International Journal of Sustainable Social Culture, Science Technology, Management, and Law Humanities, 3(1), (2026)

Active Learning Strategies in Higher Education Biology: A Literature Review of Inquiry-Based Learning, Problem-Based Learning, and Flipped Classroom Approaches

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Article history
Received: 13 March 2026
Revised:21 April 2026
Accepted:10 June 2026

Keywords
Active Learning
Biology Education
Inquiry-based learning
Problem-based learning
Flipped classroom
Higher education

Abstract

Biology education in higher education faces significant challenges in fostering conceptual understanding, critical thinking, and scientific inquiry skills among students. Traditional teacher-centered instruction often positions students as passive recipients of information, limiting their engagement in knowledge construction. Consequently, active learning strategies have gained considerable attention as effective approaches to improve the quality of biology education. This review aims to examine the implementation of active learning strategies in higher education biology through three major pedagogical approaches: Inquiry-Based Learning (IBL), Problem-Based Learning (PBL), and the Flipped Classroom model. A literature review methodology was employed to synthesize findings from previous studies concerning the implementation of active learning in biology education. The findings indicate that Inquiry-Based Learning effectively enhances scientific reasoning, investigative skills, and conceptual understanding. Problem-Based Learning promotes critical thinking, collaborative learning, and the application of biological concepts to authentic problems. Meanwhile, the Flipped Classroom model encourages self-directed learning and optimizes classroom interaction through active discussions and problem-solving activities. Integrating these approaches provides a promising framework for developing meaningful, student-centered biology instruction that supports the acquisition of twenty-first-century competencies.

1. Introduction

Biology is a multidisciplinary science that investigates living systems from molecular structures to ecosystem dynamics. Consequently, biology education requires students not only to master theoretical concepts but also to develop scientific reasoning, problem-solving skills, laboratory competencies, and critical thinking abilities.

Despite these requirements, biology instruction in many higher education institutions continues to rely heavily on conventional lecture-based approaches. Such teacher-centered instruction often results in passive learning, where students primarily memorize information without fully understanding its application in real-world biological contexts.

Recent educational reforms advocate a shift toward student-centered learning, emphasizing students' active participation in constructing knowledge through investigation, collaboration, reflection, and authentic problem-solving. Active learning strategies align well with constructivist learning theory by encouraging learners to engage cognitively, socially, and practically throughout the learning process.
Among various active learning approaches, three instructional models have received increasing attention in biology education:

- Inquiry-Based Learning (IBL)
- Problem-Based Learning (PBL)
- Flipped Classroom

These instructional approaches share a common objective of improving students' engagement while simultaneously enhancing higher-order thinking skills, scientific literacy, and independent learning.
This literature review synthesizes current evidence regarding these three approaches and discusses their implications for improving biology education in higher education.

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doi: https://doi.org/10.71131/wqrvrv15

2. Method

This study employed a literature review methodology by analyzing previous research investigating active learning implementation in higher education biology.

The review focused on studies discussing:

- Active learning in biology classrooms
- Inquiry-Based Learning
- Problem-Based Learning
- Flipped Classroom implementation

Each article was analyzed according to:

- instructional characteristics
- pedagogical implementation
- learning outcomes
- strengths
- implementation challenges

The synthesis aims to identify common patterns and provide recommendations for biology educators.

3. Result and Discussion

3.1 Inquiry-Based Learning in Biology Education

Inquiry-Based Learning (IBL) is one of the most widely adopted active learning approaches in science education, emphasizing students' active involvement in the process of scientific investigation. Rooted in constructivist learning theory, IBL positions students as active knowledge constructors rather than passive recipients of information. Within this approach, instructors serve primarily as facilitators who guide students through scientific inquiry while encouraging independent thinking and evidence-based reasoning.

The inquiry process generally consists of six interconnected stages: identifying a phenomenon, formulating research questions, developing hypotheses, collecting data, analyzing findings, and drawing conclusions. These stages closely resemble the scientific method employed by biologists, making Inquiry-Based Learning particularly suitable for biology education. Through repeated engagement in scientific inquiry, students gradually develop scientific reasoning skills, analytical thinking, and a deeper understanding of biological concepts.

The implementation of Inquiry-Based Learning is highly appropriate across various biology courses, including Cell Biology, Plant Physiology, Ecology, and Plant Diversity. For example, in a Plant Diversity course, students may investigate morphological adaptations of xerophytic, hydrophytic, and halophytic plants by conducting field observations, documenting anatomical characteristics, and comparing their findings with established scientific literature. Rather than memorizing descriptive characteristics from textbooks, students actively construct conceptual understanding through observation, investigation, and scientific interpretation.

