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Effects of Inquiry-Based Biology Instruction on Advanced-Level Secondary Students' Understanding in Rwanda: A Quasi-Experimental Pre-Post Study

Zahara Dusabimana^{1*}, David Opanga²  & Venuste Nsengimana³ 

¹African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science; University of Rwanda- College of Education, Kayonza, Rwanda

² St John's University of Tanzania, Dodoma, Tanzania

³ University of Rwanda-College of Education, Kayonza, Rwanda

Abstract

The effect of inquiry-based instruction (IBI) on understanding of biology subject content remains understudied in the Rwandan context. This study investigates the effects of the IBI approach on students' understanding of biology at the advanced secondary school level in Rwanda. A total of 75 students and three teachers participated in the study. Classroom observations, interviews with teachers, and the administration of pre- and post-tests to Senior Five students were used to collect data. Teachers were trained in the use of inquiry-based teaching and learning. Afterwards, each teacher prepared the improved lesson according to the scheme of work. Furthermore, a post-test was administered to students to assess their understanding of the biology content. The results of classroom observations and interviews showed that the teachers have improved their application of IBI after intervention. Similarly, the statistical analysis results from the analysis of variance (ANOVA) of repeated measures showed a statistically significant main effect of test, $F(1, 72) = 30.19, p = .00$, with a large partial eta squared of .30, indicating the overall students' performance from pre- to post-test scores. Also, the interaction between test and school was statistically significant, $F(2, 72) = 4.30, p = .02$, with a partial eta squared of .11, indicating the improvement from pre-test to post-test among students from Schools A, B, and C. However, the school variable was not statistically significant ($F = 2.5, p = .089$), with an effect size (partial eta squared) of .065, indicating a small learning gain. The study concludes that inquiry-based teaching significantly improved advanced-level students' biology performance and teacher pedagogical practice within the schools (A, B, and C). The results demonstrate that IBI is an effective and scalable method for enhancing conceptual understanding across diverse school environments. **Keywords:** Biology conceptual understanding, biology teaching practices, inquiry-based teaching and learning, senior Five students, teaching and learning of biology

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* **Corresponding author:** Zahara Dusabimana: zaharadusabimana@gmail.com

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Introduction

Learning biology is a process of interaction between students and the subject they are learning. In this perspective, teaching and learning biology become more meaningful when students observe, engage in practical activities related to the subject they are learning, and ask questions (Konicsek en Keeley, 2015). However, not all biological concepts can be easily grasped by students, especially when teaching and learning materials are inadequate (Igaro, Adjivon,. Thus, providing students with an environment where they can ask questions may enhance their deep understanding of biology concepts. Based on an analysis of students' conceptual understanding, it has been found that students receive and memorise biological concepts presented by teachers during teaching and learning (Byukusenge, Nsanganwimana en Tarmo, 2022). As a result, when students are given a test on understanding concepts, they often have difficulty answering questions because their knowledge is limited to what they have learned (Ukobizaba en Nizeyimana, 2022).

Difficulties students faced in learning biology were found to be related to the amount of content to teach, the nature of some abstract subject content, and limited learning time. These difficulties are compounded by some concepts and biological phenomena that may be difficult to observe with the naked eye, as well as insufficient instructional hours in the sciences (Çimer, 2012). As a consequence, students memorise biological facts most of the time without understanding their meaning or application, resulting in low understanding of the content they learn (Lemma, 2013). This is evident in the low learning outcomes, particularly among students at the advanced level in secondary schools in Rwanda (Byukusenge, Nsanganwimana en Tarmo, 2022).

To solve the problem, several effective strategies for learning biology can help students understand the material they are studying. One of them is an inquiry-based teaching and learning approach (IBTL), which has been extensively employed in the teaching and learning sciences. IBI was appreciated for contributing to effective science learning by investigating and exploring learning materials to test a hypothesis. Further, IBI allows students to take responsibility for their learning, which leads to the creation of content that is accurate, easy to remember, and well-suited for effective application (Damopolii *et al.*, 2018). IBI is an instructional practice in which students explore content by asking questions, investigating the material, and answering teacher questions. Through IBI, students are at the centre of the learning experience and take ownership of their learning.

According to Sandika and Fitrihidajati (2018), inquiry-based teaching and learning is one of the inductive teaching methods in which learners are interested in asking questions to the teacher and learning lessons by finding solutions to the questions posed by the teacher. During the IBI lesson, a clear understanding of the content helps the learner to be actively involved in the scientific investigation of a particular phenomenon, explain their observations, and justify the findings (Opanga en Nsengimana, 2021). Further, students often work independently and collaboratively in small groups. However, during the application of the IBI, the teacher guides students to build knowledge (Powell en Kalina, 2009).

