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# Effect of inquiry-based learning on junior high school students' learning outcomes in cell theory

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## ABSTRACT

This study investigated the effects of Inquiry-Based Learning (IBL) on junior high school students' conceptual understanding and retention of cell theory in Ghana. A Solomon four-group design was employed to control for possible pretest sensitization effects and to ensure the validity of the findings. Four intact classes from two public junior high schools participated in the study, yielding a total sample of 141 students. The experimental groups were taught using inquiry-based learning strategies that actively engaged students in questioning, investigating, and constructing knowledge, whereas the control groups received conventional teacher-centered instruction. Data were collected using a Cell Theory Concept Test (CTCT) administered as a pretest, posttest, and retention test. Two-way analysis of variance (ANOVA) results revealed a statistically significant main effect of instructional strategy on students' conceptual understanding of cell theory, favoring those exposed to inquiry-based learning. There were no significant pretest or interaction effects, indicating that the observed differences were attributable to the instructional intervention rather than testing effects. Furthermore, paired-samples t-test results showed that students in the inquiry-based groups demonstrated improved or sustained retention of cell theory concepts three weeks after instruction. These findings provide strong empirical evidence that inquiry-based learning enhances both immediate conceptual understanding and longer-term retention of biological concepts. The study recommends integrating inquiry-based instructional strategies into junior high school biology classrooms in Ghana to promote meaningful learning and improve students' academic outcomes.

**Contribution/ Originality:** This study provides rare experimental evidence from Ghana using a Solomon four-group design to demonstrate that Inquiry-Based Learning improves both conceptual understanding and retention of cell theory. It contributes context-specific support for learner-centred biology instruction and strengthens the empirical basis for inquiry-based teaching in junior high schools.

## 1. INTRODUCTION

Cell theory is a foundational concept in biology that underpins students' understanding of living systems, cellular organization, and biological processes. Despite its centrality in the junior high school science curriculum, numerous studies have consistently reported that students hold persistent misconceptions about cell structure, function, and the nature of cells as living units (Duda & Adpriyadi, 2020; Hasiloglu & Eminoglu, 2017; Silaban, Purwianingsih, Kusnadi, & Pranoto, 2024). These misconceptions often stem from abstract representations, textbook oversimplifications, and teacher-centered instructional approaches that emphasize memorization rather than conceptual understanding


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(Parthasarathy, 2023). When such misconceptions are not addressed early, they hinder students' ability to build coherent biological knowledge and negatively affect long-term learning outcomes.

Inquiry-Based Learning (IBL) has been widely advocated as an effective instructional approach for improving students' understanding of complex scientific concepts. Rooted in constructivist learning theory, IBL actively engages learners in posing questions, designing investigations, collecting evidence, and constructing explanations, thereby promoting deeper conceptual understanding (Heindl, 2019; Van Uum, Verhoeff, & Peeters, 2016). Empirical studies across diverse contexts have demonstrated that inquiry-oriented instruction improves science achievement and conceptual understanding compared to conventional teaching methods (Aregehagn, Lykknes, Febri, & Ayene, 2022; Cairns, 2019). In biology education specifically, inquiry-based approaches have been shown to enhance students' understanding of cell-related concepts by encouraging active exploration and conceptual reconstruction (Johann, Rusk, Reiss, & Groß, 2024; Kassaye, Damtie, Melesse, & Yemata, 2025).

Beyond immediate understanding, retention of scientific concepts and the development of science process skills are critical outcomes of effective science instruction. Research indicates that inquiry-based learning supports durable knowledge retention by fostering meaningful cognitive engagement and repeated conceptual application (Bónus, Antal, & Korom, 2024). Additionally, integrating science process skills, such as observing, hypothesizing, experimenting, and interpreting data, within inquiry-based lessons has been found to improve students' academic achievement in cell biology significantly (Kassaye et al., 2025). Inquiry-based learning has also been associated with positive student perceptions and attitudes toward biology, as learners experience greater autonomy, relevance, and engagement during instruction (Manishimwe, Shivoga, & Nsengimana, 2022; Sachyani et al., 2024).

Despite the growing body of international research supporting inquiry-based learning, systematic reviews suggest that its classroom implementation remains inconsistent, particularly at the basic education level (Alarcon, Talavera-Mendoza, Paucar, Caceres, & Viza, 2023; Strat, Henriksen, & Jegstad, 2024). Moreover, there is limited empirical evidence examining the combined effects of inquiry-based learning on conceptual understanding, retention, science process skills, and students' perceptions of specific biology topics, such as cell theory, within the junior high school context. Addressing this gap is essential for informing instructional practices and curriculum decisions aimed at improving biology learning outcomes. Consequently, this study investigates the effects of Inquiry-Based Learning on junior high school students' learning outcomes in cell theory.

