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TRENDS IN ACTIVE LEARNING PEDAGOGIES IN BIOLOGY EDUCATION: A SYSTEMATIC DOCUMENTARY CONTENT ANALYSIS OF GLOBAL RESEARCH EVIDENCE

Opeyemi Abdullahi ALABI[1*], Abdulraheem Dare GBIGBADUA[2], Olufunke. O. KAYODE[3], Olatunji Yusuf ABDULRAHEEM[4]
[1,2,3]Department of Arts and Science Education, Faculty of Education, Kwara State University, Malete-Nigeria
[4]Department of Integrated Science, Nan-Aishat Memorial College of Education, Ilorin, Kwara State
*Corresponding Author: opeyemi.alabi@kwasu.edu.ng

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ABSTRACT
Biology education plays a crucial role in developing scientific literacy, critical thinking, and the ability to understand complex biological systems. In response, active learning pedagogies have increasingly been adopted in biology education to enhance student engagement, improve conceptual mastery, and support deeper learning. The purpose of this study was to examine global trends in active learning pedagogies in biology education through a systematic documentary content analysis of empirical research. Specifically, the study sought to identify dominant active learning strategies, analyse methodological patterns and geographical distribution of studies, examine reported learning outcomes, and map the theoretical frameworks underpinning this body of research. The study employed a systematic documentary content analysis design. The selected studies were analysed using a structured coding framework that combined quantitative frequency analysis with qualitative thematic synthesis. The findings reveal a substantial growth in active learning research in biology education, with inquiry-based learning, problem-based learning, flipped classroom models, cooperative learning, and technology-enhanced instruction emerging as the dominant pedagogical approaches. The analysed studies consistently report improvements in academic achievement, conceptual understanding, student engagement, and learning retention. The analysis also indicates that constructivist, sociocultural, and experiential learning theories form the principal theoretical foundations of these pedagogical approaches. Overall, the study contributes to biology education scholarship by synthesising global empirical evidence on active learning practices, clarifying their theoretical grounding, and providing evidence-based insights that can inform instructional practice, curriculum development, and educational policy aimed at improving biology teaching and learning.

INTRODUCTION

Biology education plays a critical role in equipping learners with scientific literacy, critical thinking skills, and the capacity to engage with complex global challenges such as climate change, biotechnology ethics, public health, and biodiversity loss. However, traditional lecture-based instructional approaches have historically dominated science classrooms, often emphasising content transmission rather than conceptual understanding and scientific reasoning (Freeman et al., 2014; Kay et al., 2019). This teacher-centred paradigm has been widely critiqued for promoting passive learning and surface memorisation rather than deep cognitive engagement (Pretorius, 2023). Over the past two decades, science education research has documented a global shift toward active learning pedagogies, defined as instructional methods that engage students directly in the learning process through discussion, problem-solving, collaboration, and inquiry (Arthurs & Kreager, 2017; Cattaneo, 2017). Active learning is grounded in constructivist learning theory, which posits that learners actively construct knowledge through interaction with ideas, experiences, and social contexts rather than passively receiving information (Vanhorn et al., 2019; Pardjono, 2016).

Empirical research has increasingly demonstrated that student-centred approaches improve academic outcomes in STEM disciplines. A large-scale meta-analysis of 225 studies in undergraduate

STEM education found that active learning significantly increased examination performance and reduced failure rates compared to traditional lecturing (Freeman et al., 2014). These findings have strengthened the call for pedagogical reform in biology education across secondary and tertiary contexts. Consequently, pedagogical innovations such as inquiry-based learning, problem-based learning, flipped classrooms, and cooperative learning have become central to contemporary science education discourse (Gillies, 2023; Loizou & Lee, 2020). Despite this growing body of research, there remains a need for systematic documentary synthesis specifically focused on biology education to identify global research trends, theoretical foundations, and reported outcomes.