Because the targets for human capital development and human welfare set by the government of Rwanda in its 2020 vision, now extended to 2050, have not yet been met. One option to achieve these targets is to provide affordable, high-quality basic education and a thriving economy by enhancing science education.

However, this might be limited by poor teaching practices, as it was in past years. For instance, the results published by the Rwanda Education Board (REB) in 2020-2021 showed that some students did not perform well generally in almost all mathematics and science subjects. The root cause of poor performance might be the difficulties faced by students in learning some biological topics (Byukusenge, Nsanganwimana en Tarmo, 2022). In addition, poor performance in national examinations may be attributed to ineffective, traditional teaching methods in which the teacher is the master of everything and students remain passive listeners (Ndayambaje en Ngendahayo, 2014). This results in students memorizing some of the concepts without understanding their meaning and importance.

Negative outcomes of teacher-centred methods are associated with the nature of these teaching techniques. It is known as “rote learning” and is not effective for teaching abstract and complex topics such as cell biology, the nervous system, coordination, and genetics, among others (Byukusenge, Nsanganwimana en Tarmo, 2022). Indeed, the way teachers teach and interact with students has an impact on students’ performance (Ukobizaba, Ndiokubwayo, and Uworwabayeho, 2020). However, Rwanda meets the goals stated in its 2050 vision, as there will be improved understanding not only of biology but also of mathematics and other science subjects. This may, in turn, contribute to skill development and academic performance, produce skilled people able to compete on the labour market, and enhance students’ ability to solve the daily problems faced by society.

This study aims to investigate the contribution of the inquiry-based teaching and learning approach to students’ understanding of biology subject content in senior five secondary schools in Rwanda.

Specific objectives:

- (1) To investigate the teachers’ knowledge and use of inquiry-based teaching and learning.
- (2) To examine the impacts of inquiry-based teaching and learning approach on students’ understanding of biology concepts.
- (3) To examine the impacts of the inquiry-based teaching and learning approach in schools A, B, and C.
- (4) To examine the differences in schools’ performance after the intervention.

Hypotheses:

H01: There is no significant difference between students’ pre-test and post-test scores overall.

H02: There is no significant difference in pre–post test score gains among students from Schools A, B, and C.

H03: There is no difference in schools’ performance after the intervention.

Literature review

O’Connell (2008) found that effective teaching strategies in IBI involve students acquiring knowledge and applying what they have learned to new situations and contexts in their daily lives. The most active teaching method applied to engage learners in teaching and learning is IBI. The IBI approach follows five steps commonly known as (1) Engage/Excite, (2) Explore, (3) Explain, (4) Elaborate, and (5) Evaluate (Nyirahagenimana, Uwahoro en Ndiokubwayo, 2022). During the first stage, the teacher introduces the lesson with a simple discrepant-event experiment that sparks curiosity and motivates learners to ask questions. The teacher works with students to formulate the key question. In the second phase, students explore the prepared materials to satisfy their curiosity. During the execution of the activity, students discuss among themselves, ask questions to the teacher, and write down the report that is presented to other group members. During the explain phase, students present findings from group discussion, and the teacher helps them solve the misconceptions. In the elaborate phase, the teacher provides activities that

help learners to apply the learned concepts in daily lives, while in the evaluation phase, the teacher evaluates the achievement of the lesson objectives and whether the key question has been answered. The outcome was found to enhance skills development and subject understanding (Sandika en Fitrihidajati, 2018). The steps of inquiry-based teaching and learning are detailed in Table 1.

Table 1. Steps of the inquiry-based teaching and learning

5Es	Teacher's activities	Learner's activities
1. Engage/Excite	<ul style="list-style-type: none"> • Demonstrates difficult phenomenon, defines a challenging problem, talks about historical events, and shows pictures. • Activates prior knowledge of learners • Motivates learners to provide a good key question 	<ul style="list-style-type: none"> • Try to get a first understanding of the phenomenon • Ask questions (why? How?) • Formulate a key question
2. Explore	<ul style="list-style-type: none"> • Provides the material and the time learners need to find answers (example experiments, pictures). • Stimulates observation by asking observation questions. • Coaches the learners in constructing their explanations. 	<ul style="list-style-type: none"> • Explore the materials of the teachers • Try to formulate answers to the key questions
3. Explain	<ul style="list-style-type: none"> • Ask for an explanation of the learners. • Ask thinking questions, for example, to confront the explanations with the evidence. • Helps the learners to write down a good scientific explanation. 	<ul style="list-style-type: none"> • Try to answer the key questions. • Listen to other learners' answers and help them find the scientifically correct answer. • Write down the answer.
4. Elaborate	<ul style="list-style-type: none"> • Challenges the learners with new problems and discrepant events. • Coaches the learners in solving the questions 	<ul style="list-style-type: none"> • Apply their understanding to the new challenges • Use all available sources (handbooks, external experts) to solve the challenges.
5. Evaluate	<ul style="list-style-type: none"> • Provides the learners with some testing questions • Observes how learners solve these questions. • Uses the test results to provide feedback to the learners and improve his/her own lessons. 	<ul style="list-style-type: none"> • Apply their current understanding to the questions. • Analyses their mistakes, trying to improve their understanding.