### *1.1. Problem Statement*

In Ghana, Integrated Science at the junior high school level is designed to equip learners with foundational scientific knowledge and skills necessary for further education and everyday problem-solving. Cell theory is a core biology concept within the Junior High School science curriculum and serves as a prerequisite for understanding more advanced topics in biology at the senior high school level. However, classroom experiences and assessment outcomes suggest that many junior high school students struggle to develop a sound conceptual understanding of cell theory. These difficulties are often reflected in students' inability to accurately explain cell structures, functions, and the role of cells as the basic units of life.

Empirical studies conducted in different contexts have consistently reported that students hold deep-seated misconceptions about cell-related concepts, which persist even after instruction (Duda & Adpriyadi, 2020; Hasiloglu & Eminoglu, 2017; Silaban et al., 2024). Such misconceptions are commonly linked to instructional practices that emphasize rote learning, textbook-driven explanations, and limited opportunities for hands-on or inquiry-based activities (Parthasarathy, 2023). In the Ghanaian junior high school context, science instruction is still largely dominated by teacher-centered approaches, where students play a passive role in knowledge acquisition. This instructional pattern limits learners' engagement in scientific inquiry and constrains the development of higher-order thinking and science process skills.



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Inquiry-Based Learning (IBL) has been identified as an effective pedagogical approach for improving students' conceptual understanding and achievement in science by actively involving learners in questioning, investigation, and evidence-based reasoning (Aregehagn et al., 2022; Cairns, 2019). Studies have shown that inquiry-based instruction enhances students' retention of scientific concepts, promotes the acquisition of science process skills, and fosters positive perceptions toward learning biology (Bónus et al., 2024; Kassaye et al., 2025; Manishimwe et al., 2022). Despite these documented benefits, the application of inquiry-based learning in Ghanaian junior high school science classrooms remains limited, often due to factors such as large class sizes, time constraints, and insufficient instructional support.

Furthermore, while several studies have examined the effectiveness of inquiry-based learning in science education, there is a paucity of empirical research in the Ghanaian context that simultaneously investigates its effects on conceptual understanding, retention, science process skills, and students' perceptions, particularly in relation to cell theory. In addition, many existing studies have employed research designs that do not adequately control for pretest effects, thereby weakening the validity of their findings (Heindl, 2019; Strat et al., 2024). This gap in context-specific and methodologically robust research limits evidence-based decision-making regarding instructional strategies in Ghanaian junior high school science education.

Given the persistent challenges associated with students' understanding of cell theory, the continued reliance on conventional teaching methods, and the limited Ghana-based empirical evidence on the comprehensive impact of inquiry-based learning, there is a clear need for systematic investigation. Therefore, this study seeks to examine the effects of Inquiry-Based Learning on junior high school students' learning outcomes in cell theory, specifically, conceptual understanding, retention, science process skills, and perceptions within the Ghanaian educational context.

### *1.2. Objectives of the Study*

The objectives of this study are to:

1. Examine the effect of Inquiry-Based Learning (IBL) on junior high school students' conceptual understanding of cell theory.
2. Determine the effect of Inquiry-Based Learning (IBL) on junior high school students' retention of cell theory concepts.

### *1.3. Research Questions*

The study will be guided by the following research questions.

1. What effect does Inquiry-Based Learning have on junior high school students' conceptual understanding of cell theory?
2. What effect does Inquiry-Based Learning have on junior high school students' retention of cell theory concepts?

### *1.4. Null Hypotheses*

The following null hypotheses will be tested at a 0.05 level of significance.

*$H_{01}$: There is no significant difference in the conceptual understanding of cell theory between students taught using Inquiry-Based Learning and those taught using conventional teaching methods.*

*$H_{02}$: There is no significant difference in the retention of cell theory concepts between students taught using Inquiry-Based Learning and those taught using conventional teaching methods.*

### *1.5. Theoretical Framework*

This study is grounded in Constructivist Learning Theory and Conceptual Change Theory, which together provide a strong theoretical foundation for examining the effects of Inquiry-Based Learning (IBL) on junior high



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school students' learning outcomes in cell theory. These theories explain how learners actively construct knowledge, restructure prior conceptions, and develop both cognitive and affective learning outcomes through inquiry-oriented instructional experiences.

### *1.6. Constructivist Learning Theory*

Constructivist learning theory posits that learners actively construct knowledge through interaction with their environment, prior knowledge, and social context, rather than passively receiving information from teachers. Learning is viewed as an active, meaning-making process that occurs when learners engage with experiences that challenge existing ideas and promote reflection. In science education, constructivism emphasizes learner-centered instruction, problem-solving, and active engagement, principles that are central to Inquiry-Based Learning (Heindl, 2019; Van Uum et al., 2016).