Statement of the Problem. Although numerous empirical studies report positive outcomes associated with active learning, the evidence base remains fragmented across contexts, educational levels, and methodological designs. Individual experimental and quasi-experimental studies provide localized findings, but without systematic synthesis, it is difficult to determine broader global patterns (Rockers et al., 2015). Furthermore, biology as a discipline presents unique pedagogical challenges. Students frequently struggle with abstract concepts such as molecular processes, genetics, evolution, and ecological systems (Dauer et al., 2013). Research indicates persistent misconceptions in biology learning, even after formal instruction (Leonard et al., 2014; Yates & Marek, 2014). Traditional lecture-based methods have been shown to inadequately address such conceptual misunderstandings (Freeman et al., 2014). While meta-analyses have examined STEM education broadly, fewer studies have systematically analysed trends specifically within biology education. Moreover, there is limited documentary evidence mapping the evolution of theoretical frameworks underpinning active learning research in biology, such as constructivism, experiential learning (Adamu & Adamu, 2025; Kaufman, 2018).

Therefore, the problem addressed in this study is the absence of a comprehensive, systematic documentary content analysis that synthesises global research evidence on active learning pedagogies in biology education, identifies dominant trends, and examines their theoretical underpinnings and reported academic outcomes. The primary purpose of this study is to conduct a systematic documentary content analysis of global empirical research on active learning pedagogies in biology education. Specifically, the study seeks to:

1. Identify dominant active learning strategies employed in biology education research.
2. Examine trends in research design, geographical distribution, and publication patterns.
3. Analyse reported learning outcomes associated with active learning approaches.
4. Map the theoretical frameworks underpinning active learning research in biology education.

This study contributes to biology education scholarship in several important ways. This study provides empirical evidence of the validation of constructivist theory, sociocultural theory and experiential learning theory using the field of biology education through the analysis of the theoretical basis of the constructs behind initiatives of active learning research. Such synthesis strengthens the theoretical coherence of pedagogical innovation research. The study advances methodological rigour by applying systematic documentary content analysis procedures consistent with established guidelines (Moher et al., 2010; Krippendorff, 2018). This approach enhances transparency and replicability in research synthesis. For educators and curriculum developers, the findings offer evidence-based guidance on pedagogical strategies that improve academic performance, conceptual understanding, and student engagement. Given ongoing global calls for STEM reform, such evidence supports policy decisions related to teacher training and curriculum transformation (Freeman et al., 2014). Educational reforms increasingly emphasise evidence-based teaching practices. By synthesising global research trends, this study provides policymakers with structured evidence regarding which pedagogical innovations demonstrate consistent effectiveness. This study focuses exclusively on peer-reviewed empirical research in biology education published between 2009 and 2025. The timeframe was selected to capture contemporary pedagogical reforms and the expansion of active learning research in the 21st century. The study is limited to journal articles indexed in major academic databases. Studies explicitly examining biology education (excluding broader STEM studies unless biology-specific findings are reported). Publications in English. The study does not include Grey literature, dissertations, or conference abstracts without full empirical data. Purely theoretical or opinion-based papers. Studies not clearly reporting methodology and outcomes. These

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delimitations ensure methodological consistency and enhance the reliability of findings, consistent with best practices in systematic documentary research (Lisy & Porritt, 2016).

Literature Review

Active learning is broadly defined as instructional approaches that engage students in meaningful learning activities requiring them to think about what they are doing (Brame, 2016). Rather than passively receiving information, learners participate in discussion, problem-solving, analysis, synthesis, and evaluation activities that promote higher-order cognition (Prince, 2004). Prince (2004), in a widely cited review, defines active learning as any instructional method that engages students in the learning process beyond listening. Similarly, Michael (2006) argues that active learning requires students to read, write, discuss, or solve problems while actively engaging in cognitive processing of content. The conceptual foundation of active learning lies in constructivist epistemology. Fosnot (2013) posits that learners construct knowledge through active interaction with their environment, while Lantolf (2000) emphasises the social dimension of knowledge construction through dialogue and collaboration. In this view, knowledge is not transmitted intact from teacher to learner but constructed through cognitive engagement and social mediation. In contrast, teacher-centred paradigms are grounded in transmission models of learning, where knowledge is delivered by the instructor and received by students (Freeman et al., 2014). Research has increasingly questioned the effectiveness of such approaches in promoting deep conceptual understanding, particularly in complex disciplines such as biology. Thus, active learning represents not merely a set of techniques but a fundamental shift in epistemological assumptions about how learning occurs.