According to Opanga and Nsengimana (2021), there are four levels of inquiry-based teaching and learning.

The first is level 0, where the learner follows the teacher's directions. The second is level 1, where the learner is given the problem and procedure and must evaluate the results and suggest alternative solutions to the given problem. The third is level 2, where the learner is given a challenging situation and a question to explore and then must devise a feasible procedure to follow and find an appropriate solution to the problem. The fourth and highest level is level 3, in which the learner is given a rough idea and is required to create the problem and suggest what to investigate, design, and follow appropriate methods to find the solution to the investigated problem. The levels of inquiry-based teaching and learning are listed in Table 2.

Table 2: Levels of inquiry-based teaching and learning

Levels	Learner's activities
0	The learner is acting in accordance with the directions given by the teacher
1	The learner is given the problem and procedure, and must evaluate the results and suggest alternative solutions to the given problem
2	The learner is given a challenging situation and the question to explore, and then must devise a feasible procedure to follow and find an appropriate solution to the problem
3	A rough idea is given, and the learner must create the problem and suggest what to investigate, design, and follow appropriate methods to find the solution to the investigated problem

Brown (2016) evaluated the effectiveness of practical inquiry-based teaching and learning in the bioinformatics module of the undergraduate program. The author divided students into small collaborative groups with distinctive central themes. The evaluation used was pre- and post-module quizzes, which incorporated process- and content-specific questions. Based on the outcomes, the author concluded that inquiry-based, peer-assisted learning increased students' engagement, practical skills development in bioinformatics, and knowledge development. Similarly, Tindangen (2018) investigated the role of IBI in enhancing students' higher-order thinking with four biology teachers and 80 grade 10 students. The author used students' higher-order thinking skills and scoring rubrics to assess their abilities in developing and presenting a scientific report from the experiment they conducted. For teachers, the author used observation sheets. The study found that students' higher-order thinking skills increased in classes taught by teachers who followed the inquiry-based teaching and learning model workshop, compared to those taught by teachers without such skills.

In another study conducted by Wu and Hsieh (2006) on 58 sixth graders, the authors used inquiry skills to construct explanations in inquiry-based teaching and learning environments. The results showed that students' inquiry skills improved significantly after participating in a series of learning activities. Similarly, Gormally *et al.* (2009) conducted a study on the effects of inquiry-based teaching and learning on students' science literacy and confidence. The study's findings showed improvements in students' science literacy and research skills, as well as the development of self-confidence in their scientific abilities. Based on previous literature, inquiry-based teaching and learning have been promoted to increase students' literacy and skill development. However, little is known about how much inquiry-based teaching and learning contribute to the students' understanding of biology subject content in Rwanda. Hence, the motivation for this study is to assess the contribution of inquiry-based teaching and learning to understanding of the biology subject in advanced secondary schools in Rwanda.

Research theoretical context

This research was supported and governed by the constructivist theory of learning (Vygotsky en Cole, 2018). Constructivist theory supports the fact that learners actively participate in and contribute to the construction of knowledge. This is achieved when students interact with the world through teacher-planned activities and reflect on their experiences. In this regard, students construct their own representations and

incorporate new information into their pre-existing knowledge (Powell et al., 2009). This viewpoint appears to be fundamental to the content of learning biology, in which students ask questions and actively construct their own knowledge through inquiry-based teaching and learning (Byusa, Kampire, and Rwekaza, 2021).

Research Methodology

Research design

This study used a quasi-experimental design with pre- and post-tests to collect data (Cohen, Manion and Morrison, 2018; Walker and Baxter, 2019). The classroom observation and interview with three teachers were organized at the school level. A pre-test was also given to 75 students from three different schools. Afterwards, based on the findings, teachers received training on inquiry-based teaching and learning. After the training sessions, every teacher prepared a lesson following the inquiry-based teaching and learning process and taught it to students. Others were the observers during the lesson delivery. After teaching, there was a plenary session to discuss key points, weak points, and areas for improvement. During the lesson evaluation, teachers are expected to identify the challenges encountered while teaching using the IBI. A post-test was administered to students to assess their understanding after the intervention.

Population, sample, and sampling techniques

The study was conducted in the Rwamagana District, Eastern Province of Rwanda, and focused on Senior Five students enrolled in combinations that include Biology. While sampling, the list of schools that have Biology was made. Three secondary schools were randomly selected from the district based on accessibility and the availability of Biology classes at the Senior Five level.

