AI-Powered Technology in Enhancing Biology Education

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LIST OF ABBREVIATIONS

AI - Artificial Intelligence

ANCOVA - Analysis of Covariance

SD - Standard Deviation

M - Mean

df - Degrees of Freedom

AI Literacy - Artificial Intelligence Literacy

R Studio - Statistical Computing Environment

Cronbach's α - Cronbach's Alpha Reliability Coefficient

N - Number of Participants

p - Probability Value

t - t-test Statistic

ABSTRACT

This study investigated the impact of AI-supported learning on academic achievement, student perceptions, engagement, independent learning, and AI literacy in university biology education. The research was conducted among 52 undergraduate students enrolled in a biology course focusing on nervous system anatomy. A quasi-experimental design was employed, involving a control group receiving traditional instruction and an experimental group participating in AI-supported learning activities. Data were collected using pre-tests, post-tests, and a student perception questionnaire. The results demonstrated significant improvements in academic achievement within both groups. Although the AI-supported group achieved higher mean post-test scores, the difference between groups was not statistically significant according to independent-samples t-tests and ANCOVA analyses. Questionnaire findings revealed highly positive student perceptions of AI-supported learning. Students reported that AI facilitated understanding of complex biological concepts, supported independent learning, enhanced engagement, and helped identify knowledge gaps. Participants also demonstrated awareness of AI-related challenges, including misinformation, inaccuracies, and excessive reliance on AI-generated content. The findings suggest that AI-supported learning represents a valuable complement to traditional biology instruction. While no statistically significant achievement advantage was identified, AI contributed positively to student engagement, independent learning, conceptual understanding, and responsible.

Keywords: *artificial intelligence, AI-supported learning, biology education, academic achievement, student engagement, independent learning, AI literacy, higher education.*

АҢДАТПА

Бұл зерттеу жоғары оқу орнындағы биология пәнін оқыту барысында жасанды интеллектке негізделген оқытудың академиялық жетістікке, студенттердің қабылдауына, оқу белсенділігіне, өзіндік оқуына және AI сауаттылығына әсерін анықтауға бағытталды. Зерттеуге жүйке жүйесінің анатомиясы тақырыбын меңгерген 52 бакалавриат студенті қатысты. Зерттеу барысында квазиэкспериментік әдіс қолданылып, студенттер бақылау және эксперименттік топтарға бөлінді. Бақылау тобы дәстүрлі оқыту әдісімен білім алса, эксперименттік топ жасанды интеллект құралдарын пайдалану арқылы оқытылды. Деректер алдын ала тест, қорытынды тест және сауалнама арқылы жиналды. Нәтижелер екі топта да академиялық жетістіктің статистикалық тұрғыдан мәнді артқанын көрсетті. Эксперименттік топтың қорытынды тест нәтижелері жоғары болғанымен, тәуелсіз t-тест және ANCOVA нәтижелері бойынша топтар арасындағы айырмашылық статистикалық мәнді деңгейге жеткен жоқ. Сауалнама нәтижелері студенттердің жасанды интеллектті оқытуда қолдануға оң көзқарас танытқанын көрсетті. Студенттер AI күрделі биологиялық ұғымдарды түсінуге көмектескенін, өзіндік оқуды қолдағанын, оқу белсенділігін арттырғанын және білімдегі олқылықтарды анықтауға мүмкіндік бергенін атап өтті.

Түйін сөздер: *жасанды интеллект, AI-негізделген оқыту, биологияны оқыту, академиялық жетістік, студенттердің оқу белсенділігі, өзіндік оқу, AI сауаттылығы, жоғары білім.*

АННОТАЦИЯ

Данное исследование было направлено на изучение влияния обучения с поддержкой искусственного интеллекта на академическую успеваемость, восприятие студентов, вовлеченность в обучение, самостоятельное обучение и ИИ-грамотность в биологическом образовании. В исследовании приняли участие 52 студента бакалавриата, изучавшие тему анатомии нервной системы. Был использован квазиэкспериментальный дизайн, включающий контрольную группу, обучавшуюся традиционным способом, и экспериментальную группу, использовавшую инструменты искусственного интеллекта в учебном процессе. Данные собирались с помощью входного и итогового тестирования, а также анкетирования студентов. Результаты показали статистически значимое улучшение академической успеваемости в обеих группах. Несмотря на то что экспериментальная группа продемонстрировала более высокие средние показатели итогового тестирования, различия между группами не достигли статистической значимости по результатам независимого t-теста и ANCOVA. Результаты анкетирования свидетельствуют о положительном отношении студентов к использованию искусственного интеллекта. Участники отметили, что ИИ способствовал пониманию сложных биологических концепций, поддерживал самостоятельное обучение, повышал вовлеченность и помогал выявлять пробелы в знаниях. Студенты также продемонстрировали понимание ограничений ИИ, включая риск получения неточной информации и чрезмерной зависимости от технологий.

Ключевые слова: *искусственный интеллект, обучение с поддержкой ИИ, биологическое образование, академическая успеваемость, вовлеченность студентов, самостоятельное обучение, ИИ-грамотность, высшее образование*

INTRODUCTION

Background of the Study

The rapid advancement of artificial intelligence (AI) has transformed many aspects of modern society, including education. Recent developments in AI technologies have created new opportunities for teaching, learning, assessment, and academic support. AI-powered tools are increasingly being integrated into educational environments, providing learners with personalized feedback, adaptive learning experiences, and immediate access to information (Tlili et al., 2024; Almasri, 2024).

The emergence of generative AI has further accelerated this transformation. Unlike traditional educational technologies, generative AI systems such as ChatGPT can generate human-like responses, explain concepts, answer questions, summarize information, and support independent learning activities. These capabilities have attracted considerable attention from educators, researchers, and students worldwide (Kasneci et al., 2023; Cotton et al., 2023). Higher education institutions have shown growing interest in the use of AI-supported learning tools. Previous studies have reported that AI can enhance student engagement, improve access to learning resources, support self-regulated learning, and facilitate personalized instruction (Wang et al., 2024; Zhu et al., 2025). At the same time, researchers have emphasized that the educational impact of AI depends on how these technologies are integrated into teaching and learning processes (Tlili et al., 2024).

In biology education, AI technologies may provide particular benefits because students frequently encounter complex concepts, extensive terminology, and abstract processes that require repeated explanation and practice. Topics such as anatomy, physiology, genetics, and molecular biology often present challenges for undergraduate learners. AI-supported learning environments may help address these challenges by providing additional explanations, interactive support, and opportunities for independent learning (Hu, 2024; Siamika & Prayogi, 2025). Despite the growing interest in AI-supported learning, concerns regarding the responsible use of AI remain. One of the most frequently discussed challenges is the phenomenon of AI

hallucinations. AI hallucinations occur when generative AI systems produce information that appears accurate and convincing but is factually incorrect, misleading, or unsupported by reliable sources. Such outputs may include fabricated citations, inaccurate explanations, or incorrect interpretations of scientific concepts. Consequently, students must develop AI literacy skills that enable them to critically evaluate and verify AI-generated information before using it in academic work (Kasneci et al., 2023; Tlili et al., 2024).

Although numerous studies have explored AI in higher education, relatively limited research has examined the combined relationship between AI-supported learning, academic achievement, student perceptions, self-regulated learning, and AI literacy within biology education. Furthermore, many existing studies have focused on general educational contexts rather than discipline-specific learning environments. Therefore, there is a need for empirical research investigating how AI-supported learning influences students' learning experiences and academic outcomes in university biology courses. Understanding these relationships may help educators make informed decisions regarding the effective and responsible integration of AI technologies into biology education.

Statement of the Problem

The rapid development of artificial intelligence has significantly influenced teaching and learning practices in higher education. Generative AI tools such as ChatGPT are increasingly being used by university students to access information, explain concepts, summarize learning materials, and support independent study.

As a result, educators are exploring ways to integrate AI into educational environments while maintaining academic quality and promoting meaningful learning. Although previous studies have reported positive effects of AI on learning experiences, student engagement, and self-regulated learning, the evidence regarding its impact on academic achievement remains inconsistent. Some studies have demonstrated improvements in learning outcomes, whereas others have reported limited or non-significant effects. These mixed findings suggest the need for further investigation of

AI-supported learning in specific disciplinary contexts. Biology education presents unique challenges because students are required to understand complex scientific concepts, detailed anatomical structures, and extensive biological terminology. Traditional teaching approaches may not always provide sufficient opportunities for personalized support and independent exploration of these topics. AI technologies have the potential to address these challenges by offering additional explanations, immediate feedback, and individualized learning assistance.

At the same time, concerns have emerged regarding the reliability of AI-generated information. AI systems may occasionally produce inaccurate or misleading responses, commonly referred to as AI hallucinations. Consequently, students must develop AI literacy skills that enable them to critically evaluate and verify AI-generated content before applying it in academic work. Despite increasing interest in AI-supported learning, relatively little research has examined the relationship between AI use, academic achievement, student perceptions, self-regulated learning, and AI literacy within university biology education. Therefore, there is a need for empirical research that investigates both the educational benefits and challenges associated with AI-supported learning in biology courses.

Purpose of the Study

The purpose of this study was to investigate the impact of AI-supported learning on academic achievement, student perceptions, self-regulated learning, and AI literacy among undergraduate students enrolled in a university biology course. Specifically, the study examined whether the integration of AI-supported learning activities influenced students' academic performance and explored students' experiences, attitudes, and perceptions regarding the use of AI technologies in biology education.

Particular attention was given to students’ awareness of both the benefits and limitations of AI in an academic context. Through a quasi-experimental mixed-methods design, the research aimed to provide a comprehensive understanding of the pedagogical potential of AI-supported learning in higher education biology instruction.

Aim of the Study

The aim of this study was to investigate the impact of AI-supported learning on academic achievement, student perceptions, self-regulated learning, and AI literacy among undergraduate students enrolled in a university biology course.

Objectives

- To examine the effect of AI-supported learning on students' academic achievement in a university biology course.
- To explore students' perceptions of AI-supported learning in biology education.
- To investigate the extent to which AI-supported learning supports student engagement and independent learning.
- To assess students' perceptions of AI literacy and their awareness of the challenges associated with AI-supported learning.
- To evaluate students' views regarding the benefits and limitations of AI technologies in biology education.

Research Questions

The study was guided by the following research questions:

1. Does AI-supported learning influence students' academic achievement in a university biology course?
2. How do students perceive the use of AI-supported learning in biology education?
3. To what extent does AI-supported learning support student engagement and independent learning?
4. What are students' perceptions of AI literacy and the challenges associated with AI-supported learning?
5. How do students evaluate the benefits and limitations of AI technologies in biology education?

Research Hypotheses

To address the research questions, the following hypotheses were formulated:

Null Hypothesis (H_0): There is no statistically significant difference in academic achievement between students who participate in AI-supported learning and students who receive traditional instruction.

Alternative Hypothesis (H_1): Students who participate in AI-supported learning demonstrate significantly higher academic achievement than students who receive traditional instruction.

In addition to the achievement-related hypothesis, the study was based on the assumption that students would generally perceive AI-supported learning positively and that AI tools would support self-regulated learning, independent learning, and engagement in biology education. Furthermore, it was expected that students would demonstrate awareness of both the benefits and limitations of AI technologies, including the importance of evaluating the accuracy of AI-generated information.

