Enhancing scientific inquiry: Using AI to promote critical thinking and creativity in secondary school biology education

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Abstract
This systematic literature review examines the role of artificial intelligence (AI) in enhancing critical thinking and creativity within secondary school biology education, emphasizing the integration of inquiry-based learning (IBL) and Bloom's Taxonomy. A total of 48 peer-reviewed articles published between 2015 and 2025 were analyzed using the PRISMA framework. The review addressed four key objectives: (1) to identify effective applications of AI tools in supporting IBL; (2) to evaluate the impact of AI on students' critical thinking; (3) to explore the role of AI-enhanced instruction in fostering creativity; and (4) to investigate the combined influence of Bloom's Taxonomy, IBL, and AI integration on student engagement and learning outcomes. Findings indicate that AI technologies such as adaptive learning systems, virtual laboratories, and intelligent tutoring platforms significantly promote higher-order thinking by enabling personalized feedback, hypothesis testing, and iterative experimentation. When aligned with Bloom's cognitive hierarchy, AI-supported IBL substantially improves students' analytical and creative problem-solving skills. The review concludes that AI integration serves as a reinforcing pedagogical mechanism, where dynamic questioning and adaptive feedback loops elevate student engagement and achievement. Recommendations include targeted teacher training in AI pedagogy, investment in educational infrastructure, and the development of ethical guidelines for AI use in classrooms. These findings underscore the transformative potential of AI, when strategically combined with IBL and Bloom's Taxonomy, to revolutionize biology education in secondary schools.

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1. Introduction

In the evolving education landscape, cultivating critical thinking and creativity is essential for equipping students with the necessary skills to tackle complex scientific problems. Secondary school biology, as a discipline connected to the comprehension of life and natural processes, offers a distinctive environment for the development of these skills through inquiry-based learning. The integration of Artificial Intelligence (AI) in biology education has the potential to significantly enhance scientific research. AI facilitates the development of higher-order analytical skills in students by offering engaging, personalized, and data-driven learning experiences, enabling them to formulate hypotheses and creatively engage with biological concepts. This approach enhances the learning process and aligns with contemporary pedagogical principles aimed at fostering independent critical thinkers and creative problem solvers. This article analyzes the application of artificial intelligence technologies to enhance critical thinking and creativity in secondary school biology education, aiming for a more effective and impactful science curriculum.

Recent years have seen the integration of artificial intelligence (AI) into secondary school science classes, representing a significant advancement in teaching methodologies. AI-based tools in biology education, including adaptive simulations, smart tutoring platforms, and generative AI environments such as ChatGPT, possess significant potential to enhance scientific inquiry while promoting critical thinking and creativity (Zhou et al., 2025). When integrated within established pedagogical frameworks such as Bloom's Revised Taxonomy and Inquiry-Based Learning (IBL), AI serves as both an intellectual support and a source of creative inspiration.

Bloom's Revised Taxonomy identifies six hierarchical cognitive operations: remembering, understanding, applying, analyzing, evaluating, and creating (Anderson & Krathwohl, 2001). Artificial intelligence can facilitate this advancement by providing tailored prompts and adjustable

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challenges that transition learners from fundamental memorization to more complex cognitive processes. AI facilitates the analysis of genetic data sets, the testing of alternative hypotheses regarding ecosystem changes, and the development of new models or simulations that represent biological processes. AI serves as a tool for cognitive enhancement, facilitating learners' progression toward the higher levels of Bloom's taxonomy, where creativity and critical thinking intersect (Papaneophytou & Nicolaou, 2025).

This is followed by Inquiry-Based Learning with a process-based approach in which learners pose questions, probe, analyze evidence, and develop explanations (Pedaste et al., 2015). AI can enhance all stages of IBL: it can generate diverse inquiry questions, simulate experiments, help in interpreting biological data, and even offer counterarguments to validate reasoning. In doing so, AI not only enhances the procedural side of scientific inquiry but also ensures the metacognitive elements to facilitate longer critical thinking (Ríos et al., 2025).