Biology education has been a fertile field for the implementation of diverse active learning strategies due to the discipline's conceptual complexity and reliance on systems thinking. Inquiry-based learning (IBL) engages students in the processes of scientific investigation, including questioning, hypothesis generation, experimentation, and data interpretation (Gomez, 2025). The approach reflects the scientific method and promotes epistemic understanding of how biological knowledge is constructed. Moallem (2019) argue that inquiry-based approaches enhance conceptual understanding by situating learning within authentic problem contexts. Similarly, Hassard and Dias (2013) emphasise that inquiry fosters scientific reasoning and understanding of biological processes. In biology classrooms, inquiry-based instruction has been associated with improved conceptual mastery in areas such as genetics and ecology, where students must integrate multiple interacting variables (Minner et al., 2010). Problem-Based Learning (PBL) is a student-centred pedagogy in which learners acquire knowledge by working collaboratively to solve complex, real-world problems (Borhan et al., 2020). Originally developed in medical education, PBL has been widely adopted in biology education, particularly in physiology and microbiology. Learning (2013) demonstrates that PBL promotes deeper understanding, self-directed learning skills, and improved retention of biological concepts. The effectiveness of PBL stems from its alignment with constructivist principles, as students must activate prior knowledge, identify learning gaps, and construct solutions collaboratively. In biology education, PBL is particularly effective in promoting integrative thinking across molecular, cellular, and systemic levels of analysis.

The flipped classroom reverses traditional instructional sequencing by delivering content outside the classroom (often via video lectures) and using classroom time for interactive problem-solving and collaborative learning. Bishop and Verleger (2013) define the flipped classroom as a pedagogical model that combines direct instruction outside class with active learning activities during class time. Empirical evidence suggests that flipped models enhance engagement and academic performance when active learning components are meaningfully integrated (Freeman et al., 2014). In biology education, flipped classrooms have shown positive effects on examination scores and conceptual understanding, particularly in large-enrollment undergraduate courses where traditional lectures often dominate (Ryan & Reid, 2016). Cooperative learning involves structured group activities designed to promote positive interdependence, individual accountability, and collective problem-solving. Johnson and Johnson (2013) provide evidence that cooperative learning improves achievement, retention, and interpersonal skills compared to competitive or individualistic learning structures. Biology education research indicates that collaborative concept mapping, peer instruction, and group-based case analysis enhance understanding of complex biological systems (Michael, 2006). Peer instruction, in particular, has been shown to improve conceptual accuracy in scientific reasoning tasks. STEM integration connects biology with mathematics, technology, and engineering to promote interdisciplinary problem-solving. This approach reflects the interconnected nature of contemporary scientific inquiry. Schweingruber et al. (2014) argue that integrated STEM instruction enhances transfer of knowledge across domains and strengthens problem-solving competence. In biology education, interdisciplinary approaches are especially relevant in fields such as bioinformatics, biotechnology, and environmental science.

Active learning in biology education is anchored in several foundational learning theories. Rutherford (2011) conceptualises learning as a process of cognitive development involving assimilation and accommodation. In biology education, this framework explains how students restructure misconceptions about evolution, genetics, and cellular processes. Rahman (2024) emphasises social interaction and the Zone of Proximal Development (ZPD), suggesting that collaborative dialogue supports cognitive advancement. Active learning strategies, such as peer discussion, align directly with this sociocultural perspective. Bergsteiner and Avery (2014) propose a cyclical model of learning involving concrete experience, reflective observation, abstract conceptualisation, and active experimentation. Laboratory investigations and field-based biology instruction exemplify experiential learning in practice. Experiential frameworks are particularly relevant to biology due to the discipline's reliance on experimentation and empirical observation. Situated learning theory posits that knowledge is constructed within authentic contexts and social practices (Bell et al., 2013). In biology education, case-based and inquiry-driven activities simulate authentic scientific practice, thereby fostering disciplinary identity and epistemic understanding.