Significance of the Study

This study is significant because it contributes to the growing body of research on the use of artificial intelligence in higher education, particularly within biology education. As AI technologies become increasingly integrated into educational environments, understanding their influence on learning outcomes and student experiences has become an important area of educational research. The study provides empirical evidence regarding the effectiveness of AI-supported learning in a university biology course. The findings may help educators better understand how AI tools can be incorporated into teaching practices to support student learning, engagement, and independent study. The study is also significant for students. By examining students' perceptions of AI-supported learning, the research provides insights into how learners interact with AI technologies and how these tools influence their educational experiences. Understanding these perceptions may help educators design learning environments that effectively integrate AI while addressing student needs and expectations. Furthermore, the study contributes to discussions on AI literacy. As generative AI tools become more widely used in academic settings, students must develop the ability to critically evaluate AI-generated information and use AI

responsibly. The findings may assist educators and institutions in developing strategies that promote critical thinking, information verification, and responsible AI use.

Finally, the study may be useful for policymakers, curriculum developers, and higher education institutions seeking evidence-based approaches for integrating AI technologies into teaching and learning processes.

Scope and Delimitations of the Study

This study focused on the implementation of AI-supported learning in a university biology course. The research was conducted among undergraduate students enrolled in a biology-related program at a higher education institution. The study specifically examined the topic of the anatomy of the nervous system and investigated the impact of AI-supported learning activities on students' academic achievement, perceptions of learning, self-regulated learning, and AI literacy. The participants consisted of 52 undergraduate students divided into a control group and an experimental group. The control group received traditional instruction, whereas the experimental group participated in AI-supported learning activities during the intervention period. Several delimitations should be acknowledged. First, the study was limited to a single university and therefore may not fully represent students from other institutions or academic disciplines. Second, the intervention focused on one biology topic and may not reflect the effectiveness of AI-supported learning across all areas of biology education. Third, the duration of the intervention was limited to the period of the instructional unit and did not assess long-term learning outcomes. Therefore, the findings should be interpreted within the context of the specific participants, educational setting, and instructional content investigated in this study.

LITERATURE REVIEW

2.1 Artificial Intelligence and Its Role in Modern Education

Artificial intelligence (AI) has become one of the most important technological developments of the twenty-first century (Haenlein & Kaplan, 2019). AI is now widely used in healthcare, business, industry, transportation, and education (Delipetrev et al., 2020; Crompton & Burke, 2023). The concept of AI refers to computer systems that can perform tasks normally associated with human intelligence, including learning, reasoning, problem-solving, decision-making, and language processing (Crompton & Burke, 2023). The rapid development of AI has been driven by advances in computing power, big data, and machine learning technologies (Delipetrev et al., 2020; Kaul et al., 2020). During the last decade, educational institutions have increasingly adopted AI technologies, and researchers suggest that AI has the potential to transform teaching and learning processes across different educational levels (Crompton & Burke, 2023; Abdul Rahman, 2024; Zawacki-Richter et al., 2019; Crompton & Song, 2021).

One of the most significant advantages of AI in education is its ability to support personalized learning (Usak, 2024; Adamakis & Rachiotis, 2025). Traditional educational approaches often provide identical learning materials to all students regardless of their individual needs and abilities (Usak, 2024). In contrast, AI systems can adapt instructional content, feedback, and assessment activities according to students' learning progress and performance (Crompton & Song, 2021; Adamakis & Rachiotis, 2025). Such adaptation enables learners to study at their own pace while receiving additional support when necessary (Usak, 2024). Previous studies have shown that personalized learning environments may contribute to improved understanding of subject content and enhanced academic achievement (Aleksandrovich et al., 2024; Ajibike, 2025).

Artificial intelligence is also widely applied in intelligent tutoring systems that provide explanations, answer questions, and guide students throughout the learning process (Zawacki-Richter et al., 2019; Crompton & Burke, 2023). Many AI-powered

educational platforms are available around the clock, allowing students to access learning support whenever they need it (Ng et al., 2025). Another important application of AI involves automated feedback systems, which can provide immediate responses to student performance (Crompton & Burke, 2023). Timely feedback helps learners identify mistakes, strengthen understanding, and improve academic performance more efficiently (Adamakis & Rachiotis, 2025). Researchers further suggest that prompt feedback can enhance student motivation and contribute to more positive learning outcomes (Ajibike, 2025).

In addition, AI plays an important role in learning analytics, which involves the collection and analysis of educational data to monitor student progress and identify learning difficulties (Zawacki-Richter et al., 2019; Crompton & Burke, 2023). Information generated through learning analytics can assist educators in providing targeted support and timely interventions for students who may require additional assistance (Crompton & Song, 2021). As a result, AI technologies offer opportunities to improve both instructional effectiveness and student success. The emergence of generative artificial intelligence has further expanded the educational applications of AI (Ng et al., 2025; Giannakos et al., 2025). Generative AI refers to systems capable of creating new content, including text, images, audio, and computer code (Mittal et al., 2024). Among these technologies, ChatGPT has attracted considerable attention from educators and researchers worldwide because of its ability to generate human-like responses to user prompts (Al-Shidi & Al Maawali, 2025; Qadir, 2023; Alasadi & Baiz, 2023).

Students increasingly use ChatGPT to search for information, summarize texts, generate ideas, and support various learning activities (Ng et al., 2025). Several studies have identified educational benefits associated with ChatGPT, including personalized learning experiences, instant feedback, content generation, and academic support (Al-Shidi & Al Maawali, 2025; Giannakos et al., 2025). Despite these advantages, researchers have expressed concerns regarding the use of AI in educational settings (UNESCO, 2023; Alasadi & Baiz, 2023). One major concern involves academic

integrity and the potential misuse of AI-generated content for academic assignments (UNESCO, 2023). Additional concerns relate to data privacy and the ethical use of student information (UNESCO, 2023; Ng et al., 2025). Researchers have also highlighted the risk of excessive dependence on AI technologies, which may reduce opportunities for students to develop critical thinking and independent problem-solving skills (Qadir, 2023). Another growing concern is the phenomenon known as AI hallucination, which occurs when AI systems generate information that appears credible but is actually inaccurate or fabricated (Center for Democracy & Technology, 2024). Such outputs may include false references, incorrect explanations, and misleading factual statements, potentially affecting learning outcomes if students accept them without verification (Center for Democracy & Technology, 2024; Agathokleous et al., 2023).

For this reason, many scholars emphasize the importance of developing AI literacy among both students and educators (Hornberger et al., 2025; Kong et al., 2023). AI literacy refers to the knowledge and skills required to understand, evaluate, and use AI technologies responsibly and effectively (Černý, 2024). Students should be able to verify AI-generated information, critically assess digital content, and recognize the limitations of AI systems (Hornberger et al., 2023). As AI technologies continue to evolve, these competencies are becoming increasingly important within higher education environments (Aldossary et al., 2024). Overall, the literature indicates that artificial intelligence offers substantial opportunities to improve teaching and learning through personalization, automated support, intelligent feedback, and enhanced access to educational resources (Crompton & Burke, 2023; Giannakos et al., 2025). However, successful implementation requires responsible use, ethical awareness, critical evaluation skills, and an understanding of the limitations associated with AI technologies (UNESCO, 2023; Center for Democracy & Technology, 2024). Therefore, AI literacy is increasingly recognized as a key competency for university students. These competencies are becoming increasingly important as AI technologies continue to play a larger role in higher education and professional practice.

2.2 Artificial Intelligence in Higher Education

Artificial intelligence has become an important component of modern higher education systems (Zawacki-Richter et al., 2019; Crompton & Burke, 2023). Universities increasingly integrate AI technologies into teaching, learning, assessment, and administrative processes (Abdul Rahman, 2024; Ahsina et al., 2025). Researchers argue that AI can support both students and educators by improving educational efficiency and learning outcomes (Crompton & Song, 2021). The rapid growth of AI in higher education has attracted significant academic interest during the last decade, with bibliometric studies demonstrating a substantial increase in AI-related publications, particularly after 2018 (Maphosa & Maphosa, 2023; Abdul Rahman, 2024). This trend accelerated further following the public release of generative AI technologies such as ChatGPT, which significantly expanded opportunities for educational innovation (Xu & Thien, 2026). One of the most common applications of AI in higher education is personalized learning, which enables educational content to be adapted according to individual student needs, abilities, and learning preferences (Crompton & Song, 2021; Usak, 2024). AI systems can analyze student performance, identify areas requiring additional support, and provide targeted assistance based on learner progress (Adamakis & Rachiotis, 2025).

As a result, students are able to progress at their own pace while receiving individualized guidance throughout the learning process (Usak, 2024). Another important application involves intelligent tutoring systems, which provide explanations, answer questions, and guide students through learning activities in a manner similar to human tutors (Zawacki-Richter et al., 2019; Crompton & Burke, 2023). Previous studies have reported that such systems can improve conceptual understanding and contribute positively to student achievement (Xu & Ouyang, 2022). Artificial intelligence is also increasingly used in educational assessment and evaluation processes (Crompton & Burke, 2023). AI-powered tools can assess assignments, generate feedback, and support formative assessment activities, allowing students to identify mistakes and improve their performance more efficiently

(Zawacki-Richter et al., 2019; Adamakis & Rachiotis, 2025). In addition, learning analytics has emerged as a major area of AI implementation in higher education. Learning analytics involves the collection and analysis of educational data to support decision-making and enhance student success (Crompton & Burke, 2023). These systems can identify learners who may be at risk of academic difficulties and enable educators to implement timely interventions before problems become more serious (Bates et al., 2020). Researchers suggest that predictive analytics may contribute to improved student retention rates and higher academic achievement (Bates et al., 2020). The emergence of generative artificial intelligence has created new opportunities for teaching and learning in higher education (Ng et al., 2025; Giannakos et al., 2025).

Generative AI systems are capable of producing text, explanations, summaries, quizzes, and various educational materials that can support both instructors and students (Gupta et al., 2025). Among these technologies, ChatGPT has become one of the most widely used tools among university students because of its ability to generate human-like responses and provide immediate academic support (Al-Shidi & Al Maawali, 2025). Students frequently use ChatGPT to obtain information, clarify complex concepts, generate ideas, and assist with academic writing tasks (Ng et al., 2025). Several studies have reported positive student perceptions of AI-assisted learning environments, with learners describing AI tools as accessible, useful, and supportive of independent learning (Giannakos et al., 2025; Ng et al., 2025).

Researchers have also found that AI technologies may enhance student engagement and motivation (Paredes-Ventura et al., 2025). Interactive learning environments encourage active participation, continuous learning, and greater involvement in educational activities (Abdulmumin et al., 2026). Personalized recommendations, adaptive support, and immediate responses may increase learner motivation and create more student-centered learning experiences (Ajibike, 2025; Crompton & Song, 2021). Furthermore, AI technologies may contribute to the development of important academic competencies, including critical thinking, problem-solving, digital literacy, and self-directed learning skills (Ajibike, 2025; Kong

et al., 2023). These competencies are increasingly recognized as essential for success in contemporary higher education and future professional environments (Aldossary et al., 2024).

Despite these advantages, the implementation of AI in higher education is accompanied by several challenges and concerns (Akinwalere & Ivanov, 2022). Researchers have raised questions regarding academic integrity, plagiarism, and the inappropriate use of AI-generated content in academic work (UNESCO, 2023). Students may rely on AI-generated responses without fully understanding the underlying concepts or evaluating the accuracy of the information provided (Qadir, 2023). Additional concerns relate to data privacy, ethical use of educational technologies, transparency, and algorithmic bias (UNESCO, 2023; Ng et al., 2025; Alasadi & Baiz, 2023).

The increasing popularity of generative AI has also heightened concerns regarding misinformation and AI hallucinations, which occur when AI systems generate inaccurate or fabricated information while presenting it as factual (Center for Democracy & Technology, 2024). Such outputs may negatively affect learning if students fail to verify information using reliable academic sources. For this reason, researchers emphasize the growing importance of AI literacy among university students and educators (Hornberger et al., 2025). AI literacy encompasses the knowledge and skills necessary to understand, evaluate, and use AI technologies responsibly and effectively (Černý, 2024). Students should develop the ability to critically evaluate AI-generated information, recognize potential limitations, and verify claims using trustworthy academic sources (Černý, 2024; Kong et al., 2023).