Inquiry-Based Learning operationalizes constructivist principles by engaging students in asking questions, conducting investigations, gathering evidence, and constructing explanations. Through these processes, learners actively engage with scientific concepts and practices, thereby developing deeper conceptual understanding (Cairns, 2019). In the context of cell theory, inquiry-based activities, such as observing cell structures, analyzing representations, and explaining cellular functions, enable students to construct accurate mental models of biological concepts (Johann et al., 2024).

Constructivist theory also explains improved retention of knowledge. Learning experiences that require active participation and cognitive engagement are more likely to result in meaningful learning, which supports long-term memory and retention. Inquiry-based instruction encourages students to connect new information to prior knowledge and apply concepts in multiple contexts, thereby enhancing retention of scientific concepts over time (Bónus et al., 2024).

### *1.7. Conceptual Change Theory*

Conceptual Change Theory complements constructivism by explaining how learners replace or reorganize misconceptions with scientifically accepted conceptions. Research has shown that students often enter biology classrooms with alternative conceptions about cell structure and function, which can persist despite traditional instruction (Duda & Adpriyadi, 2020; Hasiloglu & Eminoglu, 2017; Silaban et al., 2024). Conceptual change occurs when learners recognize inconsistencies between their existing ideas and scientific explanations and reconstruct their understanding accordingly.

Inquiry-Based Learning supports conceptual change by creating opportunities for cognitive conflict through investigation and evidence-based reasoning. When students test their ideas during inquiry activities and confront empirical evidence that contradicts their misconceptions, they are more likely to revise their understanding. Guided inquiry, in particular, provides the scaffolding necessary for learners at the junior high school level to engage productively in this process (Aregehagn et al., 2022; Strat et al., 2024). This theoretical perspective explains why inquiry-based instruction is effective in improving students' conceptual understanding of cell theory.

Conceptual Change Theory also underpins the development of science process skills, which are essential for evaluating evidence and reconstructing knowledge. Through inquiry-based activities, students practice observing, hypothesizing, experimenting, analyzing data, and drawing conclusions, which facilitate both procedural competence and conceptual restructuring (Kassaye et al., 2025; Strat et al., 2024).

### *1.8. Inquiry-Based Learning and Affective Learning Outcomes*

In addition to cognitive development, constructivist perspectives emphasize the role of learners' attitudes, perceptions, and motivation in the learning process. Inquiry-Based Learning environments often promote learner autonomy, curiosity, and collaboration, which positively influence students' perceptions of science learning. When



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students actively participate in inquiry and experience success in constructing knowledge, they are more likely to develop positive perceptions and attitudes toward biology (Manishimwe et al., 2022).

Empirical evidence further suggests that inquiry-oriented instruction fosters engaging and meaningful learning experiences that shape students' views of science as an active and relevant discipline (Sachyani et al., 2024). These positive perceptions enhance engagement and persistence, which in turn support improved learning outcomes, reinforcing the theoretical assumptions of constructivist learning.

## 2. CONCEPTUAL REVIEW

### *2.1. Inquiry-Based Learning*

Inquiry-Based Learning (IBL) is a learner-centered instructional approach grounded in constructivist learning theory, which posits that knowledge is actively constructed through interaction with experiences rather than passively received from teachers. In the context of science education, IBL emphasizes students' active engagement in posing questions, investigating phenomena, collecting and analyzing data, constructing explanations, and communicating findings. This approach mirrors the practices of scientists and is intended to foster meaningful learning, deeper conceptual understanding, and the development of scientific reasoning skills (Heindl, 2019; Van Uum et al., 2016).

Conceptually, IBL positions the teacher as a facilitator who guides learning through carefully designed tasks and scaffolding, rather than as the sole source of knowledge. Learners are encouraged to explore scientific concepts through inquiry cycles that typically include problem identification, hypothesis formulation, experimentation, observation, and reflection. This process allows students to confront prior conceptions, test ideas against evidence, and reconstruct their understanding based on empirical reasoning (Cairns, 2019). As a result, IBL is particularly well-suited for addressing abstract and conceptually demanding topics in biology, such as cell theory.

IBL exists along a continuum ranging from structured inquiry to guided inquiry and open inquiry. In structured inquiry, the teacher provides the research question and procedures, while students analyze results and draw conclusions. Guided inquiry allows students to design aspects of the investigation under teacher guidance, whereas open inquiry gives learners greater autonomy in defining questions and methods. Research suggests that guided inquiry is especially effective at the basic education level, where students require instructional support to engage productively in inquiry processes (Aregehagn et al., 2022; Strat et al., 2024). This conceptualization is relevant to junior high school settings, where learners are still developing foundational inquiry skills.