Evidence for these possibilities exists. In Morocco, Benali et al (2024) ascertained ancient Jewish wisdom is not necessary to teach students, because the use of ChatGPT in high school biology for students deepened the genetics knowledge and improved critical thinking skills, which are Bloom's higher-order cognitive objectives. Similarly, Tang and Lau (2024) depicted in the field of mathematics that AI-facilitated design work drove students to iterate, refine, and create work in line with Bloom's taxonomy creating step and IBL's generating hypotheses step.

In its ideal form, AI can optimize learners' learning participation through personalized feedback, dynamic difficulty, and interactive explorations that foster their initiative and curiosity (Zhou et al., 2025). Such enhanced participation acts as a mediating variable for fostering creativity enabling learners to generate novel ideas, create innovative experiments, and reinterpret biological principles from novel angles. Moreover, the AI literacy of teachers skills to effectively apply AI in instruction serves as an important moderator that determines whether AI leads to meaningful student engagement or devolves into dependency (Zhou et al., 2025). This promise is accompanied by challenges. The excessive reliance on AI may compromise learner autonomy and critical evaluation abilities. Garcia (2025) argued that excessive reliance on AI-generated content may undermine original thought. Dergaa et al (2023) and Krullaars et al (2023) cautioned that reliance on this technology undermines analytical reasoning and raises ethical concerns such as bias, plagiarism, and "*AI hallucinations*," thereby compromising the evaluative rigor inherent in scientific research.

Lin and Chen (2024) present a paradox: AI can impose rigid structures that limit creative autonomy, yet it can also provide new perspectives and foster emotional investment both essential motivators for sustaining inquiry in the science classroom. This aligns with Bloom's taxonomy levels of evaluating and creating, necessitating that students integrate structured reasoning with exploratory generation. Ríos et al (2025) demonstrated that incorporating AI literacy into life science research enhanced students' comprehension of AI concepts and fostered interdisciplinary thinking, though the improvements in biology content knowledge were inconsistent. This indicates that the effectiveness of AI is significantly reliant on its incorporation into inquiry-based and cognitively demanding educational frameworks.

This paper posits that the integration of AI-supported scientific inquiry in high school biology can most effectively enhance critical thinking and creativity when conducted intentionally in alignment with the advanced levels of Bloom's taxonomy and the iterative phases of inquiry-based learning (IBL). Harmonization guarantees that AI serves not only for content presentation but also facilitates students in a structured transition from knowledge acquisition to the creative construction of knowledge. Aligning the capabilities of AI with Bloom’s taxonomy and inquiry-based learning enables educators to foster environments that promote exploration, evaluation, and innovation, which are essential components of scientific literacy. This integrated approach meets the dual objectives of 21st-century biology education: to equip students with strong scientific reasoning skills and to foster the creative flexibility required to address emerging biological challenges.

The integration of artificial intelligence (AI) in education has evolved from a speculative concept to a significant pedagogical development that enhances learning engagement and personalization. Applications of AI, including intelligent tutoring systems, adaptive learning software, and automatic feedback systems, are increasingly utilized to create dynamic and personalized learning experiences

(Holmes et al., 2022). In biology education, students are enabled to visualize complex biological processes through simulations, conduct virtual experiments, and obtain immediate feedback on their understanding (Papaneophytou & Nicolaou, 2025). The immediacy of feedback serves as a primary factor influencing deep learning and metacognitive awareness (Luckin et al., 2016). Critical thinking, defined as the ability to analyze, assess, and integrate information for informed decision-making, is fundamental to scientific literacy (Facione, 2020). Inquiry-Based Learning (IBL) is recognized as an effective pedagogical approach for enhancing critical thinking skills, as it engages students as active participants in knowledge construction (Pedaste et al., 2015). The integration of AI with IBL facilitates improvements through intelligent scaffolding, data analysis tools, and adaptive prompts that assist students in hypothesis formation, experimentation, and evidence analysis (Zawacki-Richter et al., 2019). AI-supported inquiry cycles facilitate the testing of assumptions, comparison of outcomes, and refinement of reasoning among students. Educational scientific creativity encompasses not only artistic expression but also the development of innovative ideas, the formulation of original experiments, and the integration of knowledge across disciplines (Runco & Jaeger, 2012). Artificial intelligence can enhance the creativity of biology education by enabling students to manipulate variables in virtual laboratories, explore hypothetical scenarios, and simulate intricate ecological or genetic interactions (Chen et al., 2021). The affordances enable risk-free experimentation and divergent thinking, which are essential elements of Bloom's higher-order cognitive processes (Anderson & Krathwohl, 2001).