Only three secondary schools were selected for this study due to practical and methodological considerations. First, the study adopted a school-based intervention approach, which required close monitoring and consistent implementation of the inquiry-based teaching and learning strategy. Limiting the number of schools made it possible to ensure fidelity of implementation, regular follow-up, and effective coordination with teachers throughout the study period.

Second, the inclusion of three schools allowed the researcher to compare the impact of the inquiry-based teaching and learning approach across three distinct groups of students. This comparative perspective helped to identify similarities and differences in students' understanding of Biology under similar instructional conditions, thereby strengthening the analysis of the intervention's effectiveness.

At each selected school, one Biology teacher was purposively chosen based on their experience in teaching the subject. Students were included if they were enrolled in Senior Five and actively taking Biology during the study period. The sample consisted of intact classes, meaning that existing classroom groups were used without reassigning students. The final sample comprised 26 students from School A, 28 from School B, 21 from School C, and 3 biology teachers, for a total of 78 participants.

While this sample size is adequate for examining within-subject changes, the study acknowledges that the use of intact groups and a relatively small sample may limit the generalizability of the findings.

Pre-intervention stage

Data were collected in three major steps during this stage. In Stage 1, we conducted an interview with three biology teachers about their knowledge and use of inquiry-based teaching and learning. The interview was composed of open-ended questions that the teacher could answer either in writing or verbally. The second stage consisted of classroom observation using the observation checklist. This was made up of five steps from the 5Es, and for each step, we assessed whether it happened mostly, fairly, rarely, or not at all. We have also assessed the level of understanding of the taught biology content by administering the biology assessment test (BAT), which consisted of 20 questions developed following the levels of Bloom's taxonomy and scored out of 20. The main purpose of this stage was to assess teachers' knowledge of inquiry-based teaching, the current teaching techniques they use, and how those techniques contribute to understanding the biology subject content.

Intervention: The training sessions on the use of IBI in biology instructions

These training sessions were held at one of the schools in the sample. The training focused on the definition of inquiry-based teaching and learning, the steps of an inquiry-based teaching and learning lesson, and the formulation of the teacher's and learner's activities. Before training, we requested permission to hold training within the school, and it was granted. We began the training by establishing a shared understanding of what inquiry-based teaching and learning are, and then we discussed its application in the classroom. During the training, we discussed the teacher's role as a facilitator and the students' role as active learners. Teachers were also trained in the use of the 5Es during the teaching and learning of biology, and in how the 5Es learning cycle leads students through five steps: engage, explore, explain, elaborate, and evaluate. To ensure the training's effectiveness, each teacher prepared a lesson on the topic from the scheme of work. The other teachers served as observers during the teaching process. A plenary session was held immediately after teaching to assess the lesson's success and plan the way forward for improvement. This session was about showing the observed teacher her strengths and areas for improvement in the next lesson planning.

Post-intervention stage

After the intervention, another classroom lesson observation was organized for three teachers. The observation checklist had the same structure as the one used in the pre-intervention stage. Further, the post-intervention test was administered to students using a 20-question test prepared according to Bloom's taxonomy. The responses were later graded out of 20. Besides, lesson observations and interviews with teachers were conducted to collect their insights on teaching practices after the intervention.

Instruments validity and reliability

According to Fraenkel, Wallen, and Hyun (2012), validity and reliability are important in research, particularly in confirming the instruments to be used before implementation and in generalising results from the sample to the whole population. To ensure the instrument's validity and reliability, the observation checklist and BAT were checked by an expert in education from the College of Education, University of Rwanda, to assess their validity. Further, the instruments were piloted in one school within the sample, which had the same characteristics but was not part of our study sample.

To determine the instruments' reliability, we have employed a test-retest approach during the piloting phase. Within this context, the researcher administered a test and re-administered it after 2 weeks. This was done to determine how items correlate with one another and to provide a measure of the internal consistency of the test items. Thus, the test-retest reliability (Pearson r) over two weeks was calculated. The Pearson

product correlation (r) for the biology achievement test (BAT) was 0.61. This is an acceptable reliability coefficient since it is in a range of $0.6 < r < 0.7$. Hence, the instruments were reliable enough to be utilised for the study.

Ethical considerations

Before starting data collection, clearance to conduct this study was obtained from the Unit of Research and Innovation at the University of Rwanda College of Education. The approval letter was presented to the district level to seek permission from the district education officer. Then, education officers introduced the researcher to the secondary school headmasters where this study was conducted. An informed consent letter was prepared to ensure that participants' information would be kept confidential, and to assure them that the data would be used for academic purposes only.

