraw at any point without any negative consequences. To protect participants' rights, confidentiality and anonymity were maintained by using codes rather than names during data collection and reporting. The research design and implementation adhered to principles of fairness, respect, and integrity, ensuring that participation did not result in physical or psychological harm. These practices align with the ethical considerations outlined in contemporary educational research literature [32].

3. Findings and discussion

3.1. Effectiveness of the 5E Learning Cycle on conceptual understanding

The primary goal of this study was to evaluate the impact of the 5E Learning Cycle model on students' understanding of respiration concepts compared to conventional lecture-based methods. As shown in table 3, both groups significantly improved their scores from pre-test to post-test (experimental: $t = 13.92$, $p < 0.001$; control: $t = 6.14$, $p < 0.001$). However, the magnitude of improvement differed substantially. The experimental group improved from a pre-test mean of 10.2 to a post-test mean of 16.8, yielding a mean gain of 6.6 and a large effect size (Cohen's $d = 1.30$). The control group improved from 10.1 to 12.3, a mean gain of only 2.2 with a moderate effect size ($d = 0.52$).

Table 3
Descriptive and inferential statistics for RCT scores.

Group	*N*	Pre-test mean (SD)	Post-test mean (SD)	Mean difference	*t*-value	*p*-value	Cohen's *d*
Experimental	101	10.2 (2.4)	16.8 (2.0)	+6.6	13.92	<0.001	1.30
Control	107	10.1 (2.6)	12.3 (2.3)	+2.2	6.14	<0.001	0.52

A between-group comparison of post-test scores further confirmed these differences. As shown in table 4, the experimental group achieved a significantly higher mean score (16.8) than the control group (12.3). The independent samples *t*-test ($t = 9.02$, $p < 0.001$) confirms that this difference is statistically significant.

Table 4
Comparison of post-test scores between groups.

Group	Mean score	Standard deviation	*t*-value ($p < 0.001$)	*p*-value	Interpretation
Experimental ($n = 101$)	16.8	2.0	9.02	<0.001	Statistically significant
Control ($n = 107$)	12.3	2.3	–		

These findings provide strong evidence for the effectiveness of the 5E model in promoting deeper learning. Unlike conventional instruction, which typically focuses on content delivery through lectures, the 5E model encourages active engagement through its structured phases, enabling students to construct their own understanding via inquiry, collaboration, and reflection [10]. This framework fosters higher-order thinking skills that are essential for understanding complex topics such as cellular respiration. Prior research in various educational settings has similarly reported significant learning gains when employing the 5E model [1, 5], and the present findings resonate with international evidence underscoring the model's transferability across diverse contexts [21]. These results suggest that even in low-resource settings, inquiry-based constructivist approaches can substantially enhance student learning outcomes.

It is important to acknowledge that the control group also showed significant improvement, indicating that traditional instruction is not entirely ineffective. Conventional methods may efficiently convey basic factual knowledge, especially when time is limited. Furthermore, the potential influence of test reactivity – where exposure to a pre-test sensitises students to certain concepts – may partially contribute to post-test performance. Factors such as the novelty of the instructional method, teacher enthusiasm, or classroom resources may also have played a role. Nonetheless, the substantially greater gains observed in the experimental group, supported by a large effect size, demonstrate that the 5E model facilitates deeper understanding and better retention, particularly for abstract topics involving microscopic cellular processes [38].

3.2. Student engagement findings

The second objective of this study was to assess student engagement during lessons on respiration when taught using the 5E Learning Cycle compared to traditional methods. Observational data were collected using a Student Engagement Checklist comprising 10 behavioural indicators. Table 5 summarises the average frequency of observed engagement behaviours per lesson in both groups.

Table 5
Observed engagement behaviours per lesson in both groups.