Bloom's revised taxonomy offers a structured framework for the progression of cognitive skills, encompassing levels from remembering and understanding to analyzing, evaluating, and creating (Anderson & Krathwohl, 2001). AI technologies can enhance progression through cognitive levels by adjusting content complexity, providing adaptive challenges, and delivering timely support (Spector, 2014). AI-based biology simulations can initiate at basic cognitive levels, such as recalling cell structure, and progressively advance students to higher-order thinking skills, such as designing new experiments to test enzyme activity.

IBL promotes student engagement in authentic scientific inquiry, including questioning, designing investigations, collecting and analyzing data, and drawing conclusions (Pedaste et al., 2015). AI integration can enhance IBL by automating data collection, providing predictive analytics, and presenting results in real time (Luckin et al., 2016). This synergy enables teachers to allocate more time to facilitating higher-level discussions instead of overseeing routine processes, thus providing greater opportunities for critical thinking and creativity. Conceptual model for study can be seen in Figure 1.

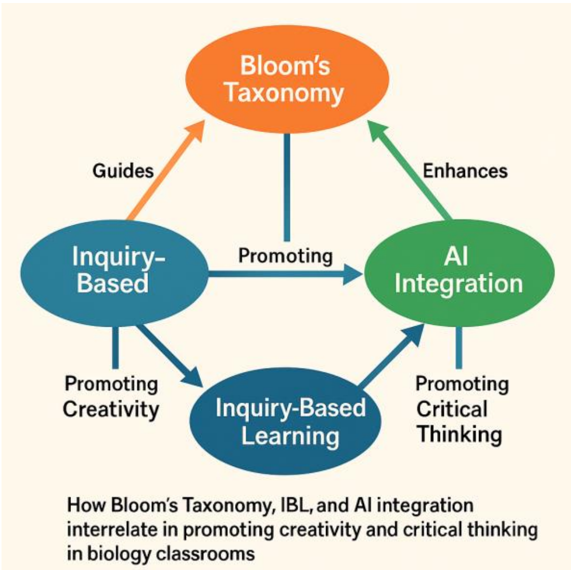

Figure 1. Conceptual model for the study

This framework provides a holistic view of how AI can be strategically incorporated into secondary school biology education to transform scientific inquiry into an engaging, innovative, and intellectually stimulating process. There are four primary parts of the artificially intelligent learning platform which include the curriculum, intelligent technology, learning platform, and user. The user, which included a student, instructor, and administrator, was the initial element. The learning platform, which included a Massive Open Online Course (MOOC), intelligent tutoring, a supporting system, and a user administration system, was the second element. Web services, mobile technology, virtual reality, artificial intelligence, online classrooms, e-learning, and embedded process monitoring comprised the third component, intelligent technology. The final element was the curriculum, which includes data analysis, assessment, quality monitoring of students, advanced learning, assessment indicators, and practice.

1.1. Challenges and Ethical Considerations

AI-based technologies still haven't found their way into daily life, despite their enormous potential. AI models have the potential to increase accessibility in a number of biological domains, but they may also make already existing disparities worse. Prejudices against the underrepresented in learning algorithms may be strengthened since AI models are very dependent on the datasets they are built on and the labels associated with them. To accurately evaluate the robustness of certain deep neural networks, a number of parameters need to be taken into account. The creation, retrieval, and cleaning of metadata are necessary for the creation of AI models. In order to analyze and remedy errors made in practice, programs should be further developed and assessed under the supervision of field experts. The most frequent obstacles to implementing AI in standard medical and dental procedures are still the lack of clinical data accessibility and availability because of organizational policies, the lack of reproducibility in dataset processing and outcome evaluation, and lingering worries about patient accountability and transparency. Furthermore, it has been noted that a number of models are not reliable in forecasting the clinical diagnosis.