Training schedule and key activities

The intervention consisted of structured training followed by classroom implementation of inquiry-based instruction (IBI) using the 5Es learning cycle. The training was conducted over three consecutive days, with two sessions per day, each lasting approximately two hours. Day 1 focused on developing a shared understanding of inquiry-based teaching and learning, discussing teacher and learner roles, and introducing the 5Es learning cycle (engage, explore, explain, elaborate, and evaluate). Day 2 emphasised lesson planning using the 5Es model, formulating inquiry questions, and preparing teaching and learning materials aligned with the scheme of work. Day 3 involved micro-teaching activities in which each teacher presented an inquiry-based lesson while others acted as observers using an observation checklist, followed by plenary discussions to provide feedback, identify strengths, and suggest improvements.

Following the training, teachers implemented IBI in their classrooms for 4 weeks, with 2 inquiry-based lessons per week, for a total of 8 lessons per teacher. The same biology topics planned collaboratively during training were taught using the inquiry approach. Each lesson followed the 5Es model's five phases: engage, explore, explain, elaborate, and evaluate. Teaching resources included learners' worksheets, locally available laboratory materials, and guided inquiry questions prepared during the training. Students worked in small groups, conducted investigations, discussed findings, and presented conclusions, while teachers acted as facilitators.

To ensure fidelity of implementation, classroom observations were conducted using the 5Es observation checklist previously validated during the pilot phase. Each teacher was observed during five lessons, and implementation was scored according to whether each phase occurred mostly, fairly, rarely, or not at all. However, using a field notebook, each phase was described to explain how it was implemented. The qualitative observation data were later reported. Different topics were observed during pre- and post-intervention. In addition, peer observation was conducted during the training micro-teaching sessions, followed by plenary feedback. The observer checklist and explanations for each phase were explained to observers before use to ensure consistency.

Data analysis

Qualitative data collected through classroom observation were analyzed descriptively. The data from the semi-structured interview were analyzed thematically. In this regard, codes were generated and placed under each research theme to identify the common arguments provided by the respondents. Further, quantitative data obtained from BAT were analyzed using the Statistical Package for Social Sciences (SPSS) and Excel software. Thus, the correlation coefficient was calculated to assess students' performance before

and after the intervention. In addition, the analysis of variance (ANOVA) was used to investigate if there were mean differences in scores between three groups of students before and after the intervention. During reporting, teachers' identifications were anonymized. Instead of mentioning real names of teachers, we used teachers A, B, and C.

Results

i) Teacher baseline understanding and practice

To address the first research objective, which aimed to investigate teachers' knowledge and use of inquiry-based teaching and learning, interviews were conducted with three biology teachers before the intervention. The findings revealed varied and generally limited knowledge of inquiry-based teaching and learning among the teachers. The first teacher described it as a way for students to find solutions based on what they observe and discover, while the third teacher explained that it is a student-centred approach in which the teacher acts as a facilitator and students explore answers on their own. For instance, Teacher A said, *"The IBI is a way for the student to find a solution based on what he sees and discovers."* Teacher B added, *"IBI is a type of method used in learning and teaching activities where students are centered, and the teacher is the facilitator."* The teacher C further explained, *"IBI is a method where students explore answers themselves"*. In contrast, teacher B reported insufficient knowledge, stating that she had only heard about it and had read about it online. Teacher B said, *"I don't have knowledge about IBI; I have only heard about it and read about it on the internet."*

Regarding its use, two teachers indicated they did not like to implement inquiry-based teaching and learning because they lacked understanding of how to apply it in biology lessons, whereas one teacher reported using it because it makes lessons more understandable, though he highlighted a lack of teaching materials. The teacher B said, *"I have insufficient knowledge about how it is used in class. Besides, teacher, C argued, "The IBI is a method used in the learning and teaching process where the student is in the center, and the teacher is the facilitator."* Teacher A said, *"I don't have enough knowledge about IBI because I remember that word from when I first started teaching in primary school."*

Despite these limitations, teachers mentioned strategies such as grouping students, assigning discussion tasks, using pictures for analysis, encouraging research, and facilitating collaboration. Classroom observations further showed that students were engaged in practical work, conducted experiments, expressed ideas, and drew conclusions with teacher guidance, indicating partial implementation of inquiry-based teaching and learning. For instance, teacher A said that he likes to use the IBI in the classroom since it appears simple to use. The teacher added, *"Once I use IBI, it makes the lesson more understandable."* The same teacher claimed, *"I do not have enough teaching materials for effective implementation of the IBI."* "To deeply understand what teachers know about IBI, we asked teachers about the key points to follow when using IBI for teaching sciences like biology. All teachers argued that the strategies they use in IBI include putting children into groups and assigning tasks for discussion. The second teacher continued and said, *"It is during discussion that students touch and explore materials given to them and then make a presentation."*

While the practices reported by the teachers, such as group collaboration, student research, and the use of visual analysis, incorporate elements of active learning, they do not fully reflect the rigorous framework of inquiry-based teaching and learning. For instance, teacher A explained, *"while employing inquiry-based teaching and learning, I put students in groups because when students are in groups, they learn from each other, and they deeply understand the lesson by themselves."* Teacher C complemented her and said, *"I train*

students to do their own research and find answers to problems.” In that context, I facilitate the lessons. I also provide students with a room for collaboration, where they can exchange ideas and build a relationship with the teacher. “Finally, I reflect on the learning and give feedback to the students.”