A substantial body of empirical research supports the academic benefits of active learning in STEM disciplines. Freeman et al. (2014), in a meta-analysis of 225 studies, found that active learning increased examination scores and reduced failure rates compared to traditional lecturing. Prince (2004) similarly concludes that active learning consistently produces positive learning outcomes across disciplines. In biology specifically, Michael (2006) reports improved conceptual understanding and long-term retention when students engage in interactive pedagogies. Minner et al. (2010) further demonstrate that inquiry-based instruction positively influences student understanding of scientific concepts and processes. Collectively, these findings provide strong empirical support for replacing purely lecture-based instruction with student-centred pedagogies in biology education. Despite strong empirical support, several gaps remain in the literature. First, many studies are localised and context-specific, limiting generalizability. Second, although meta-analyses exist for STEM broadly, fewer systematic syntheses focus exclusively on biology education. Third, theoretical integration is sometimes implicit rather than explicitly articulated. While many studies employ active learning strategies, they do not always clearly connect findings to constructivist or experiential theory (Mattar, 2018; Wilson & Novak, 2024). Finally, the geographical distribution of research appears uneven, with disproportionate representation from North America and Europe, suggesting the need for broader global analysis. These gaps justify the need for a systematic documentary content analysis to map global trends, theoretical foundations, and empirical outcomes in active learning research within biology education.

RESEARCH METHOD

This study adopted a systematic documentary content analysis design. Documentary research involves the systematic identification, selection, evaluation, and interpretation of existing documents to extract meaning, gain understanding, and develop empirical knowledge (Morgan, 2022). Unlike traditional literature reviews, documentary content analysis applies explicit inclusion criteria, systematic coding procedures, and replicable analytical frameworks (Scott, 2014). Content analysis is defined as a research technique for making replicable and valid inferences from texts to the contexts of their use (Krippendorff, 2018). In educational research, documentary content analysis is particularly appropriate for synthesising patterns across published empirical studies, identifying trends, and mapping theoretical developments (Williams, 2022).

The systematic component of this design aligns with review protocols that require transparency in document identification, screening, eligibility determination, and inclusion (Moher et al., 2010). By

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combining systematic review procedures with qualitative and quantitative content analysis, the study ensures methodological rigour, replicability, and analytical depth. To ensure comprehensive coverage of global research evidence, documents were retrieved from major international academic databases known for indexing peer-reviewed education research: Scopus, Web of Science, ERIC (Education Resources Information Centre) and Google Scholar (for supplementary retrieval). Systematic searching followed structured keyword combinations using Boolean operators (AND, OR). Typical search strings included: “active learning” AND “biology education” “, inquiry-based learning” AND “biology” “, problem-based learning” AND “science education” “, flipped classroom” AND “biology achievement” “, constructivist pedagogy” AND “biology performance”. The use of structured search strings is recommended in systematic reviews to improve transparency and replicability (Petticrew & Roberts, 2008). Database searching was supplemented with backward and forward citation tracking to minimise omission of relevant studies, a strategy supported in systematic evidence synthesis (Xiao & Watson, 2019).

Clear eligibility criteria were established before document screening to reduce selection bias and enhance methodological transparency (Petticrew & Roberts, 2006). Inclusion Criteria: Peer-reviewed journal articles, published between 2000 and 2025, that focus explicitly on biology education (secondary or tertiary levels), investigate at least one active learning pedagogy, report empirical findings (quantitative, qualitative, or mixed methods), Published in English. Exclusion Criteria: Editorials, opinion papers, conference abstracts without full data. Studies focused broadly on STEM without specific biology data. Duplicates across databases. Establishing such criteria aligns with best practice in systematic documentary analysis to enhance credibility and reproducibility (Snyder, 2019). Document selection followed a multi-stage screening process consistent with systematic review guidelines (Moher et al., 2010): Identification Stage – Retrieval of all records from selected databases. Screening Stage – Removal of duplicates and initial screening of titles and abstracts. Eligibility Stage – Full-text review against inclusion criteria. Inclusion Stage – Final corpus of documents retained for analysis. A PRISMA-style flow diagram was used to document the number of records at each stage, ensuring procedural transparency (Moher et al., 2010). Purposive sampling was inherent in the eligibility filtering process, as only documents directly relevant to active learning in biology education were retained. Such criterion-based sampling is appropriate in documentary studies where relevance to the research problem determines inclusion (Morgan, 2022).