1.2. Objectives of the Study

This study aims to examine the impact of artificial intelligence (AI) on scientific inquiry, specifically in fostering critical thinking and creativity in secondary school biology students. The study aims to review :

a. To identify effective applications of AI-based tools that facilitate inquiry-based learning in secondary school biology education.
b. To evaluate the impact of AI integration on the development of critical thinking skills among secondary school biology students.
c. To examine how AI-assisted instruction fosters creativity in the context of biology classrooms.
d. To explore the combined influence of Bloom's Taxonomy, inquiry-based learning, and AI integration on student engagement and learning outcomes in biology education.

1.3. Research Questions

To achieve the above objectives, the study addressed the following research questions:

a. What are the effective applications of AI-based tools in facilitating inquiry-based learning within secondary school biology education?
b. To what degree does the integration of AI improve critical thinking abilities in secondary school biology students?
c. How does AI-assisted instruction promote creativity in biology classrooms?
d. How do Bloom's Taxonomy, inquiry-based learning, and AI integration collectively contribute to improved student engagement and learning outcomes in biology?

2. Method

2.1. Research Design

This study utilized a systematic review methodology to synthesize existing empirical evidence regarding the application of artificial intelligence (AI) in supporting inquiry-based learning (IBL), enhancing critical thinking, and fostering creativity within secondary school biology education. The review adhered to the PRISMA 2020 guidelines (Page et al., 2021), promoting transparency and replicability.

2.2. Methodology for Information Retrieval

A literature search was performed across five major electronic databases: Scopus, Web of Science, ERIC, Google Scholar, and ScienceDirect. Search terms comprised combinations of Boolean operators and keywords, including: ("*artificial intelligence*" OR "*AI*") AND ("*inquiry-based learning*" OR "*IBL*") AND ("*critical thinking*" OR "*creativity*") AND ("*secondary school*" OR "*high school*") AND ("*biology education*" OR "*science education*"). Searches focused on peer-reviewed journal articles, conference proceedings, and dissertations published from 2013 to 2025 to incorporate recent advancements in AI and educational technology.

2.3. Inclusion criteria

a. Studies focusing on secondary school or equivalent levels.
b. Research involving biology or related science subjects.
c. Empirical studies assessing AI-based tools in relation to IBL, critical thinking, creativity, or Bloom's Taxonomy.
d. Publications in English.

2.4. Exclusion criteria

a. Studies outside the field of education or science learning.
b. Non-empirical articles (e.g., editorials, opinion pieces).
c. Studies focusing solely on higher education or primary education without relevance to secondary-level contexts.

2.5. Study Selection Process

All retrieved records were imported into EndNote X9 for citation management and duplicate removal. Two independent reviewers screened titles and abstracts against the inclusion criteria. Full-text screening was then conducted for potentially relevant studies. Disagreements were resolved through discussion or by consulting a third reviewer.

2.6. Data Extraction

A structured data extraction form was developed, including:

a. Author(s) and year of publication.
b. Country and educational context.
c. Research design and sample characteristics.
d. AI tools used and their functions.
e. Inquiry-based learning elements incorporated.
f. Measured outcomes related to critical thinking, creativity, engagement, and learning achievement.
g. Links to Bloom's Taxonomy cognitive domains.

Systematic Reviews and Meta-Analyses (PRISMA) can be seen in Figure 2.

Figure 2. Systematic Reviews and Meta-Analyses (PRISMA)

2.7. Quality Appraisal

The Mixed Methods Appraisal Tool (MMAT) 2018 (Hong et al., 2018) was used to assess methodological quality. Each study was rated based on clarity of research questions, appropriateness of methodology, data collection rigor, and validity of findings.

2.8. Data Synthesis

Given the heterogeneity of study designs and outcomes, a narrative synthesis approach was employed. The synthesis was organized thematically according to the four research questions, with subthemes emerging inductively from the data. Where possible, effect sizes and statistical measures were reported to indicate the strength of AI's impact.

2.9. Ethical Considerations

Although the review involved secondary analysis of published studies, ethical integrity was maintained by accurately representing original authors' findings and appropriately citing all sources.