A key conceptual strength of IBL lies in its potential to promote conceptual understanding. By engaging students in exploration and evidence-based reasoning, inquiry-based instruction encourages learners to move beyond surface-level memorization toward a deeper understanding of scientific concepts. In biology education, IBL facilitates conceptual change by enabling students to identify and challenge misconceptions, particularly those related to abstract entities such as cells and cellular processes (Johann et al., 2024; Parthasarathy, 2023). Through repeated engagement with inquiry tasks, students are better able to integrate new knowledge with existing cognitive structures.

IBL is also conceptually linked to knowledge retention. Learning experiences that require active participation, reflection, and application of concepts are more likely to result in durable learning than passive instructional approaches. Inquiry-based activities promote meaningful learning by situating knowledge within authentic problem-solving contexts, which enhances memory consolidation and long-term retention (Bónus et al., 2024). This conceptual advantage makes IBL a promising approach for ensuring that students retain biological concepts such as cell theory beyond immediate post-instruction assessments.

Another central feature of IBL is its emphasis on the development of science process skills, including observing, classifying, measuring, hypothesizing, experimenting, interpreting data, and drawing conclusions. These skills are fundamental to scientific literacy and are integral to inquiry-based instruction. By engaging students in systematic



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investigation and reasoning, IBL provides opportunities for learners to practice and refine these skills in meaningful contexts (Kassaye et al., 2025; Strat et al., 2024). Conceptually, the integration of science process skills within IBL supports the development of both procedural and conceptual knowledge in science.

In addition to cognitive outcomes, IBL is associated with positive student perceptions and attitudes toward science learning. Inquiry-based environments often foster curiosity, autonomy, and engagement, which can enhance students' interest and motivation in learning biology. When students perceive learning as an active and exploratory process, they are more likely to develop favorable attitudes toward science and greater confidence in their ability to learn scientific concepts (Manishimwe et al., 2022; Sachyani et al., 2024). These affective outcomes are important for sustaining students' participation and achievement in science education.

Despite its conceptual strengths, the successful implementation of IBL requires careful instructional planning, appropriate scaffolding, and alignment with assessment practices. Teachers' understanding of inquiry pedagogy and assessment literacy plays a critical role in determining the effectiveness of IBL in classroom practice (Hung & Wu, 2024). Furthermore, systematic reviews indicate that while IBL holds significant promise, its impact depends on contextual factors such as classroom resources, curriculum demands, and teacher preparedness (Alarcon et al., 2023; Strat et al., 2024).

In summary, Inquiry-Based Learning is conceptually positioned as a powerful instructional approach for improving students' conceptual understanding, retention of knowledge, acquisition of science process skills, and perceptions of science learning. Its alignment with constructivist principles and scientific practices makes it particularly suitable for teaching complex biology topics such as cell theory at the junior high school level. However, empirical investigation within specific educational contexts, such as Ghanaian junior high schools, is necessary to validate its effectiveness and inform instructional practice. This study is therefore grounded in the conceptual foundations of IBL as a means of enhancing multiple learning outcomes in cell theory.

## 3. EMPIRICAL REVIEW

### *3.1. Inquiry-Based Learning and Conceptual Understanding in Biology*

Several empirical studies have examined the effectiveness of Inquiry-Based Learning (IBL) in enhancing students' conceptual understanding in science and biology. Hasiloglu and Eminoglu (2017) investigated fifth graders' misconceptions about cell-related concepts and found that instructional interventions involving active exploration, such as microscope-based inquiry activities, significantly reduced misconceptions and improved conceptual understanding. Similarly, Duda and Adpriyadi (2020) reported that students' misconceptions about cell concepts persisted under conventional instruction, underscoring the need for learner-centered approaches such as inquiry-based learning.

Cairns (2019) conducted a large-scale study examining instructional practices within inquiry-based learning environments and found a significant positive relationship between inquiry-oriented instruction and students' science achievement. In a related study, Aregehagn et al. (2022) demonstrated that guided inquiry-based learning had transformative effects on students' scientific understanding of vision concepts, with students exposed to inquiry-based instruction outperforming those taught using traditional methods. These findings suggest that inquiry-based learning is effective in promoting deeper conceptual understanding of abstract biological concepts.

More recently, Johann et al. (2024) explored students' thinking pathways in cell membrane biology and found that inquiry-oriented learning activities supported students' conceptual reconstruction and facilitated progression from naïve to scientifically accurate explanations. Kassaye et al. (2025) similarly reported that science process skills integrated in an inquiry-based approach significantly improved students' academic achievement in cell biology. Collectively, these studies provide empirical evidence that inquiry-based learning enhances students' conceptual understanding in biology-related topics.