The analytical process combined deductive and inductive coding approaches. Initial coding categories were derived from established literature on active learning pedagogies, including: Inquiry-based learning, Problem-based learning, Flipped classroom, Cooperative learning, STEM integration, Learning outcomes (achievement, retention, engagement), and Theoretical framework applied. Deductive coding enhances theoretical alignment and ensures that analysis connects with established constructs (Vaismoradi et al., 2013). During analysis, additional categories emerging from the data were identified and incorporated. This approach aligns with conventional content analysis, where new themes are allowed to emerge from the textual data (Kyngäs, 2019). Coding procedures followed the stages recommended by Krippendorff (2018): Unitising (defining units of analysis), Sampling (selecting documents), Coding (assigning categories), Reducing data and Concluding. Coding was conducted using a structured coding matrix developed in spreadsheet format to allow frequency counts and thematic synthesis. Ensuring trustworthiness is central to documentary content analysis. Inter-coder reliability procedures were implemented by independently coding a subset of documents and comparing results. Agreement was assessed using percentage agreement or Cohen’s kappa, where applicable. Krippendorff (2018) emphasises that reliability testing strengthens replicability and analytical consistency. Additionally, triangulation between frequency analysis and thematic interpretation enhanced analytical robustness (Williams, 2022).

The study employed both quantitative and qualitative analytical techniques. Frequency counts and percentages were used to identify: Publication trends over time. Geographical distribution of studies, Dominant pedagogical strategies and Research design patterns. Descriptive statistics are commonly used in systematic reviews to identify trends across large corpora of studies (Petticrew & Roberts, 2008). Thematic synthesis was conducted to interpret patterns in: Reported learning outcomes, Theoretical frameworks employed and Reported pedagogical impacts. Thematic analysis enables the identification of recurrent patterns across texts while preserving contextual meaning (Ahmed et al., 2025). Findings were integrated using narrative synthesis techniques to explain relationships between pedagogical approaches and reported academic outcomes. Narrative synthesis is recommended where studies vary in methodology and context.

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RESULT AND DISUSSION

Descriptive Trends in Active Learning Research

The documentary analysis revealed a substantial growth trajectory in publications examining active learning pedagogies in biology education between 2000 and 2025. From approximately 2010 onward, publication frequency increased markedly, reflecting the broader expansion of active learning scholarship in STEM disciplines. This temporal expansion aligns with the broader empirical consolidation of active learning research following large-scale syntheses demonstrating its effectiveness (Freeman et al., 2014). The post-2014 period shows an especially notable increase in quasi-experimental and mixed-methods studies, suggesting a shift toward more rigorous research designs. Geographically, the distribution of studies is uneven. A substantial proportion of publications originate from North America and Western Europe, with comparatively fewer studies from Sub-Saharan Africa, Latin America, and parts of Asia. This pattern mirrors broader global research production disparities documented in educational scholarship (Demeter, 2022). The underrepresentation of certain regions suggests the need for expanded contextual research in biology education across developing educational systems. Institutional context analysis further indicates that the majority of active learning research in biology occurs at the undergraduate level, particularly in introductory courses with large enrollments. Secondary school contexts are represented, but to a lesser extent. This distribution reflects reform pressures in tertiary STEM education, where high failure rates in foundational science courses have prompted pedagogical innovation (Freeman et al., 2014).

The analysis identified five dominant pedagogical categories in biology education research:

1. Inquiry-Based Learning (IBL)
2. Problem-Based Learning (PBL)
3. Flipped Classroom Models
4. Cooperative/Collaborative Learning
5. Technology-Enhanced Active Learning (including simulation-based learning)

Inquiry-based learning and problem-based learning emerged as the most frequently investigated approaches in the early decades of the dataset. These pedagogies reflect the epistemological alignment of biology with scientific inquiry and problem-solving (Aidoo, 2024; Gomez, 2025; Morris, 2025). From 2015 onward, flipped classroom models and technology-integrated strategies increased significantly. This shift corresponds with advances in digital learning technologies and expanded access to learning management systems (Bishop & Verleger, 2013). Cooperative learning strategies—particularly peer instruction and structured group discussion—appear consistently across the entire timeframe. Their persistence reflects strong empirical support for collaborative learning structures in science education (Millis, 2023). Overall, the trend suggests a progressive diversification of active learning modalities, with increasing integration of digital tools and hybrid instructional designs.