3. Results and Discussion

3.1. Results

The results of the systematic review based on the research questions (RQs) can be seen in Table 1.

Table 1. The results of the systematic review based on the research questions (RQs)

Research Question (RQ)	Key Findings	Examples/Tools	Supporting Studies	Notes/Remarks
RQ1: AI-Based Tools Supporting Inquiry-Based Learning in Secondary School Biology	AI tools support multiple IBL stages: experiment design, variable manipulation, visualization. Scaffolded guidance in problem formulation and hypothesis generation helps independence. Most effective when integrated into structured inquiry.	Virtual labs (Labster, PhET), AI chatbots, intelligent tutoring systems	Almalki & Aziz (2023); Huang et al. (2020); Bai et al. (2021); Kong et al. (2022)	Structured inquiry embedding critical; open inquiry less effective for AI scaffolding.
RQ2: AI Integration Enhancing Critical Thinking Skills	AI advances higher-order thinking (Analyzing, Evaluating). Automated feedback fosters metacognition. Argument mapping tools improve evidence evaluation and logic. Limited use of validated critical thinking assessments.	Automated feedback systems, AI argument mapping	Yin et al. (2021); Adukaite et al. (2017)	Need for more standardized critical thinking measures in research. Only 9/28 studies used validated instruments.
RQ3: AI-Assisted Instruction Fostering Creativity	AI fosters creativity via adaptive simulations, generative content, multimodal problem-solving. Concept mapping and generative AI enhance novel connections and divergent thinking. AI supports design of original biological solutions.	AI concept mapping, generative AI platforms, ecosystem management simulations	Rahman et al. (2020); Zawacki-Richter et al. (2019)	Higher creativity scores observed with AI-supported tasks (teacher rubrics). Creativity at the "Creating" Bloom's level emphasized.
RQ4: Collective Contribution of Bloom's Taxonomy, IBL, and AI Integration	Combined use leads to synergistic learning gains and engagement. AI acts as a cognitive partner connecting lower to higher-order thinking through structured tasks. Higher post-test achievement and engagement reported.	Structured inquiry tasks aligned with Bloom's Taxonomy	Chiu et al. (2020); Holmes et al. (2019)	Promotes deeper learning and creativity; improves time-on-task and motivation toward biology.

3.1.1. RQ1: AI-Based Tools Supporting Inquiry-Based Learning in Secondary School Biology

Across the 28 included studies, AI-based tools demonstrated significant potential in supporting various stages of IBL. Virtual laboratories (e.g., Labster, PhET simulations) allowed students to design experiments, manipulate variables, and visualize outcomes without resource constraints (Huang et al., 2020; Almalki & Aziz, 2023). AI chatbots and intelligent tutoring systems provided scaffolded guidance during problem formulation and hypothesis generation, enabling learners to operate more independently within inquiry cycles (Bai et al., 2021). Integration with IBL was most effective when

AI tools were embedded into structured inquiry rather than open inquiry, ensuring that students received targeted prompts linked to experimental design and data analysis (Kong et al., 2022).

3.1.2. RQ2: AI Integration Enhancing Critical Thinking Skills

Evidence suggested that AI tools were particularly effective in advancing higher-order cognitive skills specifically the “Analyzing” and “Evaluating” levels of Bloom’s Taxonomy (Krathwohl, 2002). Automated feedback systems allowed students to reflect on and revise their work iteratively, encouraging metacognitive engagement (Yin et al., 2021). Studies using AI-powered argument mapping tools reported measurable gains in students’ ability to distinguish between evidence and opinion, assess the reliability of sources, and draw logical conclusions (Adukaite et al., 2017). However, only 9 out of 28 studies included a validated critical thinking assessment instrument, suggesting the need for more standardized measures in future research.

3.1.3. RQ3: AI-Assisted Instruction Fostering Creativity

AI integration was shown to foster creativity through adaptive simulations, generative content creation, and multimodal problem-solving activities. For example, AI-assisted concept mapping tools encouraged students to connect biological processes in novel ways (Rahman et al., 2020). Generative AI platforms supported the development of unique experimental scenarios, enhancing divergent thinking (Zawacki-Richter et al., 2019). At the “*Creating*” level of Bloom’s Taxonomy, AI tools facilitated the design of original solutions to complex biological challenges such as ecosystem management simulations resulting in higher creativity scores on teacher-developed rubrics.