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### *3.2. Inquiry-Based Learning and Retention of Scientific Concepts*

Empirical evidence also suggests that inquiry-based learning supports students' retention of scientific knowledge. Bónus et al. (2024) examined the effects of digital game-based inquiry learning on eighth graders' inquiry skills and reported that students not only demonstrated improved performance but also retained learned concepts over time due to sustained engagement and repeated application of knowledge. The study highlights the role of inquiry-oriented activities in fostering durable learning.

Aregehagn et al. (2022) further observed that students exposed to guided inquiry-based learning retained scientific concepts more effectively than those taught using conventional methods. These findings align with the view that inquiry-based instruction promotes meaningful learning experiences that enhance long-term retention. However, systematic reviews indicate that relatively few studies explicitly measure retention using delayed post-tests, particularly at the basic education level (Heindl, 2019; Strat et al., 2024), revealing a gap that warrants further investigation.

### *3.3. Inquiry-Based Learning and Science Process Skills*

The development of science process skills is a core objective of inquiry-based learning, and several studies have empirically examined this relationship. Kassaye et al. (2025) found that integrating science process skills into inquiry-based instruction significantly improved grade nine students' academic achievement in cell biology, suggesting that the development of these skills contributes directly to learning outcomes. Similarly, Bónus et al. (2024) reported significant improvements in students' inquiry skills when inquiry-based strategies were embedded within biology instruction.

Strat et al. (2024), in a systematic review of inquiry-based science education in teacher education, concluded that inquiry-oriented approaches consistently promote students' engagement in scientific practices, including observing, hypothesizing, experimenting, and interpreting data. These empirical findings support the assertion that inquiry-based learning plays a critical role in fostering science process skills necessary for scientific literacy.

### *3.4. Inquiry-Based Learning and Students' Perceptions and Attitudes*

Beyond cognitive outcomes, empirical studies have also explored the influence of inquiry-based learning on students' perceptions and attitudes toward science. Manishimwe et al. (2022) investigated the effect of inquiry-based learning on students' attitudes toward biology and found that students taught using inquiry-based approaches developed more positive attitudes compared to those taught using conventional methods. The study attributed these outcomes to increased learner autonomy and engagement.

Sachyani et al. (2024) examined teachers' views of future-oriented pedagogy within inquiry-based molecular biology teaching and reported that inquiry-oriented practices positively influenced students' engagement and perceptions of biology learning. Similarly, Jeffery, Nomme, Deane, Pollock, and Birol (2016) found that inquiry-based biology laboratory courses positively shaped students' attitudes toward science and their views about scientific inquiry. Although this study predates more recent work, it provides foundational empirical support for the affective benefits of inquiry-based instruction.

### *3.5. Methodological Trends and Identified Gaps in the Literature*

Systematic reviews provide further insight into methodological trends and gaps in inquiry-based learning research. Heindl (2019) and Alarcon et al. (2023) reported that while many studies affirm the effectiveness of inquiry-based learning, variations in implementation, assessment methods, and research design limit the generalizability of findings. Strat et al. (2024) further observed that few studies employ robust experimental designs that control for pretest effects, such as the Solomon four-group design.



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Additionally, although several studies have examined inquiry-based learning in biology, limited empirical research has focused specifically on cell theory at the junior high school level, particularly within African and Ghanaian contexts. Moreover, existing studies tend to examine learning outcomes in isolation, with few investigations simultaneously addressing conceptual understanding, retention, science process skills, and students' perceptions. This gap highlights the need for comprehensive, methodologically rigorous studies that examine multiple learning outcomes within a single instructional intervention.

## 4. METHODOLOGY

### *4.1. Research Design*

The study adopted a Solomon four-group experimental design, a true experimental design that combines the strengths of the pretest–posttest control group design and the posttest-only control group design. This design was considered appropriate because it allows for the examination of the effect of Inquiry-Based Learning (IBL) on students' learning outcomes while controlling for potential pretest sensitisation effects (Edmonds & Kennedy, 2017; Frey, 2018). The design comprised four groups: two experimental groups and two control groups. Experimental Groups 1 and 2 were exposed to Inquiry-Based Learning, while Control Groups 1 and 2 were taught using the conventional instructional approach. Experimental Group 1 and Control Group 1 were pretested before the intervention, whereas Experimental Group 2 and Control Group 2 did not receive a pretest.

The Solomon four-group design enhances internal validity by enabling the separation of treatment effects from testing effects and supports stronger causal inference in educational research (Allen, 2017; El Karkri, Quesada, & Romero-Ariza, 2025). It also allows for the use of two-way analysis of variance (ANOVA) to examine the main effects of treatment and pretesting, as well as their interaction. Table 1 illustrates the design of the study.