Overall, the literature suggests that artificial intelligence has significant potential to improve higher education by supporting personalized learning, assessment, engagement, and skill development (Crompton & Burke, 2023; Xu & Ouyang, 2022; Giannakos et al., 2025). However, successful implementation requires responsible use, ethical awareness, and the continuous development of AI literacy among both students and educators (UNESCO, 2023; Hornberger et al., 2025).

2.3 Generative Artificial Intelligence in Education

Generative artificial intelligence represents one of the most significant recent developments in educational technology and has rapidly attracted the attention of researchers, educators, and students worldwide (Ng et al., 2025; Gupta et al., 2025). Unlike traditional AI systems that primarily analyze data or automate specific tasks, generative AI is capable of creating new content based on user instructions (Alasadi & Baiz, 2023). These systems can generate text, images, audio, video, computer code, and various educational materials, making them highly versatile tools for educational applications (Gupta et al., 2025). Generative AI is built upon advanced machine learning models trained on vast amounts of data, while recent developments in natural language processing have substantially improved the quality and accuracy of generated outputs (Alasadi & Baiz, 2023; Al-Shidi & Al Maawali, 2025).

As a result, generative AI technologies have become increasingly accessible and widely adopted within higher education environments (Ng et al., 2025). Among the various generative AI tools currently available, ChatGPT has become one of the most widely recognized and frequently used systems in education (Al-Shidi & Al Maawali, 2025). Developed by OpenAI and released to the public in 2022, ChatGPT demonstrated the ability to understand natural language prompts and generate human-like responses across a wide range of topics (Alkaabi et al., 2025; Alasadi & Baiz, 2023). Its introduction attracted significant interest from educational institutions and researchers, many of whom viewed the technology as a potentially transformative innovation for teaching and learning (Giannakos et al., 2025; Qadir, 2023).

Students increasingly use ChatGPT to search for information, summarize academic texts, generate ideas, clarify complex concepts, and support various learning activities (Ng et al., 2025). The success and popularity of ChatGPT have also stimulated the development and adoption of other generative AI systems, including Google Gemini, Microsoft Copilot, Claude, and additional large language models that continue to expand the educational possibilities of artificial intelligence (Gupta et al., 2025; Giannakos et al., 2025).

Researchers have identified numerous educational benefits associated with the use of generative AI technologies (Al-Shidi & Al Maawali, 2025). One of the most frequently discussed advantages is the ability to provide personalized learning support that adapts to individual student needs and learning preferences (Ng et al., 2025). Generative AI systems can offer customized explanations, answer questions repeatedly, and provide immediate responses without time limitations, allowing learners to receive assistance whenever necessary (Al-Shidi & Al Maawali, 2025). Such flexibility enables students to study independently and progress at their own pace while maintaining continuous access to learning support (Ng et al., 2025).

In addition, generative AI can support content creation by assisting educators with the development of lesson plans, quizzes, assignments, presentations, and other instructional materials (Gupta et al., 2025; Giannakos et al., 2025). These capabilities may reduce preparation time and facilitate more efficient instructional design processes (Ng et al., 2025). Interactive conversations with AI systems can encourage active participation in learning activities and promote deeper exploration of educational content (Al-Shidi & Al Maawali, 2025). Many students perceive AI tools as accessible, convenient, and easy to use, which may contribute to increased motivation and more positive learning experiences (Ng et al., 2025; Giannakos et al., 2025).

Furthermore, generative AI can support self-directed learning by enabling students to review concepts, generate examples, explore additional resources, and obtain explanations outside formal classroom settings (Al-Shidi & Al Maawali, 2025). Researchers suggest that these opportunities may contribute to improved learning outcomes, stronger learner autonomy, and greater responsibility for the learning process (Ng et al., 2025). Generative AI may also support the development of important digital competencies by encouraging students to interact with AI systems, evaluate information critically, and develop responsible technology-use practices (Aldossary et al., 2024; Hornberger et al., 2025). These competencies are increasingly important for success in both higher education and future professional environments (Wang et al., 2024).

Despite these advantages, the implementation of generative AI in education presents several challenges and concerns (UNESCO, 2023). One major issue involves academic integrity, as students may submit AI-generated work without demonstrating their own understanding of the subject matter (Qadir, 2023; UNESCO, 2023). Such practices raise questions regarding assessment validity, authentic learning, and the overall quality of educational outcomes (Giannakos et al., 2025). Researchers have also expressed concerns about overreliance on AI technologies, arguing that excessive dependence on AI-generated answers may reduce opportunities for independent thinking, creativity, and problem-solving development (Qadir, 2023).

Another challenge concerns the accuracy and reliability of AI-generated content. Generative AI systems may occasionally produce false or misleading information while presenting it in a confident and convincing manner, a phenomenon commonly referred to as AI hallucination (Center for Democracy & Technology, 2024). Hallucinations may include fabricated references, inaccurate facts, incorrect explanations, and misleading academic information that can negatively influence learning if students fail to verify content using reliable sources (Center for Democracy & Technology, 2024; Agathokleous et al., 2023).

Ethical issues have also become a major focus of recent discussions surrounding generative AI in education (UNESCO, 2023). Researchers have highlighted concerns related to privacy, transparency, algorithmic bias, and the responsible use of AI technologies in educational environments (Alasadi & Baiz, 2023).

In response, many educational institutions are developing policies and guidelines aimed at promoting the safe and ethical integration of generative AI into teaching and learning practices (UNESCO, 2023). Several scholars emphasize that the successful implementation of generative AI should be accompanied by the development of AI literacy among students and educators (Hornberger et al., 2025). AI literacy includes understanding how generative AI systems function, recognizing their limitations, critically evaluating generated content, and verifying information using reliable academic sources (Černý, 2024 Wang et al., 2024). Overall, the literature suggests that

generative artificial intelligence offers substantial opportunities to enhance teaching and learning through personalized support, content creation, student engagement, and independent learning (Giannakos et al., 2025; Ng et al., 2025; Al-Shidi & Al Maawali, 2025).

However, realizing these benefits requires responsible implementation, ethical awareness, critical evaluation skills, and the effective development of AI literacy among both students and educators (UNESCO, 2023; Hornberger et al., 2025).

2.4 Artificial Intelligence in Biology Education

Artificial intelligence is becoming increasingly important in biology education as educators seek innovative approaches to address the growing complexity of biological sciences and improve student learning outcomes (Usak, 2024; Duran & Dikmenli, 2025). Biology contains numerous abstract concepts that students often find difficult to understand, including genetics, meiosis, molecular biology, heredity, and various cellular processes that require learners to integrate information across multiple levels of biological organization (Baroud et al., 2025).

Researchers have consistently reported that students experience difficulties when learning these topics, creating a need for instructional approaches that can provide additional support and enhance conceptual understanding (Baroud et al., 2025). Consequently, educators and researchers have increasingly explored the potential of artificial intelligence as a tool for improving biology teaching and learning (Usak, 2024).

Artificial intelligence can support biology education through a wide range of applications, including personalized learning, intelligent tutoring systems, automated assessment, virtual laboratories, learning analytics, educational chatbots, and collaborative learning environments (He & Krajcik, 2026; Abdulmumin et al., 2026). AI-powered educational systems can provide explanations tailored to individual learning needs, allowing students to receive immediate feedback and additional support when they encounter difficulties during the learning process (Duran & Dikmenli, 2025;

He & Krajcik, 2026). Researchers suggest that these capabilities may improve conceptual understanding, learning efficiency, academic performance, and student satisfaction (Paredes-Ventura et al., 2025; Abdulmumin et al., 2026). Personalized learning has emerged as one of the most frequently reported applications of AI in biology education because it enables educational content to be adapted according to students' abilities, learning preferences, and academic progress (He & Krajcik, 2026).

In addition, AI systems can facilitate collaborative learning by supporting communication, providing recommendations, and encouraging knowledge sharing among learners, thereby contributing to greater participation and engagement during educational activities (He & Krajcik, 2026; Paredes-Ventura et al., 2025).

The development of virtual laboratories has created additional opportunities for biology education by allowing students to explore biological phenomena and conduct learning activities in safe, flexible, and accessible environments (Doğru & Faulconer, 2026). Researchers suggest that AI-supported virtual laboratories can enhance practical understanding while reducing limitations associated with laboratory equipment, resources, and accessibility (Doğru & Faulconer, 2026).

At the same time, artificial intelligence has become increasingly important in biological research itself, particularly in fields such as genetics, genomics, bioinformatics, and protein structure prediction, where machine learning algorithms are now widely applied (Hassoun et al., 2021).

As a result, biology students must develop not only strong biological knowledge but also digital competencies that enable them to work effectively with AI-supported technologies (Usak, 2024). Several researchers argue that AI literacy is becoming an essential competency for future biologists because of the growing integration of artificial intelligence into both scientific research and professional practice (Usak, 2024; Hassoun et al., 2021). Recent studies have highlighted the growing role of ChatGPT and other generative AI tools in biology education (Nguyen et al., 2023; Baroud et al., 2025). ChatGPT can provide explanations, answer questions, summarize information, generate learning materials, and support independent learning activities,

leading some researchers to describe it as a virtual tutor capable of assisting students beyond traditional classroom settings (Nguyen et al., 2023). Students can interact with the system repeatedly and receive immediate responses to their questions, which may support self-directed learning and increase access to educational resources (Nguyen et al., 2023).

One of the most significant contributions of ChatGPT involves helping students understand complex biological concepts that are often difficult to master through traditional instruction alone (Baroud et al., 2025). For example, Baroud et al. (2025) investigated the use of ChatGPT in genetics education among Moroccan high school students, focusing on meiosis, a topic widely recognized as one of the most challenging concepts in genetics. The study reported that students who used ChatGPT achieved significantly higher post-test scores than those who received traditional instruction, while the experimental group demonstrated stronger cognitive performance and improved problem-solving abilities (Baroud et al., 2025). These findings suggest that ChatGPT can enhance understanding of complex biological concepts and contribute positively to academic achievement (Baroud et al., 2025). Similar findings were reported by Nguyen et al. (2023), who examined the use of ChatGPT in biology teaching and learning in Vietnam. Their study indicated that ChatGPT could assist students in understanding biological concepts, generating learning materials, and receiving personalized explanations tailored to individual needs. The authors also emphasized the potential of ChatGPT to support teachers in lesson preparation and instructional design, highlighting its value for both learners and educators (Nguyen et al., 2023).

Another important application of ChatGPT involves laboratory learning. Doğru and Faulconer (2026) investigated the use of ChatGPT as a virtual laboratory teaching assistant in undergraduate biology courses and found that the system could answer procedural questions and provide guidance during laboratory activities. Based on these findings, the authors concluded that ChatGPT may serve as a valuable supplementary learning tool within biology laboratory environments (Doğru & Faulconer, 2026).

Artificial intelligence has also been associated with increased student engagement, motivation, and confidence in biology learning (Paredes-Ventura et al., 2025). Interactive AI systems encourage students to participate more actively in educational activities, while immediate feedback and personalized support may strengthen motivation and facilitate more meaningful learning experiences (Abdulmumin et al., 2026; Paredes-Ventura et al., 2025). Researchers suggest that these factors contribute not only to improved academic performance but also to greater learner autonomy and responsibility for the learning process.

Despite these advantages, several challenges continue to accompany the implementation of artificial intelligence in biology education (Agathokleous et al., 2023). Researchers have raised concerns regarding the accuracy and reliability of AI-generated information, noting that generative AI systems may occasionally produce incorrect or misleading biological explanations (Agathokleous et al., 2023). Such inaccuracies may negatively affect learning if students fail to verify information using reliable academic sources.