Numerous studies have demonstrated the educational benefits of Inquiry-Based Learning in higher biology education. First, IBL significantly enhances critical thinking by encouraging students to evaluate evidence, formulate scientific explanations, and justify conclusions based on empirical data. Second, it improves research competencies by providing authentic experiences in designing investigations, collecting and analyzing data, and preparing scientific reports. Third, Inquiry-Based Learning promotes deeper conceptual understanding because students discover biological principles through direct experience rather than passive information transfer. Beyond cognitive achievement, IBL has also been associated with increased curiosity, creativity, scientific attitudes, and intrinsic learning motivation.

Despite its considerable advantages, implementing Inquiry-Based Learning presents several challenges. Inquiry activities generally require more instructional time than traditional lecture-based teaching due to the complexity of the investigative process. Furthermore, students who are accustomed to teacher-centered instruction may initially struggle with self-directed inquiry. Successful implementation also depends heavily on instructors' pedagogical competence in designing meaningful inquiry activities, facilitating classroom discussions, and providing appropriate guidance without limiting students' independence. Consequently, effective Inquiry-Based Learning requires careful instructional planning, adequate laboratory facilities, and an academic environment that supports exploration and scientific questioning.

3.2 Problem-Based Learning in Biology Education

Problem-Based Learning (PBL) is an instructional approach that utilizes authentic, real-world problems as the starting point of learning. Unlike conventional teaching methods that begin with theoretical explanations, PBL introduces students to contextual biological problems that require scientific investigation and collaborative problem-solving. This approach aligns closely with the objectives of modern biology education, which emphasize not only conceptual knowledge but also the ability to apply biological principles in addressing complex environmental and societal issues.

The PBL process typically involves several sequential phases: presenting a problem, identifying relevant concepts, collaborative group discussion, information gathering, developing alternative solutions, and presenting findings. Throughout these stages, students actively construct knowledge through collaborative inquiry while instructors act as facilitators who guide discussions and monitor learning progress.

Problem-Based Learning is particularly suitable for biology courses because biological knowledge is closely connected to real-life phenomena. For instance, students may be presented with a case in which a plant experiences wilting and eventual death despite receiving sufficient water. To solve this problem, students must analyze water transport mechanisms, xylem function, transpiration processes, and possible physiological disorders affecting plant growth. Such activities encourage students to integrate multiple biological concepts instead of memorizing isolated facts.

The literature consistently reports that Problem-Based Learning substantially improves students' problem-solving abilities by encouraging them to apply theoretical knowledge to practical situations. In addition, PBL enhances communication skills through collaborative discussions, scientific argumentation, and peer interaction. Students learn to defend their ideas using scientific evidence while respecting alternative viewpoints. Furthermore, because biological concepts are learned within meaningful contexts, students generally achieve greater conceptual retention and long-term understanding than through traditional lecture-based instruction.

Nevertheless, implementing PBL also presents several limitations. Designing authentic and appropriately challenging biological problems requires considerable instructional expertise. Problems that are too simple may fail to stimulate critical thinking, whereas excessively complex problems may reduce students' motivation and confidence. Moreover, collaborative discussions demand substantial classroom time and require instructors to effectively manage group dynamics to ensure equal participation among students. Therefore, successful implementation of Problem-Based Learning depends on well-designed learning scenarios, students' readiness for collaborative learning, and instructors' facilitation skills.

3.3 Flipped Classroom in Biology Education

The Flipped Classroom model represents a significant transformation of traditional instructional practices by relocating the initial content delivery outside the classroom through digital learning resources while utilizing face-to-face classroom sessions for higher-order learning activities. In this model, students study fundamental concepts independently before class by watching instructional videos, reading digital modules, or exploring scientific articles. Classroom time is subsequently dedicated to collaborative discussions, laboratory activities, case analyses, and problem-solving exercises.

This instructional approach aligns closely with the demands of twenty-first-century education, particularly the development of self-regulated learning and digital literacy. Within biology education, Flipped Classroom enables students to acquire foundational knowledge of topics such as cell biology, genetics, metabolism, or plant physiology before engaging in laboratory investigations or classroom discussions. Consequently, classroom interactions become more student-centered and intellectually engaging, allowing instructors to address misconceptions, facilitate scientific reasoning, and promote deeper conceptual understanding.

Research findings consistently indicate that the Flipped Classroom approach enhances students' independent learning skills by encouraging greater responsibility for pre-class preparation. Furthermore, this model optimizes classroom time by prioritizing analytical thinking, collaborative learning, and application-based activities over passive content delivery. The integration of various digital learning resources also contributes to improved technological competence and information literacy, both of which are increasingly important competencies in higher education.