Research Methodological Trends

The methodological profile of the analysed studies demonstrates a predominance of quantitative and quasi-experimental designs, particularly in undergraduate contexts. Controlled comparisons between lecture-based instruction and active learning approaches were common, often using examination scores as primary outcome measures. This methodological pattern reflects broader calls for evidence-based instructional reform supported by measurable outcomes (Prince, 2004). Randomised controlled trials remain relatively limited due to ethical and institutional constraints, but quasi-experimental designs with matched cohorts are widely used. Mixed-methods designs have increased over the past decade, incorporating student interviews, perception surveys, and classroom observations alongside performance metrics. This trend aligns with recommendations for methodological triangulation to capture both cognitive and affective learning outcomes (Turner et al., 2017). Qualitative-only studies are fewer but contribute nuanced insights into student engagement, identity formation, and epistemic development in biology classrooms. Such approaches are consistent with sociocultural perspectives emphasising context and discourse.

Across the dataset, four major categories of learning outcomes were reported:

Academic Achievement

The majority of studies measured achievement using examination scores, concept inventories, or standardised assessments. Consistent with broader STEM findings, active learning interventions were frequently associated with statistically significant gains in examination performance compared to traditional lecture methods (Freeman et al., 2014).

Conceptual Understanding

Beyond performance scores, many studies employed diagnostic instruments to assess conceptual change in areas such as genetics, evolution, and cellular respiration. Active learning approaches—particularly inquiry-based and problem-based models—were associated with reduced misconceptions and improved conceptual coherence (Michael, 2006).

Retention and Long-Term Learning

Several longitudinal studies reported improved retention rates and decreased course failure among students exposed to active learning strategies. These findings mirror broader evidence that interactive engagement enhances persistence in STEM disciplines (Freeman et al., 2014).

Student Engagement and Motivation

A substantial proportion of qualitative and survey-based studies reported increased student engagement, intrinsic motivation, and perceived relevance of biological content. Engagement gains are theoretically consistent with constructivist and experiential learning frameworks. However, the magnitude of reported effects varies depending on implementation fidelity, class size, instructor training, and assessment alignment. Some studies indicate that poorly implemented active learning yields minimal gains, highlighting the importance of pedagogical design quality.

Theoretical and Conceptual Framework Trends

The documentary analysis reveals that constructivist theory is the most frequently cited theoretical foundation across the corpus. Many studies explicitly reference Piagetian cognitive constructivism or Vygotskian sociocultural theory to justify collaborative and inquiry-driven approaches (Moemeke et al., 2025; Syah et al., 2026; Singh et al., 2025). Experiential learning theory appears prominently in studies involving laboratory simulations, fieldwork, and applied case-based learning (Towne et al., 2012; Zhao et al., 2024). The cyclical model of experience–reflection–conceptualisation–application aligns closely with practical biology instruction. Sociocultural and situated learning frameworks are increasingly cited in recent studies, particularly those examining collaborative discourse, peer instruction, and authentic scientific practice (Erdogan, 2016; Sadler, 2009). Notably, some empirical studies implement active learning strategies without clearly articulating an explicit theoretical framework. This inconsistency suggests a partial disconnect between pedagogical practice and theoretical grounding, reinforcing the need for stronger conceptual integration in biology education research.

CONCLUSION

The conclusion of this study highlights that global research trends on active learning pedagogies in biology education have significantly increased over the past two decades, with a focus on student-centered approaches such as inquiry-based learning, problem-based learning, flipped classrooms, cooperative learning, and technology-enhanced instruction. The studies consistently show that active learning strategies are associated with improvements in academic achievement, conceptual understanding, long-term retention, and student engagement. These findings emphasize the effectiveness of pedagogies that actively involve learners in problem-solving, discussion, and collaboration to address conceptual difficulties in biology compared to traditional lecture-based instruction. Furthermore, most empirical studies employ quantitative or quasi-experimental research designs, with constructivist learning theory forming the dominant theoretical foundation.

Suggestions for future research include strengthening the integration between pedagogical practices and educational theory, particularly by more explicitly articulating the theoretical foundations behind active learning strategies. This is crucial for deepening the connection between pedagogical innovations and the educational theories that underpin them. The study also stresses the importance of designing learning environments that promote inquiry, collaboration, and meaningful engagement with biological concepts, while providing a more structured understanding of how active learning has evolved globally. In this way, the research contributes to efforts to strengthen evidence-based teaching practices in biology education and the broader field of education.

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