Engagement indicator	**Experimental (N = 101) mean**	**Control (N = 107) mean**	***U*-value**	***p*-value**
Asked questions related to the lesson	4.3	2.2	4951.0	<0.01
Responded to teacher's questions	4.7	2.8	4873.5	<0.01
Participated in group discussions	4.9	2.7	4832.0	<0.01
Showed attentiveness (eye contact, note-taking)	5.2	3.3	5014.5	<0.01
Actively involved in practical activities	5.0	2.5	4791.0	<0.01
Collaborated effectively with peers	4.8	2.9	4850.4	<0.01
Remained on task throughout the lesson	5.1	3.4	4930.1	<0.01
Sought clarification when confused	3.9	2.3	4982.7	<0.01
Volunteered answers without being prompted	3.8	2.1	5090.2	<0.01
Used learning materials appropriately	4.6	2.7	4865.3	<0.01

Students in the experimental group exhibited significantly higher engagement across all measured indicators. For example, they asked lesson-related questions an average of 4.3 times per lesson compared to 2.2 in the control group, and showed markedly higher participation in practical activities (5.0 vs. 2.5) and group collaboration (4.8 vs. 2.9). All differences were statistically significant at $p < 0.01$ by Mann-Whitney U tests.

These findings align with theoretical frameworks that conceptualise student engagement as comprising behavioural, cognitive, and emotional components [18]. The 5E model's phased structure – particularly the Explore and Elaborate stages – actively encourages inquiry, peer collaboration, and hands-on application, which have been shown to increase both behavioural engagement (e.g., participation, attention) and cognitive engagement (e.g., investment in learning, self-regulation) [3, 36]. The higher frequency of volunteering answers and seeking clarification in the experimental group also reflects increased student agency and intrinsic motivation, which are key predictors of academic success [6, 11].

While observable engagement does not always guarantee deeper learning [4], the strong correspondence between enhanced engagement and significantly higher conceptual test scores in the experimental group suggests that the engagement fostered by the 5E model was meaningful. Students' self-reported positive perceptions (section 3.3) further reinforce this interpretation [25]. Nevertheless, despite observer training, subjective bias in rating behaviours cannot be fully eliminated, representing a common limitation of classroom observational research [31]. Future studies should consider triangulating engagement data with student self-reports, physiological measures, or digital tracking to strengthen validity.

3.3. Student perception findings

The third objective of this study was to explore students' perceptions of the instructional methods used to teach respiration, with particular attention to their perceived understanding, motivation, engagement, and relevance of the lesson. Students' responses to the 10-item Likert-scale perception questionnaire were analysed and compared between the two groups. As shown in table 6, students in the experimental group expressed significantly more favourable perceptions across all indicators.

The average score for the item *"The teaching method helped me understand the topic"* was 4.6 in the experimental group compared to 3.2 in the control group ($t = 8.45$, $p < 0.001$). Students also rated their teacher's clarity in explaining respiration concepts significantly higher (4.5 vs. 3.3), and reported greater motivation to participate in classroom activities (4.5 vs. 3.1). These differences were statistically significant for all items ($p < 0.001$). Students in the experimental group expressed higher confidence in their understanding of respiration (4.4 vs. 3.2), felt more encouraged to ask questions and explore ideas (4.6 vs. 3.3), and indicated more frequent opportunities to engage with lesson content actively (4.7 vs. 3.5). They also perceived the pace of the lesson as appropriate (4.3 vs. 3.4) and found it easier to relate the lesson content to real-life situations (4.5 vs. 3.2). Furthermore, a strong endorsement was given to the 5E approach itself, with a mean rating of 4.8 for the item *"I would like more lessons taught using the 5E model"*, compared to 3.3 in the control group.

The perception data demonstrate that the 5E model positively influences students' affective responses to instruction, including motivation, enjoyment, confidence, and perceived understanding. Particularly noteworthy is the strong endorsement of the item *"I think this teaching approach should be used in other science topics"* (mean = 4.8), suggesting that students valued the approach and desired continued exposure to it. These affective gains carry important educational implications: positive perceptions of learning environments have been shown to influence students' long-term interest in science and their willingness to engage with challenging topics [12, 17]. The experimental group's perception that they could connect lesson content to real-life situations (4.5 vs. 3.2) further suggests that the 5E model's emphasis on elaboration and application helps learners appreciate the societal relevance of scientific knowledge [20].