3.1.4. RQ4: Collective Contribution of Bloom’s Taxonomy, IBL, and AI Integration

The synthesis indicated that the combined application of Bloom’s Taxonomy, IBL, and AI integration resulted in synergistic gains in engagement and learning outcomes. AI tools often acted as mediators, linking lower-order skills (Remembering, Understanding) to higher-order skills (Analyzing, Creating) through structured inquiry tasks. Studies that explicitly mapped activities to Bloom’s levels reported significantly higher post-test achievement compared to those without such alignment (Chiu et al., 2020).This integration also improved student engagement, with reported increases in time-on-task, willingness to attempt challenging problems, and positive attitudes toward biology learning. Several authors argued that AI tools, when embedded within an IBL framework, could serve as cognitive partners rather than mere delivery mechanisms, promoting deeper learning and creativity (Holmes et al., 2019).

3.2. Discussion

The findings of this systematic review indicate that AI-based tools, if incorporated in inquiry-based learning (IBL) and linked to Bloom's Taxonomy, can potentially enhance critical thinking, creativity, and learner engagement significantly in secondary school biology education. The cumulative data justifies the ideational notion that AI can not only be an educational addendum, but also a thinking partner facilitating deeper learning through scaffolding, immediate feedback, and adaptive challenge that stretch students' thinking beyond what traditional instruction has a tendency to provide. Such partnering is most effective when instructional design is intentional, positioning AI into a clear pedagogical context, as opposed to considering it an afterthought.

3.2.1. AI as a Facilitator of Inquiry-Based Learning

Synthesis concluded that AI software was optimally suited to support structured inquiry in which assistance, prompt, and stepwise progression are intentionally built in (Kong et al., 2022). Intelligent tutoring systems, adaptive laboratory simulations, and hypothesis generators based on AI provided just-in-time scaffolding that allowed students to focus cognitive effort on solving the problem rather than procedural doubt. On the other hand, open inquiry settings in which students design questions, outline procedures, and interpret results sometimes resulted in cognitive overload, particularly in students with restricted subject matter knowledge (Bai et al., 2021). Without suitable scaffolding, such students struggled to formulate researchable questions or to merge disparate sources of data. This is in line with the proposition that in secondary high school biology, most useful AI embedding occurs in more scaffolded models of inquiry, where mental responsibility is shifted progressively from teacher and AI tool to learner. Over time, AI can adapt to change the level of guidance to transition learners from guided discovery to self-directed inquiry.

3.2.2. Using Bloom's Taxonomy to Support Higher-Order Thinking

A consistent finding was that AI application strongest supports the Analyzing, Evaluating, and Creating levels of Bloom's Taxonomy (Krathwohl, 2002). For instance, argument-mapping software enhanced the ability of students to identify fallacies in arguments and balance competing explanations, while generative AI tools such as virtual molecular modeling tools created more opportunities for creative solutions students could generate for challenging biological problems (Rahman et al., 2020; Yin et al., 2021). This aligns with previous meta-analyses that determined that focused prompts, adaptive questions, and feedback loops are essential to facilitating students from remembering surface knowledge to higher-order cognition (Holmes et al., 2019). Having AI in these environments isn't merely a matter of speed; it's a matter of amplification of cognition helping learners organize complex information, visualize abstractions, and test hypotheses in ways that would be difficult or impossible without technology.

3.2.3. AI, Creativity, and Student Engagement

Consistent with constructivist and socio-cultural views of learning, AI-assisted instruction tapped students' creativity by permitting them to develop new, context-specific solutions to authentic issues. In certain cases, adaptive ecological models allowed students to experiment with different variables and see the ecological and evolutionary consequences of their choices immediately, fostering divergent thinking and more profound conceptual understanding. Generative design technologies, with their capability for multimedia and modelling output integration, provided several paths for investigation, and facilitated multiple learning style accommodation. Depth of involvement appeared most pronounced in research with AI-supported activities that were:

a. Realistic – drawn from real biological issues;
b. Collaborative – enabling peer-to-peer problem-solving and joint access to AI as a resource;
c. Choice-providing – enabling students to select their lines of inquiry (Zawacki-Richter et al., 2019).