**Table 1.** Solomon's four-group design.

| *Group* | *Pretest* | *Treatment* | *Posttest* | *Retention Test* |
|---|---|---|---|---|
| 1. Experimental Group 1 (n = 37) | ✓ | Inquiry-Based Learning (IBL) | ✓ | ✓ |
| 2. Control Group 1 (n = 33) | ✓ | Conventional Instruction | ✓ | ✓ |
| 3. Experimental Group 2 (n = 35) | — | Inquiry-Based Learning (IBL) | ✓ | ✓ |
| 4. Control Group 2 (n = 36) | — | Conventional Instruction | ✓ | ✓ |

### *4.2. Population and Sampling Procedure*

The population for the study consisted of junior high school students offering Integrated Science. The study employed intact class sampling, involving four equivalent intact classes drawn from two public junior high schools. Intact classes were used because random assignment of individual students was not feasible within the regular school setting, a common constraint in school-based educational research (Frey, 2018).

The two schools were purposively selected based on similarities in curriculum implementation, student population, and instructional resources. From each school, one intact class was assigned to the experimental condition and one to the control condition to minimize school-level effects. The four intact classes were assigned as follows: Experimental Group 1 (n = 37), Control Group 1 (n = 33), Experimental Group 2 (n = 35), and Control Group 2 (n = 36), resulting in a total sample size of 141 students. This arrangement ensured group equivalence and provided adequate statistical power for data analysis.

## 5. RESEARCH INSTRUMENTS

### *5.1. Cell Theory Concept Test (CTCT)*

The Cell Theory Concept Test (CTCT) was developed to assess students' conceptual understanding of cell theory. It consisted of multiple-choice and structured items covering key concepts such as cell structure, functions,



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and the principles of cell theory. The test was used as a pretest, posttest, and retention test. Content validity was ensured through expert review by science education specialists, while reliability was established using appropriate reliability coefficients.

### *5.2. Data Collection Procedure*

The study was conducted over a specified instructional period during which the experimental groups were taught cell theory using Inquiry-Based Learning strategies, while the control groups received instruction through conventional teacher-centered methods. The pretest was administered to Experimental Group 1 and Control Group 1 before the intervention. The posttest was administered to all four groups immediately after the intervention, while the retention test was administered three weeks later to assess the durability of learning.

### *5.3. Data Analysis Techniques*

Data were analyzed using appropriate inferential statistical techniques. To address Research Question 1, a two-way ANOVA was employed to examine the main effects of treatment (IBL versus conventional instruction), pretesting, and their interaction on students' conceptual understanding of cell theory. This analysis was consistent with the Solomon four-group design and allowed for the detection of pretest sensitisation effects (Edmonds & Kennedy, 2017).

To address Research Question 2, paired-samples t-tests were used to compare posttest and retention test scores within the experimental groups. Effect sizes were calculated using Cohen's d to determine the magnitude of observed differences. Statistical significance was tested at the 0.05 alpha level.

## 6. RESULTS

### *6.1. RQ1: Effect of Inquiry-Based Learning on Students' Conceptual Understanding of Cell Theory*

Table 2 presents the results of a two-way ANOVA examining the effects of teaching method (Inquiry-Based Learning vs. conventional method) and pretesting on students' conceptual understanding of cell theory.

**Table 2.** Two-way ANOVA Test of between-subject effects.

| Source | Type III sum of squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected model | 18871.184a | 3 | 6290.395 | 76.505 | 0.000 |
| Intercept | 495831.768 | 1 | 495831.768 | 6030.43 | 0.000 |
| Treatment | 18864.478 | 1 | 18864.478 | 229.435 | 0.000 |
| Pretest | 8.292 | 1 | 8.292 | 0.101 | 0.751 |
| Treatment * Pretest | 7.495 | 1 | 7.495 | 0.091 | 0.763 |
| Error | 11264.362 | 137 | 82.222 | | |
| Total | 531157 | 141 | | | |
| Corrected total | 30135.546 | 140 | | | |
| a. R Squared = 0.626 (Adjusted R Squared = 0.618) | | | | | |

**Note:** * Indicates interaction effect.

The results indicate a statistically significant main effect of treatment on students' conceptual understanding of cell theory, $F(1, 137) = 229.44$, $p < 0.001$. This finding shows that students taught using Inquiry-Based Learning (IBL) performed significantly better on the Cell Theory Concept Test than those taught using the conventional teaching method. The main effect of the pretest was not statistically significant, $F(1, 137) = 0.10$, $p = 0.751$, indicating that exposure to the pretest did not significantly influence students' post-test conceptual understanding.

Furthermore, the interaction effect between treatment and pretest was not statistically significant, $F(1, 137) = 0.09$, $p = 0.763$. This suggests that the effect of Inquiry-Based Learning on students' conceptual understanding was not influenced by pretesting, confirming the absence of a pretest sensitization effect. The model explained a



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substantial proportion of the variance in students' conceptual understanding, with an $R^2$ value of 0.626 (adjusted $R^2$ = 0.618), indicating that approximately 62.6% of the variance in post-test scores was accounted for by the teaching method and pretesting variables.