Additional concerns include ethical issues, academic integrity, privacy, and the potential for overreliance on AI technologies, which may reduce opportunities for independent thinking and critical analysis (Usak, 2024).

Consequently, researchers emphasize the importance of responsible AI use and the development of AI literacy skills among biology students so that they can evaluate AI-generated information critically and use these technologies effectively and ethically (Usak, 2024; Hornberger et al., 2025).

Overall, the current literature indicates that artificial intelligence has substantial potential to enhance biology education by improving conceptual understanding, academic achievement, engagement, personalized learning, and independent study opportunities (Duran & Dikmenli, 2025; He & Krajcik, 2026; Paredes-Ventura et al., 2025). At the same time, successful implementation depends on the development of critical evaluation skills, ethical awareness, AI literacy, and appropriate guidance from

educators to ensure that these technologies are used responsibly and effectively within biology learning environments (Agathokleous et al., 2023; Usak, 2024).

2.5 ChatGPT in Biology Learning

The release of ChatGPT has attracted considerable attention in the field of education and has rapidly become a focus of educational research worldwide (Al-Shidi & Al Maawali, 2025; Ng et al., 2025). Among various academic disciplines, biology has emerged as one of the fields where ChatGPT demonstrates significant educational potential due to the complexity of biological concepts and the learning challenges frequently experienced by students (Nguyen et al., 2023). Biology learners often struggle with abstract concepts, scientific terminology, and complex biological processes such as genetics, meiosis, heredity, molecular biology, and cell division, all of which require substantial conceptual understanding and the integration of knowledge across different levels of biological organization (Baroud et al., 2025).

Researchers suggest that ChatGPT can support students in understanding these challenging topics by providing interactive explanations, personalized responses, and immediate feedback tailored to individual learning needs (Nguyen et al., 2023).

Unlike traditional educational resources, ChatGPT enables students to interact using natural language and receive immediate responses to their questions (Nguyen et al., 2023). Students can request additional clarification, ask follow-up questions, and engage in continuous dialogue until concepts become clearer. This interactive communication may help learners overcome difficulties more effectively than static learning materials alone (Nguyen et al., 2023). One of the most frequently reported advantages of ChatGPT is its ability to function as a virtual tutor capable of explaining biological concepts, providing examples, and supporting independent study activities (Nguyen et al., 2023).

Researchers argue that this flexibility promotes learner autonomy and strengthens self-directed learning by allowing students to access educational support beyond traditional classroom hours (Nguyen et al., 2023). In addition, students may use ChatGPT to summarize biological information, generate practice questions, review

previous lessons, and reinforce conceptual understanding, all of which may contribute to improved academic outcomes (Nguyen et al., 2023; Baroud et al., 2025).

Several empirical studies have investigated the effects of ChatGPT on biology learning. One of the most notable studies was conducted by Baroud et al. (2025) among Moroccan secondary school students studying genetics. The researchers focused specifically on meiosis, a topic widely recognized as one of the most difficult areas within biology education because students often experience difficulties understanding chromosome behavior, genetic variation, and mechanisms of heredity (Baroud et al., 2025). Using a quasi-experimental design, the study compared an experimental group that used ChatGPT during learning activities with a control group that received traditional instruction. The findings demonstrated significant improvements in post-test performance among students who used ChatGPT.

Furthermore, students in the experimental group exhibited stronger cognitive achievement and enhanced problem-solving abilities related to genetics concepts (Baroud et al., 2025). These results suggest that ChatGPT can facilitate deeper learning and improve understanding of complex biological concepts. The study also reported positive effects on student engagement and motivation. Students who interacted with ChatGPT participated more actively in learning activities and demonstrated greater interest in the subject matter (Baroud et al., 2025). These findings support broader educational research emphasizing the importance of active participation and interactive learning environments in science education (Nguyen et al., 2023).

The ability of ChatGPT to provide immediate responses and adapt explanations to individual learner needs may help create a more engaging and student-centered learning experience. Another important area of application involves biology laboratory instruction. Practical laboratory activities play a central role in biology education because they allow students to connect theoretical knowledge with experimental experience (Doğru & Faulconer, 2026).

However, students frequently require additional guidance while performing laboratory procedures and interpreting experimental results. Doğru and Faulconer

(2026) explored the use of ChatGPT as a virtual laboratory teaching assistant in undergraduate biology courses. Their findings indicated that ChatGPT was capable of answering procedural questions, providing clarification regarding laboratory activities, and offering immediate support during practical exercises. Students reported that the system helped them understand laboratory procedures more effectively and reinforced their comprehension of biological concepts. Based on these findings, the authors concluded that ChatGPT can serve as a valuable supplementary resource within biology laboratory environments (Doğru & Faulconer, 2026).

Researchers have also examined the broader implications of ChatGPT for biological and environmental sciences. Agathokleous et al. (2023) suggested that ChatGPT can facilitate access to scientific information and support educational activities by helping students locate relevant resources, generate explanations, organize information, and explore scientific topics more efficiently. The system may also assist with academic writing and information synthesis during biology courses, making it particularly useful for students working on research projects, laboratory reports, and scientific assignments (Agathokleous et al., 2023).

Several scholars further argue that ChatGPT may contribute to the development of higher-order thinking skills because students are encouraged to formulate questions, evaluate explanations, compare information from multiple sources, and reflect on alternative perspectives (Baroud et al., 2025; Nguyen et al., 2023). Such learning activities may promote critical thinking, scientific reasoning, and deeper conceptual understanding. An additional advantage of ChatGPT is its ability to support personalized learning. Students can receive explanations adapted to their existing knowledge, learning pace, and educational needs, thereby reducing learning gaps among individuals with different academic backgrounds (Nguyen et al., 2023).

Personalized support may be particularly beneficial in biology education, where learners often possess varying levels of prior knowledge and scientific literacy. By providing individualized explanations and immediate feedback, ChatGPT can create

more inclusive learning environments that accommodate diverse learner characteristics.

Despite these advantages, several challenges have been identified regarding the use of ChatGPT in biology education. One major concern involves the accuracy and reliability of AI-generated information (Agathokleous et al., 2023). ChatGPT may occasionally generate incorrect biological explanations, misleading statements, or inaccurate references while presenting them in a convincing manner. Such inaccuracies may create misconceptions if students rely on AI-generated content without verification (Agathokleous et al., 2023).

Researchers therefore recommend using ChatGPT as a supplementary educational resource rather than a replacement for textbooks, scientific articles, laboratory instruction, and teacher guidance (Doğru & Faulconer, 2026). Students should be encouraged to verify information using reliable academic sources and develop critical evaluation skills when interacting with AI-generated content (Agathokleous et al., 2023).

Additional concerns relate to academic integrity, ethical use, and responsible implementation of artificial intelligence in educational settings (UNESCO, 2023). Students must learn how to use ChatGPT ethically while maintaining academic honesty and independent thinking. Consequently, the development of AI literacy has become increasingly important for effective integration of ChatGPT into biology education (Hornberger et al., 2025; Wang et al., 2024). AI literacy enables students to understand the capabilities and limitations of AI systems, evaluate information critically, and use these technologies responsibly within academic contexts.

Overall, current evidence suggests that ChatGPT has considerable potential to support biology learning by improving conceptual understanding, academic achievement, engagement, personalized learning, and independent study opportunities (Baroud et al., 2025; Nguyen et al., 2023). The technology can serve as a virtual tutor, learning assistant, and supplementary educational resource that extends learning beyond traditional classroom boundaries. However, successful implementation

requires responsible use, critical evaluation skills, AI literacy, and appropriate guidance from educators to ensure that students benefit from the technology while avoiding potential risks associated with inaccurate information and excessive dependence on AI-generated content (Agathokleous et al., 2023; UNESCO, 2023).

2.6 Artificial Intelligence and Academic Achievement

Academic achievement is widely recognized as one of the most important indicators of educational success because it reflects the extent to which students achieve intended learning outcomes and demonstrate mastery of educational content (Aleksandrovich et al., 2024; Paredes-Ventura et al., 2025). As artificial intelligence becomes increasingly integrated into educational environments, researchers have devoted growing attention to examining its influence on academic performance and student learning outcomes (Xu & Ouyang, 2022).

Recent studies suggest that AI technologies can positively affect academic achievement through personalized learning, adaptive instruction, intelligent feedback systems, and enhanced access to educational support (Adamakis & Rachiotis, 2025; Ajibike, 2025). By adapting learning experiences according to individual student needs and learning progress, artificial intelligence creates opportunities for more efficient and learner-centered educational experiences (Usak, 2024; Crompton & Song, 2021). One of the primary mechanisms through which AI contributes to academic achievement is personalized learning.

Artificial intelligence systems can analyze student performance, identify learning difficulties, and provide targeted support tailored to individual needs (Adamakis & Rachiotis, 2025). This personalized approach allows students to receive assistance precisely when it is needed, helping them overcome misconceptions and strengthen conceptual understanding more effectively than traditional one-size-fits-all instructional approaches (Usak, 2024). As learning becomes increasingly individualized, students may progress at a pace appropriate to their abilities while receiving continuous guidance throughout the learning process (Crompton & Song,

2021). Researchers suggest that these features contribute to greater learning efficiency and improved educational outcomes (Adamakis & Rachiotis, 2025).

Several empirical studies have reported positive associations between AI-supported learning and academic performance. Aleksandrovich et al. (2024) found that students who actively used AI-supported educational tools achieved significantly better academic outcomes than students who relied exclusively on traditional learning methods. The study reported approximately a 25% increase in learning outcomes among learners who incorporated AI technologies into their educational activities. In addition to improved achievement scores, the researchers observed enhanced knowledge retention and greater student participation, suggesting that AI technologies may positively influence multiple dimensions of learning (Aleksandrovich et al., 2024).

Researchers also emphasize the role of feedback as a critical factor influencing academic achievement. Artificial intelligence systems can provide immediate and personalized feedback that helps students identify mistakes, correct misunderstandings, and improve performance in real time (Ajibike, 2025; Adamakis & Rachiotis, 2025). Feedback has long been recognized as one of the most influential variables affecting learning outcomes, and AI technologies significantly enhance the speed and accessibility of feedback processes (Adamakis & Rachiotis, 2025).

When students receive prompt responses to their work, they are able to address learning difficulties more efficiently and engage in continuous improvement, which ultimately supports stronger academic performance (Ajibike, 2025). Adaptive learning systems represent another important application of artificial intelligence that has been linked to improved educational outcomes (Xu & Ouyang, 2022). These systems continuously analyze student performance and adjust learning materials, activities, and instructional support according to individual progress. Students who require additional assistance can receive supplementary explanations and targeted learning activities, whereas students who demonstrate advanced understanding may progress to more challenging content (Crompton & Burke, 2023; Xu & Ouyang, 2022). This flexibility

allows learners to engage with educational content at an appropriate level of difficulty, thereby increasing the likelihood of academic success (Usak, 2024). Research conducted in higher education has further demonstrated that AI technologies can improve learning efficiency and reduce barriers that negatively affect academic performance (Bates et al., 2020). Learning analytics systems, for example, allow educators to monitor student progress and identify individuals who may be at risk of poor academic outcomes (Zawacki-Richter et al., 2019).

By detecting potential difficulties at an early stage, educators can implement timely interventions designed to prevent academic failure and support student success (Bates et al., 2020). Consequently, predictive analytics has become an increasingly valuable tool for improving academic achievement and promoting educational retention (Crompton & Burke, 2023).