However, despite the presence of group work, collaboration, and practical activities, inquiry-based teaching and learning was not fully implemented. In a typical IBTL approach, students are expected to formulate their own questions, design and investigate problems independently, and construct knowledge through exploration with minimal direct instruction. In contrast, the observed lessons were largely teacher-directed, with students following predetermined procedures rather than engaging in open-ended inquiry or critical questioning. This suggests that although some elements of learner-centred practices were present, the core principles of inquiry-based teaching and learning were not fully realized.

ii) Students’ baseline conceptual understanding

Table 3 presents the descriptive statistics for the BAT administered as a pre-test across three different schools before the implementation of Inquiry-Based Teaching and Learning. The data provides an initial baseline of student performance.

Table 3: Students’ results of the BAT pre-test for three schools

Descriptive statistics				
	School	Mean	Std. Deviation	N
Pre-test	School A	46.8	14.7	26
	School B	46.6	15.4	28
	School C	54.8	10.4	21
	Total	49.0	14.2	75

Table 3 shows the total sample of 75 students began with an overall mean score of 49%. Notably, School C started with the highest mean score (54.8%) and the lowest standard deviation (10.4), suggesting more consistent performance among its 21 students. In contrast, School A and School B performed at very similar levels, with means of 46.8% and 46.6%, respectively. Both schools showed greater variability in student results than School C. These results establish the starting point from which the impact of the IBI intervention can be measured.

iii) Post-intervention teachers’ practice changes

After teacher training on IBI, the lesson observations followed. Every teacher was observed 7 times, and the entire observation period for all teachers lasted 1 month. Inquiry-based teaching and learning during the biology lesson was conducted by engaging students in hands-on investigations guided by the teacher’s instructions. Students were encouraged to ask questions, design and perform simple experiments, observe biological phenomena, and record their findings. They discussed their observations, shared ideas, and drew conclusions based on evidence, while the teacher facilitated and clarified concepts. This approach allowed learners to actively construct knowledge and develop a deeper understanding of biological concepts through exploration rather than passive listening.

After the lesson, the teacher sat with the researcher to discuss the lessons. During the discussions, the identified strong points included the teachers giving opportunities to students ask questions. The teacher gave an activity to do in a group and gave an evaluation to see if the content was understood.

After the intervention, teachers reported a clearer and more structured use of inquiry-based teaching and

learning in biology lessons. Teacher A explained, “After the training, I start the lesson by presenting a problem and asking students to formulate questions before they design experiments to find answers. This helps students think scientifically and understand concepts more deeply.” Teacher B added, “I now guide students to plan investigations, use available materials during experiments, record observations, and present evidence-based conclusions. My role is mainly to facilitate and support their inquiry.” Teacher C also noted, “Following the intervention, I allow students to predict outcomes, conduct experiments in groups, discuss results, and reflect on what they discovered. I then provide feedback based on their findings, which improves participation and promotes deeper understanding of biology concepts.”

Although the teacher tried to teach following the IBI steps, some weak points needed improvement. For instance, the teacher was unable to recognise that students had completed the activity because he did not follow up or check their progress. Further, the teacher was unable to manage time effectively because he used only a small amount to facilitate the lesson.

iv) Students’ learning outcomes

To examine the effect of IBI, two tests were conducted at different times. Table 4 presents the descriptive results of students’ performance on the BAT administered before (pre-test) and after the intervention (post-test) in three schools (A, B, and C). The table reports the mean scores and standard deviations for each school, together with the gain calculated from the difference between post-test and pre-test means. It also provides overall results for all students combined, showing the general change in performance across the three schools.