### *6.2. RQ2: Effect of IBL on Students' Retention of Concepts in Cell Theory*

To determine the effect of Inquiry-Based Learning (IBL) on students' retention of cell theory concepts, a retention test was administered three weeks after the post-test to students in the experimental groups. Paired-samples t-tests were conducted to compare students' post-test and retention test scores.

### *6.3. Retention Performance of Experimental Group 1 (Pretested IBL Group)*

Table 3 presents the paired samples t-test of the Post-test and Retention-test for Experimental group 1. Students in Experimental Group 1 demonstrated a statistically significant improvement in their retention test scores compared to their post-test scores. The mean score increased from M = 70.91 (SD = 9.18) in the post-test to M = 74.54 (SD = 7.84) in the retention test.

**Table 3.** Paired samples t-test of Post-test and Retention-test for Experimental group 1.

| *Test* | *N* | *M* | *SD* | *df* | *t* | *p* | *d* |
|---|---|---|---|---|---|---|---|
| Post test | 37 | 70.91 | 9.18 | 36 | -4.85 | 0.000 | 0.800 |
| Retention | 37 | 74.54 | 7.84 | | | | |

The paired-samples t-test revealed a significant difference between the post-test and retention test scores, $t(36) = -4.85$, $p < 0.001$, with a large effect size (Cohen's d = 0.80). This result indicates that Inquiry-Based Learning not only enhanced students' immediate understanding but also supported strong retention of cell theory concepts over time.

### *6.4. Retention Performance of Experimental Group 2 (Non-Pretested IBL Group)*

Table 4 presents the results of the Paired samples t-test of the Post-test and Retention-test for Experimental group 2. The results show no statistically significant difference between the post-test (M = 70.94, SD = 7.80) and the retention test (M = 70.77, SD = 9.94) scores for Experimental Group 2.

**Table 4.** Paired samples t-test of Post-test and Retention-test for Experimental group 2.

| *Test* | *N* | *M* | *SD* | *df* | *t* | *p* | *d* |
|---|---|---|---|---|---|---|---|
| Post test | 35 | 70.94 | 7.80 | 34 | 0.135 | 0.894 | 0.023 |
| Retention | 35 | 70.77 | 9.94 | | | | |

The paired-samples t-test yielded $t(34) = 0.14$, $p = .894$, with a negligible effect size (Cohen's d = 0.023). This suggests that although students maintained their performance level, there was no significant gain or loss in retained knowledge over the three-week interval. The contrasting retention patterns between the two experimental groups suggest that pretesting may have reinforced long-term consolidation of learning when combined with Inquiry-Based Learning, even though pretest effects were non-significant. Importantly, both experimental groups maintained their conceptual understanding over time, indicating that IBL is effective in promoting retention stability of cell theory concepts.

## 7. DISCUSSION

The first research question examined the effect of Inquiry-Based Learning (IBL) on junior high school students' conceptual understanding of cell theory. The two-way ANOVA results (Table 1) revealed a significant main effect of



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treatment on students' posttest scores ($F(1,137) = 229.435$, $p < .001$), with an $R^2$ value of 0.626, indicating that approximately 63% of the variance in conceptual understanding was explained by the instructional approach. Neither the pretest nor the interaction between treatment and pretest significantly influenced outcomes, suggesting that IBL had a robust positive effect on students' conceptual understanding regardless of prior knowledge.

These findings indicate that students exposed to IBL demonstrated superior understanding of cell theory compared to those taught through conventional methods. This aligns with prior research showing that inquiry-oriented instruction facilitates active engagement, encourages exploration, and supports conceptual restructuring, particularly for abstract biological concepts such as cell structure and function (Cairns, 2019; Johann et al., 2024; Kassaye et al., 2025). By actively participating in investigations, formulating explanations, and interpreting evidence, students construct more accurate mental models of cellular phenomena, consistent with constructivist principles (Heindl, 2019; Van Uum et al., 2016).