The emergence of generative artificial intelligence has created additional opportunities for supporting student achievement. Tools such as ChatGPT can provide explanations, examples, summaries, and individualized learning assistance that help students understand difficult concepts and address knowledge gaps (Al-Shidi & Al Maawali, 2025; Ng et al., 2025). Several studies have reported positive effects of ChatGPT on learning outcomes across different educational contexts (Baroud et al., 2025). In a study investigating genetics education among Moroccan secondary school students, Baroud et al. (2025) found that students who used ChatGPT achieved significantly higher post-test scores than those who learned through traditional instructional methods. The experimental group demonstrated stronger understanding of meiosis and genetics concepts, suggesting that ChatGPT can enhance academic achievement by improving conceptual understanding and problem-solving abilities (Baroud et al., 2025).

Similar conclusions were reported by Nguyen et al. (2023), who found that ChatGPT can provide personalized explanations and support independent learning in biology education. According to the authors, these features may contribute to stronger academic performance by enabling students to access individualized learning support

whenever necessary. Review studies have further strengthened evidence regarding the positive relationship between AI technologies and academic achievement. Paredes-Ventura et al., (2025) concluded that AI applications contribute to improved learning outcomes, conceptual understanding, and academic success within biology education. The authors also reported positive effects on student motivation and engagement, which may indirectly influence achievement by encouraging greater participation in learning activities (Paredes-Ventura et al., 2025).

Likewise, Abdulmumin et al. (2026) found that AI-supported learning environments enhance educational accessibility and personalized learning experiences while contributing to improved academic performance through adaptive instruction and continuous feedback mechanisms. Artificial intelligence may also influence achievement indirectly through the development of important learning competencies.

Researchers have reported that AI-supported environments can strengthen critical thinking, problem-solving skills, self-regulated learning, and digital literacy (Ajibike, 2025). These competencies are closely associated with stronger academic performance because they enable students to engage more effectively with learning materials and develop more efficient learning strategies (Wang et al., 2024). By supporting both content mastery and skill development, AI technologies may contribute to sustainable improvements in educational achievement.

Despite these positive findings, researchers caution that the relationship between artificial intelligence and academic achievement is not always straightforward (Xu & Thien, 2026). The effectiveness of AI technologies depends on multiple factors, including instructional design, teacher support, student readiness, technological infrastructure, and equitable access to digital resources (Xu & Thien, 2026). Poor implementation strategies may limit educational benefits and reduce learning effectiveness (Akinwalere & Ivanov, 2022).

Furthermore, many scholars emphasize that AI should complement rather than replace traditional educational practices because human guidance remains essential for promoting deep learning, critical thinking, and meaningful conceptual understanding

(UNESCO, 2023; Giannakos et al., 2025). Overall, current evidence suggests that artificial intelligence has considerable potential to improve academic achievement across various educational contexts (Aleksandrovich et al., 2024; Paredes-Ventura et al., 2025). Through personalized learning, adaptive instruction, immediate feedback, learning analytics, and independent learning support, AI technologies can create conditions that facilitate stronger academic performance and improved learning outcomes (Adamakis & Rachiotis, 2025; Usak, 2024). While successful implementation requires careful instructional design and responsible use, the existing literature indicates that artificial intelligence can serve as an effective tool for enhancing educational achievement and supporting student success (Xu & Ouyang, 2022; Abdulmumin et al., 2026).

2.7 Artificial Intelligence and Student Engagement

Student engagement is widely recognized as a critical factor influencing learning success, academic achievement, and overall educational effectiveness (Paredes-Ventura et al., 2025). The concept refers to the degree of students' participation, involvement, interest, effort, and commitment during learning activities and is commonly viewed as a multidimensional construct consisting of behavioral, emotional, and cognitive components (Abdulmumin et al., 2026; Ajibike, 2025). Students who demonstrate high levels of engagement are more likely to participate actively in educational activities, maintain motivation, persist when facing challenges, and achieve positive learning outcomes (Paredes-Ventura et al., 2025).

Consequently, increasing student engagement has become an important objective for educators and researchers seeking to improve educational quality and student success. Recent studies suggest that artificial intelligence can contribute significantly to student engagement by creating interactive, adaptive, and personalized learning environments (Abdulmumin et al., 2026). AI technologies provide opportunities for students to engage with educational content in ways that are responsive to their individual needs, preferences, and learning progress (He & Krajcik, 2026). Through adaptive learning systems, educational content can be adjusted

according to students' abilities, allowing learners to interact with materials that are appropriately challenging and relevant to their learning goals (Crompton & Song, 2021). Researchers argue that personalized learning experiences increase students' interest, involvement, and sense of connection to the learning process, thereby strengthening engagement and supporting more positive educational experiences (Usak, 2024).

Furthermore, students who receive individualized support often develop greater confidence in their ability to succeed academically, which may further enhance participation and persistence during learning activities (Ajibike, 2025). Immediate feedback represents another important mechanism through which artificial intelligence can enhance engagement (Adamakis & Rachiotis, 2025). AI-powered systems can provide explanations, corrections, and recommendations without requiring students to wait for instructor responses (Crompton & Burke, 2023). This continuous interaction encourages learners to remain actively involved in educational activities and supports ongoing communication between students and learning materials. Researchers suggest that immediate feedback not only improves understanding but also promotes greater behavioral and cognitive engagement by encouraging students to reflect on their learning and make continuous improvements (Ajibike, 2025; Adamakis & Rachiotis, 2025).

Several review studies have reported positive relationships between AI-supported learning and student engagement. Paredes-Ventura et al., (2025) concluded that AI technologies contribute to increased motivation, stronger participation, and improved learning experiences within biology education. According to the authors, interactive AI-supported learning environments encourage students to become more actively involved in educational activities and support greater commitment to the learning process.

Similarly, Abdulmumin et al. (2026) reported that artificial intelligence enhances engagement through adaptive learning experiences, personalized feedback, and interactive educational resources. Their review emphasized the role of AI in

creating more accessible, inclusive, and learner-centered educational environments that encourage active participation and sustained involvement.

Researchers have also examined the role of generative artificial intelligence, particularly ChatGPT, in promoting student engagement (Baroud et al., 2025; Nguyen et al., 2023). ChatGPT enables students to interact with educational content through natural language conversations, allowing them to ask questions freely and receive immediate responses to their inquiries (Nguyen et al., 2023). This interactive communication can stimulate curiosity, encourage exploration of learning topics, and foster a more active approach to learning. Because students can engage in continuous dialogue with the system, they are often more willing to seek clarification and explore concepts in greater depth.

Researchers suggest that such interactions can increase both cognitive engagement and interest in academic content (Nguyen et al., 2023). Evidence from biology education supports these conclusions. Baroud et al. (2025) reported that students who used ChatGPT during genetics instruction demonstrated higher levels of participation, interest, and involvement in learning activities than students receiving traditional instruction. The authors observed that students interacted more actively with biological concepts, demonstrated greater willingness to solve problems independently, and engaged more frequently in discussions related to the learning content. These findings suggest that ChatGPT may contribute to more engaging educational experiences by creating opportunities for active interaction and personalized support (Baroud et al., 2025).

Furthermore, the interactive nature of generative AI may encourage students to take greater responsibility for their learning while remaining actively involved throughout the educational process.

Artificial intelligence may also enhance engagement through virtual laboratories, simulations, and interactive learning environments (Doğru & Faulconer, 2026). In biology education, virtual laboratory experiences allow students to explore scientific concepts dynamically through experimentation, observation, and inquiry-

based learning. AI-supported laboratory environments provide immediate assistance, procedural guidance, and personalized feedback during practical activities (Doğru & Faulconer, 2026). Such opportunities encourage students to participate actively in learning tasks and may strengthen both behavioral and cognitive engagement by making educational experiences more interactive and meaningful.

Another important aspect of engagement relates to self-directed learning. Researchers have suggested that AI technologies provide students with opportunities to access educational support beyond classroom hours and assume greater responsibility for their own learning (Ng et al., 2025). Students who engage in self-directed learning often demonstrate stronger persistence, higher motivation, and greater commitment to educational goals (Ajibike, 2025). Generative AI tools such as ChatGPT support this process by offering continuous access to explanations, examples, feedback, and learning assistance whenever needed (Ng et al., 2025).

As a result, students may remain engaged with educational content for longer periods and become more actively involved in managing their learning experiences.

Several studies have also identified positive relationships between artificial intelligence, motivation, and engagement (Paredes-Ventura et al., 2025). Motivated students are more likely to participate actively, complete educational tasks, and persist when confronted with academic challenges (Ajibike, 2025). The personalized and interactive characteristics of AI systems may therefore support both motivation and engagement simultaneously by creating learning experiences that are responsive, supportive, and meaningful for individual learners (Abdulmumin et al., 2026). These features help establish educational environments in which students are more willing to invest effort and maintain active involvement throughout the learning process.

Despite these positive findings, researchers have identified several challenges associated with AI-supported engagement (UNESCO, 2023). Excessive reliance on AI-generated responses may reduce opportunities for independent exploration, critical thinking, and problem-solving, potentially weakening deeper forms of engagement (Qadir, 2023). Researchers therefore emphasize the importance of balancing AI-

supported learning with active student participation, reflection, and independent inquiry (Giannakos et al., 2025). Another concern relates to the quality and accuracy of AI-generated information. Students may become passive recipients of information if they accept AI-generated responses without critically evaluating the content provided (Agathokleous et al., 2023; Center for Democracy & Technology, 2024). Consequently, AI literacy has emerged as an essential component of effective AI-supported learning because it enables students to evaluate information critically and use AI technologies responsibly (Hornberger et al., 2025; Wang et al., 2024).

Overall, the literature suggests that artificial intelligence has substantial potential to enhance student engagement across educational contexts (Abdulmumin et al., 2026; Paredes-Ventura et al., 2025). Through personalization, interactivity, immediate feedback, adaptive learning opportunities, and continuous educational support, AI technologies can create learning environments that encourage greater participation, stronger motivation, and deeper involvement in educational activities (He & Krajcik, 2026; Adamakis & Rachiotis, 2025).

Although successful implementation requires responsible use, critical evaluation skills, and appropriate educational guidance, current evidence indicates that AI can serve as a valuable tool for fostering meaningful student engagement and improving learning experiences (UNESCO, 2023; Hornberger et al., 2025).

2.8 AI Literacy among University Students

The rapid expansion of artificial intelligence across educational, professional, and social contexts has significantly increased the importance of AI literacy in higher education (Černý, 2024; Hornberger et al., 2025). AI literacy is increasingly recognized as a fundamental competency that enables university students to interact effectively, responsibly, and critically with artificial intelligence technologies (Wang et al., 2024).

Researchers argue that students must not only learn how to use AI tools but also understand how these systems operate, recognize their limitations, evaluate their outputs critically, and make informed decisions regarding their use (Černý, 2024). As generative AI technologies become more accessible and widely integrated into

everyday life, the development of AI literacy has become an important priority for higher education institutions worldwide (Hornberger et al., 2025). AI literacy is generally defined as the combination of knowledge, practical skills, attitudes, critical awareness, and ethical understanding required to engage effectively with artificial intelligence systems (Zhang & Aslan, 2021; Černý, 2024). Unlike traditional forms of digital literacy that primarily focus on information technologies, AI literacy encompasses a broader understanding of how intelligent systems collect, process, generate, and communicate information.

Researchers emphasize that AI literacy extends beyond technical competence and includes the ability to understand the capabilities and limitations of AI systems, identify risks associated with AI-generated content, and evaluate the social and ethical implications of artificial intelligence technologies (Hornberger et al., 2023; Hornberger et al., 2025). As AI applications become increasingly common in education, employment, healthcare, and everyday communication, universities are expected to prepare students for responsible participation in AI-supported environments (Wang et al., 2024; Aldossary et al., 2024).