While social desirability bias and the novelty of the teaching method may have temporarily elevated student responses, the convergence of improved academic performance (section 3.1), heightened engagement (section 3.2), and favourable perceptions provides mutually reinforcing evidence of the 5E model's holistic effectiveness.

Table 6
Student perception scores by group.

Item statement	Experimental (N = 101) mean	Control (N = 107) mean	t-value	p-value
The teaching method helped me understand the topic	4.6	3.2	8.45	<0.001
The teacher explained respiration concepts clearly	4.5	3.3	7.98	<0.001
I felt motivated to participate in class activities	4.5	3.1	8.02	<0.001
The lessons were interesting and enjoyable	4.7	3.4	7.58	<0.001
I feel more confident in my understanding of respiration	4.4	3.2	6.78	<0.001
I was encouraged to ask questions and explore ideas	4.6	3.3	7.62	<0.001
I had opportunities to actively engage with the lesson content	4.7	3.5	7.85	<0.001
I think this teaching approach should be used in other science topics	4.8	3.3	8.70	<0.001
The pace of the lesson was appropriate for my learning	4.3	3.4	6.11	<0.001
I was able to connect the lesson content with real-life situations	4.5	3.2	6.94	<0.001

4. Conclusion

This study provides robust empirical evidence that the 5E Learning Cycle instructional model enhances the teaching and learning of respiration in secondary school biology. Across three complementary measures – conceptual understanding, classroom engagement, and student perceptions – the experimental group consistently outperformed the control group. The convergence of these findings strengthens the conclusion that the benefits of the 5E model extend beyond knowledge acquisition to encompass affective and behavioural dimensions of learning.

The results are consistent with constructivist learning theory, which emphasises that meaningful learning occurs through active knowledge construction rather than passive reception of information [33, 43]. By structuring instruction around inquiry, collaboration, and reflection, the 5E model creates conditions that support deeper cognitive processing and sustained engagement – qualities that are particularly important for abstract topics such as cellular respiration.

Several limitations should be acknowledged. The quasi-experimental design, while practical for classroom-based research, does not permit causal inferences with the same confidence as true experimental designs. The novelty of the instructional approach may have temporarily elevated engagement and perception scores, and observer subjectivity in recording engagement behaviours cannot be fully eliminated. Additionally, the study was confined to four schools in a single municipality, which limits the generalizability of the findings.

Despite these limitations, the study makes a distinctive contribution by providing empirical evidence from a Sub-Saharan African context, where research on the 5E Learning Cycle remains scarce. The findings demonstrate that inquiry-based, constructivist instruction can yield substantial learning benefits even in resource-constrained settings, offering insights that are both locally relevant and internationally informative. This evidence can guide curriculum design, teacher training, and pedagogical practice in Tanzania and similar educational contexts worldwide.

5. Recommendations

Based on the findings of this study, several recommendations are put forward to enhance the teaching and learning of biology in Tanzanian secondary schools.

First, the Ministry of Education and curriculum developers should actively promote the widespread adoption of the 5E Learning Cycle model in science teaching. Integrating this instructional approach into biology lessons has been shown to improve students' conceptual understanding and increase their engagement, which are critical for effective learning.

Second, professional development opportunities should be provided for biology teachers. Training and capacity-building programs are essential for equipping educators with the practical skills to effectively design and deliver lessons that follow the 5E instructional model. Such initiatives will help ensure fidelity in the application of inquiry-based teaching methods.

Third, teacher education institutions need to incorporate student-centred pedagogies, such as the 5E model, into their pre-service training programs. By embedding this model in methodology courses, future biology teachers will develop competence and confidence in using inquiry-based approaches from the outset of their careers.

Fourth, teachers need to employ a variety of assessment tools. Complementing traditional examinations with formative assessments, observational techniques, and mechanisms for student feedback will allow for a more comprehensive evaluation of both cognitive knowledge and affective learning outcomes.

Fifth, further research is encouraged to explore the application of the 5E model in other science subjects and diverse educational settings. Such studies will help determine the scalability and adaptability of this instructional approach across different contexts.

Finally, schools and education authorities should establish monitoring and evaluation systems to track the implementation of the 5E model. Regular data collection and analysis will support informed decision-making and continuous improvement of instructional practices.

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