Table 4: Students’ results of the BAT in pre-post-test for three schools

Schools (N)	Pre Mean (SD)	Post Mean (SD)	Gain (Post-pre)
School A (26)	46.8 (14.7)	62 (13.2)	15.2
School B (28)	46.6 (15.4)	53.5 (14.7)	6.9
School C(21)	54.8 (10.4)	58.8(11.1)	4.0
Total (75)	49.0 (14.2)	58.1(13)	9.1

The results show that in the pre-test, School C had the highest mean score ($M = 54.8$, $SD = 10.4$), followed by School A ($M = 46.8$, $SD = 14.7$) and School B ($M = 46.6$, $SD = 15.4$), indicating that learners in School C started with relatively better and more consistent performance, while Schools A and B had lower and more dispersed scores. In the post-test, performance improved across all schools, with School A obtaining the highest mean ($M = 62.0$, $SD = 13.2$), followed by School C ($M = 58.8$, $SD = 11.1$) and School B ($M = 53.5$, $SD = 14.7$). The standard deviation decreased slightly for School A, suggesting improved consistency, whereas School B maintained higher variability and School C showed a slight increase in score dispersion.

The gain scores further highlight the differences in improvement among the schools. School A achieved the largest gain (15.2 points), indicating substantial improvement between pre- and post-test. School B showed a moderate gain (6.9 points), reflecting some improvement but less pronounced than School A. School C recorded the smallest gain (4.0 points), suggesting limited improvement despite having the highest pre-test performance. Overall, the combined results show that the total mean increased from 49.0 ($SD = 14.2$) in the pre-test to 58.1 ($SD = 13.0$) in the post-test, yielding an overall gain of 9.1 points, which indicates a general improvement in students’ performance across the three schools.

Inferential statistics was employed to analyze the performance between schools after the post-test. A within-subject (repeated measures) ANOVA, focusing on changes in test performance (pre-test vs. post-test) and how those changes vary across different schools, was computed. It focused on changes in test

performance both pre- and post-test and on how those changes varied across schools (See Table 5).

Table 5. Comparison of schools on their performance before and after the intervention

Source	Test	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Test	Linear	2,878.3	1	2878.34	30.19	0.00	0.30
Test * School	Linear	819.5	2	409.76	4.30	0.02	0.11
Error (Test)	Linear	6,865.7	72	95.36			

Table 5 presents the results of the between-subjects effect (schools overall). The results show a statistically significant main effect of test, $F(1, 72) = 30.19$, $p = .00$, with a large partial eta squared of .30. According to Gignac and Szodorai (2016), the effect size is interpreted as small < 0.20 ; medium = 0.20 to 0.30 , and large > 0.30 . Thus, the large Partial Eta Squared of 0.30 shows that the inquiry-based instruction had a substantial impact on the change. This indicates that students' post-test scores were significantly higher than their pre-test scores. Therefore, the null hypothesis H_{01} , stating that there is no significant difference between students' pre-test and post-test scores overall, was rejected. This finding implies that the intervention significantly improved students' academic performance.

Furthermore, the interaction between test and school was statistically significant, $F(2, 72) = 4.30$, $p = .02$, with a Partial Eta Squared of .11. This result indicates that the magnitude of improvement from pre-test to post-test differed significantly among students from Schools A, B, and C. The effect size reflects a moderate difference in gains among the schools. Therefore, the null hypothesis H_{02} , which stated that there is no significant difference in pre-post test score gains among students from the three schools, was also rejected. These findings suggest that while the intervention was effective overall, its impact varied across the participating schools.

v) Differential gain by school

Schools (A, B, and C) were compared in terms of their performance during the post-test. The analysis of variance (ANOVA) results, including Type III Sums of Squares, degrees of freedom, mean squares, F-values, significance levels, and partial eta-squared for the school factor, were conducted. These statistics are used to compare the performance of the three schools and to examine variations in students' post-test scores across Schools A, B, and C following the intervention (See Table 6).

Table 6. Between-subjects effect (School overall)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	427955.6	1	427955.6	1914.9	.000	.964
School	1120.2	2	560.1	2.5	.089	.065
Error	16090.3	72	223.5			

Table 6 presents the comparison of schools' performance after the intervention. The results show that the main effect of school was not statistically significant, $F(2, 72) = 2.50$, $p = .089$, with a partial eta squared of .065. Since the p-value is greater than the significance level of .05, this indicates that school differences were not statistically significant, though descriptive trends suggested School A's gain was larger (See Table 4). Therefore, the null hypothesis H_{03} , which states that there is no difference in schools' performance after

the intervention, was accepted. This finding suggests that after the intervention, students from the three schools performed at comparable levels. The findings suggest that students across the three schools performed comparably following instruction through the inquiry-based teaching and learning (IBI) approach.

Discussion

The way teachers understand and use IBI in their chemistry teaching influences whether they use it. Similarly, the way teachers understand and use IBI influences students' performance in biology. The results of our study showed that teachers do not effectively implement IBI because they lack sufficient knowledge of it. However, for improving students' scientific literacy, use inquiry learning (Iskandar, Sastradika, and Defrianti, 2019). Inquiry-based teaching and learning is one of the learning approaches that may provide students with an active, realistic scientific learning process, helping them strengthen their creative thinking abilities and scientific mindset (Sandika en Fitrihidajati, 2018). This aligns with social constructivist theory, which favours active student engagement and their contributions to the creation of knowledge.