One of the most important dimensions of AI literacy involves the critical evaluation of information generated by artificial intelligence systems (Wang et al., 2024). Students frequently use AI-powered tools to obtain information, generate ideas, summarize texts, and support academic tasks. However, researchers emphasize that AI-generated responses should not automatically be accepted as accurate or reliable (Hornberger et al., 2025). Artificial intelligence systems may occasionally produce inaccurate, incomplete, or misleading information, a phenomenon commonly referred to as AI hallucination (Center for Democracy & Technology, 2024).

Consequently, students must develop the ability to assess the reliability of AI-generated content, verify information using trustworthy academic sources, and recognize potential limitations within AI outputs (Hornberger et al., 2025). These skills are essential for maintaining academic integrity and ensuring the responsible use of AI technologies within educational settings.

Several researchers have investigated the current level of AI literacy among university students. Hornberger et al. (2023) developed an AI literacy assessment instrument designed to evaluate students' understanding of key artificial intelligence concepts and applications. Their findings indicated that many students possessed limited knowledge regarding how AI systems function, despite increasing exposure to AI technologies in their academic and personal lives. The authors concluded that additional educational initiatives are required to improve students' understanding of artificial intelligence and strengthen their ability to use these technologies effectively (Hornberger et al., 2023). A subsequent international study conducted by Hornberger et al. (2025) examined AI literacy among students from Germany, the United Kingdom, and the United States. The findings revealed substantial variation in AI knowledge, confidence, and understanding across different student populations.

Notably, many participants reported frequent use of AI tools despite having only a limited understanding of the underlying technologies. These results suggest that the adoption of artificial intelligence often occurs more rapidly than the development of AI literacy competencies (Hornberger et al., 2025).

Researchers have therefore emphasized the need for structured AI literacy education within higher education curricula. Zhang & Aslan, (2021) proposed that effective AI literacy education should incorporate three major dimensions: conceptual knowledge, practical skills, and ethical awareness. According to the authors, students should learn fundamental concepts related to artificial intelligence, understand how AI systems operate, and explore the broader societal impacts of these technologies.

At the same time, AI literacy education should promote responsible and ethical decision-making by encouraging students to consider issues such as fairness, accountability, transparency, and privacy (Zhang & Aslan, 2021). Wang et al. (2024) further emphasized the relationship between AI literacy, empowerment, and ethical awareness. Their findings demonstrated that students with stronger AI literacy reported greater confidence when interacting with AI technologies and exhibited increased awareness of ethical concerns related to AI use. The development of AI literacy is

influenced by a variety of personal, educational, and environmental factors. Gökçe (2025) identified prior technology experience, educational background, access to digital resources, and attitudes toward artificial intelligence as important determinants of AI literacy development. Students with greater exposure to digital technologies often demonstrate stronger understanding of AI concepts and greater confidence when interacting with AI systems (Gökçe, 2025).

In addition, cross-cultural studies have revealed significant international differences in AI literacy levels. The growing integration of artificial intelligence into education and professional environments has further strengthened arguments that AI literacy should be considered a core twenty-first-century competency. Aldossary et al. 2024 conducted a multinational investigation of AI literacy among university students and emphasized the importance of preparing learners for increasingly AI-integrated educational and workplace settings.

The researchers argued that students must develop competencies that allow them to interact effectively with AI technologies while maintaining critical judgment and ethical awareness. Similar conclusions were reached by Akhmadieva et al. (2026), who examined the relationship between AI literacy and attitudes toward artificial intelligence. Their findings indicated that students with higher levels of AI literacy generally reported more positive, balanced, and informed attitudes toward AI technologies. These students were better able to recognize both the opportunities and limitations associated with artificial intelligence systems and demonstrated greater confidence when making decisions regarding AI use (Akhmadieva et al., 2026). The emergence of generative AI tools such as ChatGPT, Gemini, and Copilot has made AI literacy even more essential (Ng et al., 2025; Giannakos et al., 2025). University students increasingly rely on these technologies to support academic activities including information searching, content generation, summarization, problem-solving, and writing assistance.

However, without appropriate AI literacy skills, students may struggle to evaluate the quality and reliability of AI-generated information, increasing their

vulnerability to misinformation, inaccurate outputs, and AI hallucinations (Hornberger et al., 2025; Center for Democracy & Technology, 2024). AI literacy therefore serves as an important foundation for responsible AI use by enabling students to verify information using textbooks, peer-reviewed research, and other reliable academic sources (Wang et al., 2024).

Furthermore, students should understand ethical issues related to privacy, bias, transparency, accountability, and academic integrity when interacting with AI systems (UNESCO, 2023). Many scholars now argue that AI literacy should become an integral component of higher education curricula rather than being treated as an optional skill (Aldossary et al., 2024). Universities are increasingly expected to prepare graduates who can effectively utilize AI technologies while maintaining critical thinking, ethical awareness, and informed decision-making abilities (Hornberger et al., 2025). Such preparation is essential not only for academic success but also for future professional participation in technology-rich environments where AI systems play an increasingly important role.

Overall, the literature indicates that AI literacy is becoming an essential competency for university students in the twenty-first century (Wang et al., 2024; Aldossary et al., 2024). AI literacy supports critical evaluation of information, responsible technology use, ethical awareness, and informed decision-making within AI-supported learning environments (Černý, 2024).

As artificial intelligence continues to expand across education, employment, and society, the development of AI literacy will remain a key priority for higher education institutions seeking to prepare students for responsible and effective participation in an increasingly AI-driven world (Hornberger et al., 2025; UNESCO, 2023).

2.9 Challenges, Ethical Issues, and AI Hallucinations

Despite the numerous educational benefits associated with artificial intelligence, researchers have identified a range of challenges that accompany its implementation in educational environments (UNESCO, 2023; Ng et al., 2025). The rapid adoption of AI

technologies has generated important discussions concerning academic integrity, ethics, privacy, transparency, algorithmic bias, and the reliability of AI-generated information (Alasadi & Baiz, 2023; Giannakos et al., 2025). Many scholars argue that addressing these challenges is essential to ensure that artificial intelligence is integrated into education in a responsible, ethical, and pedagogically effective manner (UNESCO, 2023). As AI systems become increasingly accessible to students and educators, understanding both their benefits and limitations has become a critical aspect of educational practice. One of the most frequently discussed concerns regarding artificial intelligence in education relates to academic integrity (Qadir, 2023).

Generative AI systems are capable of producing essays, reports, summaries, presentations, and other forms of academic content within a matter of seconds (Gupta et al., 2025). While this capability offers significant opportunities for learning support, it also creates challenges related to plagiarism, unauthorized assistance, and the authenticity of student work (UNESCO, 2023). Researchers have expressed concern that some students may submit AI-generated content without fully understanding the information presented or engaging meaningfully with the learning process (Qadir, 2023).

Consequently, educational institutions face increasing pressure to adapt assessment methods in ways that emphasize critical thinking, reflection, problem-solving, and the application of knowledge rather than simple reproduction of information (Giannakos et al., 2025). Privacy and data protection represent another major challenge associated with AI implementation in education (UNESCO, 2023). Many artificial intelligence systems collect, process, and analyze substantial amounts of user data during interactions (Alasadi & Baiz, 2023). Students may not always understand how their personal information is stored, used, or shared by AI platforms, creating concerns regarding informed consent and data security (UNESCO, 2023).

Researchers therefore emphasize the importance of transparent data management policies and responsible handling of user information to ensure that educational technologies comply with ethical and legal standards (Ng et al., 2025).

Closely related to privacy concerns is the issue of algorithmic bias. Artificial intelligence systems learn from large datasets that may contain social, cultural, or historical biases, which can sometimes be reflected in AI-generated outputs (UNESCO, 2023; Alasadi & Baiz, 2023). As a result, researchers argue that fairness, transparency, accountability, and inclusivity should remain central principles in the development and implementation of educational AI systems (UNESCO, 2023).

Another significant concern involves excessive reliance on artificial intelligence technologies (Qadir, 2023). Researchers warn that excessive dependence on AI may weaken critical thinking, problem-solving abilities, and independent learning skills if students rely on AI-generated answers rather than actively engaging with educational content (Giannakos et al., 2025).

For this reason, educators are encouraged to promote balanced and responsible AI use by ensuring that artificial intelligence functions as a learning support tool rather than a substitute for independent inquiry and intellectual effort (UNESCO, 2023). One of the most significant challenges associated with generative artificial intelligence is the phenomenon commonly referred to as AI hallucination (Center for Democracy & Technology, 2024). AI hallucinations occur when an artificial intelligence system generates information that appears accurate, convincing, and authoritative but is in fact incorrect, misleading, or entirely fabricated (Center for Democracy & Technology, 2024). These outputs may include invented references, inaccurate explanations, fabricated statistics, nonexistent research findings, and misleading scientific information.

Researchers emphasize that hallucinations are not deliberate errors. Rather, they occur because generative AI systems are designed to predict likely language patterns based on training data rather than independently verify factual accuracy (Center for Democracy & Technology, 2024).

Consequently, AI-generated responses may appear highly credible even when they contain substantial inaccuracies. The issue of AI hallucinations is particularly relevant within educational settings because students often assume that well-written

responses are also factually correct (Center for Democracy & Technology, 2024). Such assumptions may lead learners to accept inaccurate information without appropriate verification, increasing the risk of misconceptions and misunderstandings (Agathokleous et al., 2023).

In science education, including biology education, the consequences may be especially significant because biological knowledge is cumulative and many advanced concepts depend upon accurate understanding of foundational principles (Usak, 2024). Incorrect explanations related to genetics, molecular biology, physiology, ecology, or other scientific topics may interfere with conceptual development and negatively affect academic learning outcomes (Agathokleous et al., 2023). Researchers therefore identify AI hallucinations as one of the most important educational risks associated with generative artificial intelligence (Center for Democracy & Technology, 2024).

Several scholars argue that the growing prevalence of AI hallucinations highlights the importance of information verification and critical evaluation skills (Center for Democracy & Technology, 2024). Students should be encouraged to compare AI-generated information with textbooks, peer-reviewed journal articles, and other reliable academic sources before accepting it as accurate (Hornberger et al., 2025). Verification skills are increasingly viewed as a fundamental component of academic literacy in the era of artificial intelligence because they enable students to distinguish reliable information from potentially misleading content (Wang et al., 2024).

Researchers further emphasize that merely identifying AI-generated information is insufficient. Students must also learn how to evaluate evidence, assess source credibility, recognize unsupported claims, and critically analyze information regardless of its source (Wang et al., 2024). Such competencies help learners become active and informed participants in the learning process rather than passive consumers of information (Černý, 2024).

These challenges have contributed to the growing importance of responsible AI use in higher education (UNESCO, 2023). Responsible AI use involves understanding

both the opportunities and limitations associated with artificial intelligence technologies and applying them in ways that support meaningful learning while minimizing potential risks (Hornberger et al., 2025). Students should recognize that AI systems are educational tools designed to support learning rather than authoritative sources of knowledge that should be accepted uncritically (Center for Democracy & Technology, 2024). Educators likewise play an essential role in guiding students toward ethical, informed, and reflective use of artificial intelligence technologies (Ng et al., 2025). In response to these emerging challenges, universities around the world are increasingly developing policies and guidelines addressing academic integrity, transparency, privacy, ethical conduct, and responsible AI implementation (UNESCO, 2023).

Overall, the literature suggests that artificial intelligence offers substantial opportunities to enhance teaching and learning while simultaneously creating new educational challenges that require careful consideration (Giannakos et al., 2025). Issues related to academic integrity, privacy, algorithmic bias, overreliance on technology, and AI hallucinations represent important concerns that must be addressed by educators, institutions, and students alike (UNESCO, 2023; Center for Democracy & Technology, 2024).