Moreover, these results corroborate findings from (Hasiloglu & Eminoglu, 2017) who reported that hands-on and inquiry-based activities significantly reduced misconceptions in cell biology. Similarly, Duda and Adpriyadi (2020) highlighted that conventional teaching often fails to correct pre-existing misconceptions, whereas guided inquiry provides opportunities for students to confront and revise their alternative conceptions. Therefore, the significant effect observed in this study underscores the capacity of IBL to promote meaningful conceptual understanding in junior high school students, confirming theoretical predictions from both constructivist learning theory and conceptual change theory. The second research question assessed the effect of IBL on students' retention of cell theory concepts, measured through retention tests administered three weeks after the posttest. The results differed across experimental groups: Experimental Group 1 showed a significant increase in mean scores from the posttest ($M = 70.91$, $SD = 9.18$) to the retention test ($M = 74.54$, $SD = 7.84$), $t(36) = -4.85$, $p < .001$, Cohen's $d = -0.797$. Experimental Group 2, however, did not demonstrate a significant change, $t(34) = 0.135$, $p = 0.894$, Cohen's $d = 0.023$, suggesting stability in scores. The significant improvement observed in Experimental Group 1 suggests that IBL not only enhances immediate understanding but can also promote durable learning. This aligns with studies indicating that engagement in active, inquiry-driven tasks facilitates long-term retention by linking new knowledge to prior understanding and providing opportunities for repeated application (Aregehagn et al., 2022; Bónus et al., 2024). The large effect size (Cohen's $d = 0.797$) further indicates a practically meaningful improvement in retention, consistent with the view that meaningful learning experiences are more likely to be stored in long-term memory (Cairns, 2019). For Experimental Group 2, the absence of a significant change may reflect differences in the type or intensity of IBL exposure, highlighting the importance of instructional scaffolding and the structure of inquiry activities. Guided inquiry approaches, which provide both direction and autonomy, have been shown to produce higher retention than minimally structured or unscaffolded inquiry (Aregehagn et al., 2022; Strat et al., 2024). This finding underscores the importance of carefully designed inquiry experiences to maximize learning outcomes.

The retention results support theoretical predictions from constructivist learning theory, which posits that active engagement, reflection, and contextual application of knowledge enhance durable learning. They also align with conceptual change theory, which suggests that learners who successfully restructure misconceptions and integrate accurate scientific concepts are more likely to retain knowledge over time (Johann et al., 2024; Kassaye et al., 2025).

## 8. CONCLUSION AND RECOMMENDATIONS

This study examined the effects of Inquiry-Based Learning (IBL) on junior high school students' learning outcomes in cell theory, focusing on conceptual understanding, retention of knowledge, science process skills, and perceptions of the subject. The findings revealed that students exposed to IBL demonstrated significantly higher conceptual understanding of cell theory compared to those taught using conventional instructional methods. The two-way ANOVA results indicated that the treatment effect was substantial, with pre-existing knowledge and the interaction between pretest and treatment having no significant impact. These results suggest that IBL is effective in



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promoting meaningful learning and facilitating the reconstruction of misconceptions, consistent with constructivist learning theory and conceptual change theory. The study further showed that IBL positively influenced students' retention of cell theory concepts. Students who engaged in guided inquiry activities not only retained their knowledge over time but, in some cases, demonstrated improved performance on the retention test administered three weeks after the posttest. This indicates that inquiry-based instruction fosters durable learning by actively engaging students in constructing, applying, and reflecting on scientific concepts. The findings align with prior research demonstrating that inquiry-based learning enhances understanding, retention, and the development of science process skills, particularly in abstract topics such as cell biology (Aregehagn et al., 2022; Bónus et al., 2024; Johann et al., 2024).

Based on these findings, it is recommended that junior high school biology teachers in Ghana adopt Inquiry-Based Learning as a core instructional approach. Teachers should design lessons that engage students in asking questions, investigating phenomena, interpreting evidence, and constructing explanations, while providing scaffolding to support learners' understanding. Practical demonstrations, hands-on activities, and collaborative inquiry tasks should be prioritized to enhance conceptual understanding and long-term retention.

Curriculum developers and educational authorities should integrate inquiry-oriented strategies explicitly into the Ghanaian Junior High School science curriculum, ensuring that lesson plans, instructional materials, and assessment strategies reflect inquiry principles. Teacher education programs should emphasize pre-service and in-service training on the design and implementation of IBL, equipping educators with the knowledge and skills to facilitate effective inquiry-based instruction. Continuous professional development workshops can further support teachers in creating learning environments that promote conceptual change, develop science process skills, and foster positive perceptions of science among students. Finally, future research should explore the effects of IBL on additional learning outcomes, such as higher-order thinking, collaborative problem-solving, and attitudes toward science, while examining long-term retention across multiple biology topics. Mixed-methods studies could provide deeper insight into students' experiences and engagement during inquiry-based learning, as well as the contextual factors that influence its effectiveness. By implementing inquiry-based instructional practices in junior high school science classrooms, educators and policymakers can enhance the quality of biology education, reduce misconceptions, and promote meaningful, lasting understanding and positive perceptions of science among Ghanaian students.

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**Transparency:** The authors affirm that this manuscript is an honest, accurate, and transparent account of the study. No important aspects of the investigation have been omitted, and any deviations from the original study plan have been clearly explained. All ethical standards for research and academic writing were strictly followed.
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