The level of knowledge and use of IBI has influenced whether teachers use this learning approach. In this study, we found that some teachers have little knowledge of IBI. However, this study shows that the training participants enhanced their understanding of IBI and its effective use during teaching biology. Our findings concur with those of Mugabo (2015), who argued that teachers do not have a common understanding of inquiry. According to Mugabo (2015), most instructors associate inquiry teaching with a few distinct traits, while others have a radically different view. The author advised that instructors resort to the definition provided in the curriculum. It is vital to highlight that IBI is primarily focused on outdoor practical activities and encompasses a wide range of practical work. To minimize teacher misunderstanding, the curriculum should be explicit on what practicals should be handled in an inquiry method.

The way teachers apply IBI has an impact on students' performance. The way teachers applied for IBI before training was not effective in enhancing students' understanding of biology concepts. However, teachers showed significant use of IBI after training since they taught by creating an active environment to develop students' higher-order thinking skills. According to Iskandar, Sastradika, and Defrianti (2019), one method to improve students' scientific literacy is to use inquiry-based learning. Inquiry-based teaching and learning is one of the learning approaches that may provide students with an active, realistic scientific learning process to strengthen their creative thinking abilities and scientific mindset. Furthermore, Tindangen (2018) noted that the inquiry-based teaching and learning approach is used in the development and presentation of scientific reports after students have completed practical tasks under the supervision of student activity worksheets. As a result, instructors in inquiry-based classrooms are expected to serve as learning facilitators rather than information suppliers.

Our study found that students improved their performance, demonstrating IBI's contribution to students' biology performance. The findings from this study agree with the findings of other scholars. The use of IBI has shown a great impact on students' performance compared to when they were taught without it. For example, Tindangen (2018) found that students' higher-order thinking skills increased in quantity and quality compared to courses taught by teachers who did not use the inquiry-based teaching and learning model, workshops, or presentations. Similarly, Wu and Hsieh (2006) discovered that after participating in a series of learning activities, students' inquiry abilities increased dramatically. Furthermore, Gormally *et al.* (2009) found that inquiry lab instruction improved students' science literacy and research skills. Gormally *et al.* (2009), through IBI, students increased their self-confidence in their scientific abilities, but conventional

students gained more, indicating that the traditional curriculum generated overconfidence. Therefore, as shown by our study, we conclude that IBI use has a positive impact on students' performance in biology.

Although this study did not examine the relationship between IBI use and students' interest, we believe that IBI use not only enhances students' performance but also increases their active participation and interest in learning. Indeed, Smallhorn *et al.* (2015) argued that there are high levels of student satisfaction and a significant improvement in student learning outcomes through the use of IBI. Furthermore, Gormally *et al.* (2009) found that IBI students developed greater self-confidence in scientific skills, whereas conventional students gained more, suggesting that the traditional curriculum fostered overconfidence. As a result, Smallhorn *et al.* (2015) proposed that all disciplines explore inquiry-based activities to boost student engagement and learning outcomes, as they promote the development of autonomous learners.

This study has some limitations that should be considered when interpreting the findings. First, the intervention duration was relatively short, consisting of three days of training followed by four weeks of classroom implementation, which may not have been sufficient to capture long-term effects of inquiry-based instruction on students' learning. Second, the use of intact classes without random assignment may have introduced pre-existing differences among groups, which could have influenced the results. Third, teacher variability across the three schools, including differences in experience, teaching style, and level of adoption of inquiry-based instruction, may have affected the consistency of implementation. In addition, only three teachers participated in the study, which limits the generalizability of the findings to other contexts, schools, and teacher populations. Finally, the use of similar pre- and post-tests may have introduced testing effects, in which students' post-test performance was partly influenced by familiarity with the assessment format rather than by the intervention alone.

Conclusion

The purpose of the study was to investigate the effect of the inquiry-based teaching and learning approach to biology subject understanding in advanced-level secondary schools in Rwanda. The study was conducted within three schools. While Rwandan biology teachers initially demonstrated limited conceptual knowledge and inconsistent application of inquiry-based teaching and learning, targeted professional training effectively transformed their pedagogical practice from teacher-directed instruction to active facilitation. This shift resulted in a statistically significant improvement in student performance across all participating schools (A, B, and C), proving that IBI is a highly effective and scalable intervention for enhancing understanding of advanced-level biology, regardless of a school's starting baseline. However, the school variable was not statistically significant, suggesting a small learning effect. The study concludes that inquiry-based teaching significantly improved advanced-level students' biology performance and teachers' pedagogical practice in schools.

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