Researchers consistently emphasize that the development of AI literacy, ethical awareness, critical evaluation skills, and responsible technology-use practices will be essential for maximizing the educational benefits of artificial intelligence while minimizing its potential risks within higher education environments (Hornberger et al., 2025; Wang et al., 2024).

Despite the growing body of research on AI in education, empirical evidence regarding its effectiveness in specific disciplinary contexts remains limited. In particular, relatively few studies have examined the application of AI-supported learning in university-level biology education. As a result, the educational impact of AI-supported learning in biology education remains insufficiently explored.

2.10 Research Gap

The integration of artificial intelligence into education has become one of the fastest-growing areas of educational research during the past decade (Maphosa & Maphosa, 2023; Abdul Rahman, 2024). Recent bibliometric analyses demonstrate a substantial increase in AI-related publications within higher education, reflecting growing interest in the educational applications of artificial intelligence and its potential to transform teaching and learning processes (Ahsina et al., 2025; Xu & Thien, 2026).

Researchers have investigated a wide range of AI applications, including personalized learning, intelligent tutoring systems, adaptive learning environments, learning analytics, educational assessment, and generative artificial intelligence technologies (Zawacki-Richter et al., 2019; Crompton & Burke, 2023). The emergence of ChatGPT and other generative AI systems has further accelerated research activity by creating new opportunities for student support, content generation, and personalized learning experiences (Ng et al., 2025; Giannakos et al., 2025). A growing body of evidence suggests that artificial intelligence can positively influence educational outcomes.

Numerous studies have reported improvements in academic achievement, student engagement, motivation, self-directed learning, and skill development among learners using AI-supported educational technologies (Ajibike, 2025; Paredes-Ventura et al., 2025Researchers have also emphasized the ability of AI systems to support personalized learning and adaptive instruction by providing targeted feedback and learning experiences tailored to individual student needs (Usak, 2024; Xu & Ouyang, 2022).

Several review studies have concluded that AI technologies can enhance educational experiences and contribute to improved academic performance across various learning environments (Abdulmumin et al., 2026; Paredes-Ventura et al., 2025).

At the same time, scholars have identified important concerns related to academic integrity, ethical issues, privacy, algorithmic bias, and AI hallucinations, highlighting the need for responsible implementation of AI technologies within education (UNESCO, 2023; Center for Democracy & Technology, 2024). Despite the rapid growth of this field, several important gaps remain within the existing literature.

First, much of the current research focuses on higher education in general rather than discipline-specific educational contexts (Maphosa & Maphosa, 2023; Abdul Rahman, 2024). Many studies investigate the implementation of AI across multiple academic disciplines without considering the unique characteristics, learning challenges, and pedagogical requirements of individual subject areas (Xu & Ouyang, 2022).

Consequently, there is still limited empirical evidence regarding the specific impact of artificial intelligence within biology education (He & Krajcik, 2026; Abdulmumin et al., 2026). Although recent studies have begun to explore AI applications in biology learning, this area remains relatively underdeveloped when compared with research conducted in other educational disciplines (Duran & Dikmenli, 2025; He & Krajcik, 2026).

A second limitation concerns the outcomes examined in previous studies. Existing research frequently focuses on either academic achievement or student engagement as separate variables (Paredes-Ventura et al., 2025). Relatively few investigations examine both outcomes within a single conceptual framework despite the strong theoretical relationship between engagement and achievement (Abdulmumin et al., 2026; Ajibike, 2025). Since student engagement often influences learning performance and academic success, a more comprehensive understanding of AI-supported learning requires simultaneous examination of both constructs (Paredes-Ventura et al., 2025). Research addressing these variables together remains limited, particularly within biology education.

A third gap relates to the emphasis placed on technological capabilities rather than educational effectiveness. A considerable portion of the literature focuses on describing AI tools, system architectures, and technological innovations while providing limited empirical evidence regarding their actual impact on student learning and educational outcomes (Omarsaib et al., 2025; Xu & Ouyang, 2022). As artificial intelligence becomes increasingly integrated into educational practice, there is a growing need for studies that evaluate how these technologies influence student learning in authentic educational environments rather than under purely theoretical or technological conditions (Abdulmumin et al., 2026). Another important limitation concerns the emerging nature of research on ChatGPT and generative artificial intelligence within biology education.

Although recent studies have reported promising findings regarding the educational value of ChatGPT for learning genetics, supporting laboratory activities, and facilitating independent study, the available evidence remains limited in both scope and geographical representation (Baroud et al., 2025; Lap & Çakır, 2025). Most existing studies have been conducted within a relatively small number of educational settings and countries, making it difficult to generalize findings across diverse educational contexts (Baroud et al., 2025).

Researchers have therefore called for additional empirical investigations examining how students use ChatGPT and other generative AI tools in science education and how these technologies influence learning outcomes, engagement, and educational experiences (Lap & Çakır, 2025; Xu & Ouyang, 2022). The literature also reveals an important gap related to AI literacy.

Although researchers increasingly recognize AI literacy as a fundamental competency for university students, relatively few studies have explored how AI literacy influences educational outcomes, student decision-making, and responsible AI use within biology learning environments (Hornberger et al., 2025; Wang et al., 2024). Additional research is needed to understand how students evaluate AI-generated information, identify inaccuracies, verify content using reliable academic sources, and

manage risks associated with misinformation and AI hallucinations (Center for Democracy & Technology, 2024). Given the increasing use of generative AI technologies in education, this area represents an important direction for future investigation.

Finally, the geographical distribution of existing research remains uneven. Current evidence is concentrated primarily in developed countries, while studies conducted in developing countries and emerging educational contexts remain comparatively scarce (Omarsaib et al., 2025; Abdulmumin et al., 2026). This imbalance limits the generalizability of existing findings and highlights the need for research in underrepresented regions. Central Asian countries, including Kazakhstan, are particularly underrepresented within the current body of literature on artificial intelligence in education (Omarsaib et al., 2025). Consequently, relatively little is known about how AI-supported learning influences educational outcomes within these contexts.

The present study seeks to address several of these gaps by examining the impact of artificial intelligence on both academic achievement and student engagement in biology education. Unlike many previous investigations that focus on higher education broadly, this study specifically examines biology students and explores the educational implications of AI-supported learning within a discipline-specific context. The study simultaneously investigates academic achievement and student engagement, providing a more comprehensive understanding of educational outcomes associated with AI use.

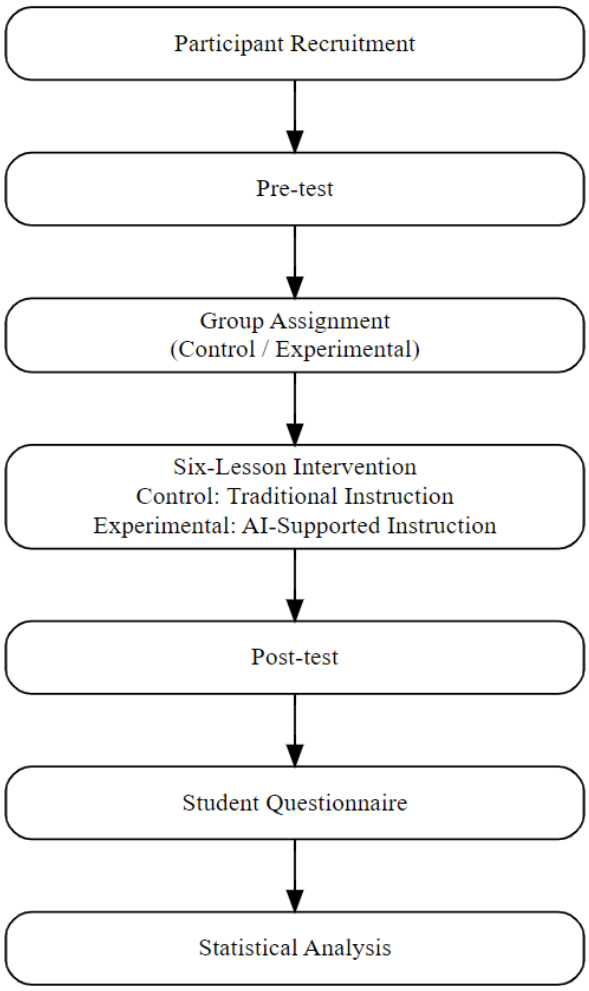
Furthermore, the research contributes empirical evidence from Kazakhstan, a context that has received limited attention in previous studies. By addressing these gaps, the study aims to expand the growing literature on artificial intelligence in biology education and provide valuable insights into the educational effectiveness of AI-supported learning in higher education.

METHODOLOGY

3.1 Research Design

This study employed a quasi-experimental mixed-methods research design using a pre-test/post-test non-equivalent group framework to investigate the effectiveness of AI-supported technologies in biology education among third-year university students studying nervous system anatomy. The research design was selected to generate both measurable academic performance data and deeper insight into student perceptions, motivation, independent learning, and instructional experiences. Since participants were assigned to naturally existing academic groups rather than randomly allocated, a non-equivalent group design was considered the most appropriate methodological approach for the educational setting. The overall procedure of the study is presented in Figure 3.1.

Figure 3.1. Research Procedure Used in the Study



The study integrated quantitative and qualitative methods to provide a comprehensive evaluation of instructional effectiveness. The quantitative component focused on academic achievement as measured through structured pre-test and post-test assessments, whereas the qualitative component examined students' experiences through post-intervention questionnaires containing both Likert-scale items and open-ended reflective questions. This mixed-methods approach allowed the study not only to evaluate the impact of AI-supported instruction on academic outcomes but also to explore students' perceptions of its educational value, benefits, challenges, and practical applications within biology learning.

3.2 Participants

The study was conducted among 52 third-year SDU University students who participated in the study. Participants were divided equally into two groups: a control group consisting of 26 students who received traditional instruction and an experimental group consisting of 26 students who engaged in AI-supported learning. Group size and score distributions were based on the full uploaded pre-test and post-test datasets. Third-year students were intentionally selected because nervous system anatomy represents a cognitively demanding stage in biology education. At this academic level, students are expected to integrate foundational biological knowledge with advanced anatomical terminology, structural-functional relationships, and systems-level conceptual understanding. Nervous system anatomy requires substantial visualization, conceptual hierarchy, and analytical integration, making it particularly appropriate for evaluating whether AI-supported technologies can function as meaningful pedagogical scaffolds.

3.3 Instructional Intervention

Both groups studied the same nervous system anatomy curriculum, including central nervous system structures, peripheral nervous system organization, neural pathways, reflex arcs, cranial nerves, and related functional biological concepts. Maintaining identical curriculum content across groups was essential to ensure that

instructional differences reflected pedagogical format rather than content variation. The instructional intervention was implemented across six structured lessons delivered in both online and face-to-face formats, creating a blended learning environment representative of contemporary higher education practice. Each lesson focused on a specific aspect of nervous system anatomy, including the structural organization of the nervous system, neural signaling and synaptic transmission, brain and spinal cord functions, peripheral and autonomic nervous system regulation, neurological case analysis, and final knowledge consolidation. This sequence was designed to support the gradual development of anatomical understanding while promoting integration between structure and function.

Instruction was not implemented as a fully student-centered or self-directed learning model. Rather, both groups followed a structured instructional sequence consisting of instructor explanations, guided discussion, diagram interpretation, concept mapping, problem-solving activities, worksheet completion, and case-based learning tasks. The instructor maintained an active facilitative role throughout the intervention by introducing key concepts, clarifying learning objectives, monitoring student progress, and providing academic feedback when necessary.