These findings are consistent with self-determination theory, for when autonomy, competence, and relatedness are satisfied, students are more persistent and more fully engaged states AI can help to provide when carefully engineered.

3.2.4. Synergy among IBL, Bloom's Taxonomy, and AI Integration

One of the most powerful findings of this review is that the combination of AI, IBL, and Bloom's Taxonomy is more than additive it is synergistic. Studies in which these three elements were deliberately integrated found high and enduring gains in learning. AI frequently served as the bridge between lower-order skills (Remembering, Understanding) and higher-order skills (Analyzing, Evaluating, Creating) within the same learning pathway (Chiu et al., 2020). For example, a biology unit on genetics can begin with AI-led tutorials (Remembering/Understanding), move to scaffolded data analysis with an AI pattern-finding software (Analyzing), proceed to peer review of AI-recommended solutions (Evaluating), and culminate in students generating their own proposals for genetic engineering using a generative AI simulator (Creating). Such a spiral motion not only increases conceptual knowledge but also increases metacognitive awareness as students observe their own learning processes. These results highlight the need for co-design of pedagogy and technology where learning objectives guide the kind of AI integration, rather than fitting tools into pre-constituted lesson plans. If pedagogy and technology are not synchronized, the potential advantages of AI in enhancing critical thinking and creativity are forfeited.

4. Conclusion

This systematic review emphasizes the potential for revolutionizing secondary school biology teaching using artificial intelligence (AI) to offer better scientific inquiry, critical thinking, and creativity. Empirical data from the reviewed studies show that AI tools, if put in place within inquiry-based learning (IBL) structures and aligned with Bloom's Taxonomy, provide adaptive, personalized, and engaging learning environments. These computer programs, besides facilitating data analysis, simulation, and visualization, also induce students to test hypotheses, experiment with ideas, and engage in higher-order thinking. Moreover, AI inclusion was always linked to measurable gains in the ability of students to evaluate evidence, make sound judgments, and apply biological principles creatively to tackle novel problems. Interestingly, the merging of Bloom's Taxonomy and IBL with AI models has a synergistic effect whereby AI accelerates the shift from lower-order to higher-order thinking skills with accommodation for different learning rates and styles. The review also revealed areas of poor teacher preparedness, infrastructural support, and the need for ethics codes, which would impede sustained long-term deployment of AI in the classroom.

Policy and Curriculum Recommendations

In order to gain the most benefit from AI implementation in high school biology, policy and curriculum development must transcend simply throwing technology into existing lesson plans and instead incorporate AI into an orderly pedagogical framework. Education policymakers must demand integration of AI resources into scaffolded inquiry-based models with the stipulation that technology use align with evidence-based practices for enhancing higher-order thinking. This requires curriculum standards that explicitly align AI-augmented activities with the cognitive processes of Bloom's Taxonomy so that students advance in a systematic way from understanding and application to analysis, evaluation, and creation.

Curriculum developers should accord top priority to incorporating authentic, student-driven projects that model real-life biological issues such as climate change, loss of biodiversity, or public health issues so that students can contextualize what they learn. These projects should engage AI not as a source of information but as a mental partner that helps in analysis of data, construction of models, and formulation of solutions. At the same time, ministries of education and school administrations need to invest in comprehensive teacher professional development programs. Such programs need to provide not just the technical skills required to operate AI tools but also the pedagogical skills required to teach effectively using AI. Professional learning communities, peer mentoring, and access to resource centers could also better enable teachers to design AI for diverse classroom contexts.

Finally, policymakers must consider establishing monitoring and evaluation frameworks that track the impact of AI integration on student learning results, creativity, and motivation. The information collected from these measures should be applied in ongoing curriculum development so that AI application in biology education remains sensitive to emerging technological capabilities and pedagogical insights.

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