However, successful implementation of Flipped Classroom requires reliable technological infrastructure, including internet access and digital learning platforms. Additionally, the effectiveness of this approach largely depends on students' motivation and commitment to completing pre-class learning activities. When students arrive unprepared, classroom discussions and collaborative activities become significantly less effective. Therefore, instructors should carefully design engaging pre-class learning materials while incorporating formative assessments to ensure adequate student preparation before face-to-face instruction.

3.4. Integration of Active Learning Strategies in Biology Education

Although Inquiry-Based Learning, Problem-Based Learning, and Flipped Classroom each possess distinctive characteristics, their integration offers significant potential for creating a comprehensive and student-centered biology learning environment. Inquiry-Based Learning primarily develops scientific reasoning through investigation and evidence-based inquiry. Problem-Based Learning emphasizes critical thinking and problem-solving by engaging students with authentic biological issues. Meanwhile, Flipped Classroom promotes self-regulated learning by encouraging students to acquire foundational knowledge independently before participating in collaborative classroom activities.

Rather than viewing these approaches as competing instructional models, they should be considered complementary components of an integrated pedagogical framework. Their combined implementation enables biology educators to address multiple dimensions of student learning, including conceptual understanding, scientific inquiry, critical thinking, communication skills, collaboration, and lifelong learning competencies.

For example, in an Ecology course, students may first study ecosystem concepts independently through digital learning materials using the Flipped Classroom approach. During face-to-face sessions, they conduct field investigations to collect ecological data using Inquiry-Based Learning principles. Subsequently, students analyze environmental issues such as biodiversity loss, habitat degradation, or ecosystem restoration through Problem-Based Learning activities. Such an integrated learning sequence enables students to acquire theoretical knowledge, develop scientific investigation skills, and apply biological concepts to solve authentic environmental problems.

Furthermore, integrating these three approaches supports the development of essential twenty-first-century competencies, commonly referred to as the 4Cs: critical thinking, creativity, communication, and collaboration. It also strengthens students' digital literacy, scientific literacy, and self-directed learning abilities, all of which are crucial for future biology educators and researchers.

3.5. Challenges in Implementing Active Learning

Despite substantial evidence supporting the effectiveness of active learning strategies in biology education, several challenges remain in their practical implementation. From the students' perspective, many learners continue to rely on teacher-centered instructional practices and may initially struggle to adapt to self-directed and collaborative learning environments. Developing independent learning habits requires gradual adaptation and continuous instructional support.

From the instructors' perspective, active learning demands considerably higher pedagogical competence than conventional lecture-based teaching. Educators must design meaningful learning activities, facilitate productive discussions, integrate laboratory investigations, and implement authentic assessment strategies that evaluate not only conceptual understanding but also scientific processes, collaboration, and critical thinking. Consequently, professional development programs focusing on active learning pedagogy are essential for improving instructional quality.

Institutional factors also play a significant role in determining the success of active learning implementation. Adequate laboratory facilities, digital learning technologies, internet accessibility, and effective Learning Management Systems (LMS) are fundamental requirements for supporting inquiry activities, problem-based learning, and flipped instruction. Without sufficient institutional support, instructors may encounter difficulties in fully implementing these innovative instructional approaches.

Overall, the successful adoption of active learning strategies requires strong collaboration among students, instructors, and higher education institutions. When these components are effectively integrated, biology education can better prepare graduates who possess not only comprehensive biological knowledge but also scientific reasoning, critical thinking, problem-solving abilities, and lifelong learning competencies required in the twenty-first century.

4. Conclusion

Active learning strategies have strong potential to improve the quality of biology education in higher education. Inquiry-Based Learning strengthens scientific reasoning and research skills through systematic investigation, Problem-Based Learning develops critical thinking and problem-solving abilities through authentic biological cases, while the Flipped Classroom promotes independent learning and allows classroom time to be used for discussion, experimentation, and higher-order thinking. Integrating these approaches can create a more comprehensive and student-centered learning environment in which students independently acquire basic concepts, investigate biological phenomena, and apply their knowledge to real-world problems.

The effectiveness of active learning, however, depends on students' readiness, instructors' pedagogical competence, appropriate assessment design, and adequate institutional support. Therefore, its implementation should be carefully planned, introduced gradually, and supported by sufficient digital infrastructure, laboratory facilities, and professional development for instructors. Future research should further examine integrated models combining inquiry, problem-based learning, and flipped instruction across different biology courses and institutional contexts.

Author Contributions

Muhammad Zainul Muttaqin: Conceptualization, Methodology, Investigation, Formal analysis, Writing – Original Draft, Writing – Review & Editing.
Suroso: Conceptualization, Methodology, Supervision, Validation, Writing – Review & Editing.
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All authors contributed equally to this work. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Funding

No funding support was received.

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