The control group learned through traditional instructional methods, including teacher explanations, handwritten notes, paper-based diagrams, worksheets, conventional case studies, and standard assessment practices. Students primarily relied on instructor-led explanation and traditional academic scaffolding. The experimental group completed equivalent instructional tasks using AI-supported technologies. These students used AI-generated explanations, prompt-based clarification, AI-assisted diagram generation, adaptive review support, digital summaries, interactive quizzes, and personalized conceptual reinforcement. AI tools were implemented as supplementary educational supports designed to enhance conceptual clarity, visualization, and learner autonomy rather than replace instructor guidance.

Across all six lessons, both groups completed equivalent educational activities, including diagram labeling, anatomical schema construction, neural pathway tracing, reflex arc interpretation, concept explanation, worksheets, case studies, and assessment tasks. Maintaining equivalent learning objectives, academic requirements, and instructional content supported internal validity and ensured that observed differences were associated with instructional format rather than curriculum content or task complexity.

Table 3.1 Overview of the Six-Lesson Instructional Intervention in Nervous System Anatomy

Lesson	Topic	Main Learning Activities
1	Organization of the Nervous System	Diagram interpretation, concept mapping
2	Neural Signaling and Synaptic Transmission	Explanation tasks, neural communication analysis
3	Brain and Spinal Cord Functions	Anatomical schema construction, pathway tracing
4	Peripheral and Autonomic Nervous Systems	Comparative analysis, applied exercises
5	Neurological Case Studies	Problem-solving, case-based discussion
6	Consolidation and Review	Knowledge synthesis, post-test preparation

3.4 Data Collection Instruments

Both the pre-test and post-test were designed to assess students' knowledge and understanding of nervous system anatomy and physiology. The assessments consisted of 40 items and included a combination of single-answer multiple-choice questions, multiple-response questions, diagram-identification tasks, and open-ended conceptual questions. Test items covered major topics including the organization of the nervous

system, neuroglial cells, embryological development of the brain, sensory pathways, cranial nerves, autonomic nervous system function, sensory physiology, neural signaling, and neurological disorders.

In addition to factual knowledge, the assessments evaluated students' ability to interpret anatomical diagrams, analyze physiological processes, apply biological concepts to clinical scenarios, and explain key principles of nervous system function. The same assessment framework was used for both pre-test and post-test administration to ensure comparability of learning outcomes and accurate measurement of academic progress throughout the intervention. Post-intervention questionnaires were additionally used to evaluate student perceptions of instructional effectiveness. The control group questionnaire primarily consisted of Likert-scale items focused on conceptual understanding, confidence, self-regulation, responsibility, and perceived instructional support under traditional learning conditions.

The experimental group questionnaire included both Likert-scale responses and extensive open-ended reflective questions. In addition to measuring understanding, confidence, motivation, and independent learning, the AI-group questionnaire specifically explored perceptions of AI efficiency, clarity of explanations, visualization support, personalization, ethical concerns, reliability of information, risk of superficial learning, and future recommendations for AI integration. This expanded qualitative dimension significantly strengthened the methodological depth of the study by allowing students to articulate both the strengths and limitations of AI-supported learning beyond numerical rating alone.

To assess the internal consistency reliability of the questionnaires, Cronbach's alpha coefficients were calculated. The control group questionnaire demonstrated acceptable reliability ($\alpha = 0.771$), while the experimental group questionnaire demonstrated excellent reliability ($\alpha = 0.941$). These results indicate satisfactory to very high internal consistency among questionnaire items and support the reliability of the instruments used in the study.

Table 3.2 Reliability Analysis of the Research Questionnaires

Questionnaire	Number of Items	Cronbach's Alpha	Interpretation
Control Group Questionnaire	12	0.771	Acceptable Reliability
Experimental Group Questionnaire	18	0.941	Excellent Reliability

The obtained reliability coefficients indicate that both questionnaires demonstrated satisfactory internal consistency and were suitable for subsequent statistical analyses.

3.5 Ethical Considerations

Participation in the study was voluntary, and all participant identities were anonymized during data analysis. Academic data and questionnaire responses were used exclusively for research purposes. No personally identifiable information was collected during the study. AI-supported tools were implemented under guided educational conditions to minimize passive overreliance, maintain academic integrity, and ensure that AI functioned as a pedagogical support mechanism rather than an unsupervised replacement for critical thinking or instructor oversight.

3.6 Data Analysis

All statistical analyses were conducted using R Studio (R Core Team, 2023). Prior to analysis, the dataset was screened for completeness, missing values, and potential data entry errors. Only students who completed both the pre-test and post-test assessments were included in the final analysis. Descriptive statistics, including means, standard deviations, minimum scores, and maximum scores, were calculated for all variables.

To evaluate the distribution of the data, the Shapiro–Wilk test of normality was performed for pre-test scores, post-test scores, and gain scores in both instructional

groups. Homogeneity of variance was assessed using Levene's test prior to conducting between-group comparisons. These procedures were performed to verify the assumptions required for parametric statistical analyses.

To determine whether the experimental and control groups differed at baseline, an independent-samples t-test was conducted using pre-test scores. This analysis was used to assess initial group equivalence prior to the instructional intervention.

To evaluate changes in academic performance within each instructional condition, paired-samples t-tests were conducted comparing pre-test and post-test scores for both the control and AI-supported groups. Gain scores were additionally calculated by subtracting pre-test scores from post-test scores in order to measure individual learning improvement throughout the intervention.

Between-group differences in academic performance were examined using independent-samples t-tests for pre-test scores, post-test scores, and gain scores. These analyses were conducted to determine whether students receiving AI-supported instruction demonstrated significantly different learning outcomes compared to students receiving traditional instruction.

To further investigate the effect of instructional condition while controlling for baseline differences in prior knowledge, an analysis of covariance (ANCOVA) was performed. In this analysis, post-test score served as the dependent variable, instructional group (AI-supported versus traditional instruction) served as the independent variable, and pre-test score was included as a covariate. ANCOVA was selected because it allows comparison of post-intervention achievement while statistically controlling for initial differences between groups, which is particularly appropriate for quasi-experimental educational research designs.

Questionnaire data were analyzed using descriptive statistics. Mean scores and standard deviations were calculated for each questionnaire item to examine students' perceptions of AI-supported learning, self-regulated learning, motivation, and AI literacy. Reliability of the questionnaire instruments was evaluated using Cronbach's alpha coefficients. Values above .70 were considered acceptable indicators of internal

consistency, whereas values above .90 were interpreted as excellent reliability. For all statistical analyses, the significance level was set at $p < .05$

RESULTS

This chapter presents the findings of the study investigating the impact of AI-supported learning on academic achievement and student perceptions in a university biology course. The results are organized according to the research questions and include quantitative analyses of academic performance as well as descriptive analyses of students' perceptions of AI-supported learning, engagement, independent learning, and AI literacy.

4.1 Academic Achievement

The first research question examined whether AI-supported learning influences students' academic achievement in a university biology course. To address this question, descriptive statistics, tests of normality, paired-samples t-tests, independent-samples t-tests, and ANCOVA were conducted using pre-test and post-test scores collected from the control and AI-supported groups.

4.1.1 Descriptive Statistics

Table 4.1. Descriptive Statistics for Pre-test, Post-test, and Gain Scores

Group	N	Pre-test M SD	Post-test M ± SD	Gain M ± SD
Control	26	28.35 ± 7.41	45.92 ± 7.69	17.58 ± 7.87
AI-Supported	26	32.62 ± 12.16	50.19 ± 8.07	17.58 ± 11.77

As shown in Table 4.1, both groups demonstrated substantial improvement following the instructional intervention. Prior to instruction, the AI-supported group obtained a higher mean pre-test score (M = 32.62, SD = 12.16) than the control group (M = 28.35, SD = 7.41). Following the intervention, the mean post-test score increased to 45.92 (SD = 7.69) in the control group and 50.19 (SD = 8.07) in the AI-supported group. The average gain score was identical for both groups (M = 17.58). However,

greater variability in gain scores was observed in the AI-supported group (SD = 11.77) compared with the control group (SD = 7.87), indicating that students may have benefited from AI-supported learning to different degrees.

Figure 4.1. Mean Pre-test and Post-test Scores of the Control and Experimental Groups

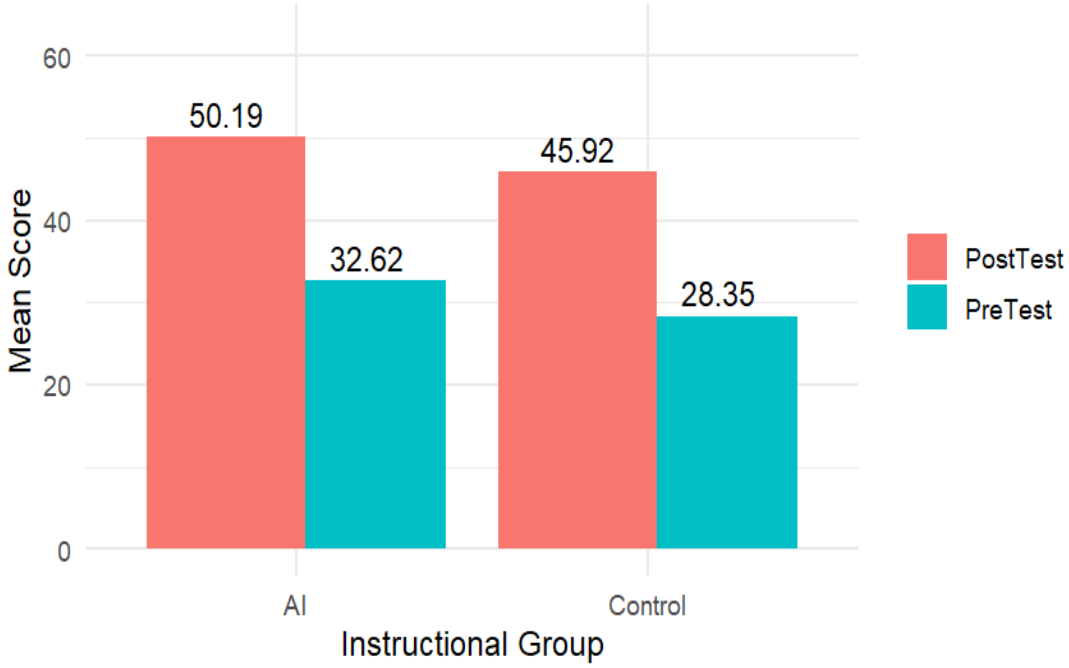


Figure 4.1 presents the mean pre-test and post-test scores for both instructional groups. The figure shows that students in both groups improved their performance following the intervention. While the AI-supported group achieved higher mean scores on both the pre-test and post-test assessments, both groups demonstrated substantial academic progress over the course of the study.

4.1.2 Analysis of Pre-test and Post-test Performance

Additional analysis of the pre-test and post-test reports provided further insight into students' learning progress. Prior to the intervention, the control group achieved an average score of 27.96 out of 65 points, while the AI-supported group achieved an average score of 31.96 points.

The pre-test results indicated that students experienced particular difficulty with higher-order anatomy questions requiring diagram interpretation, neurophysiological

reasoning, and clinical application. For example, only 4 out of 25 students correctly identified the Organ of Corti, and only 5 out of 24 students correctly identified the abducens nerve (CN VI) in a labeled brainstem diagram.

Following the instructional intervention, substantial improvements were observed in both groups. The average score increased to 45.96 points in the control group and 49.96 points in the AI-supported group.

The post-test reports demonstrated higher levels of correct responses across most content areas. In particular, students showed improved performance on questions related to nervous system organization, sensory pathways, autonomic nervous system regulation, and cranial nerve function. Many items achieved correct response rates above 80%, indicating stronger conceptual understanding after instruction.

4.1.3 Assumption Testing

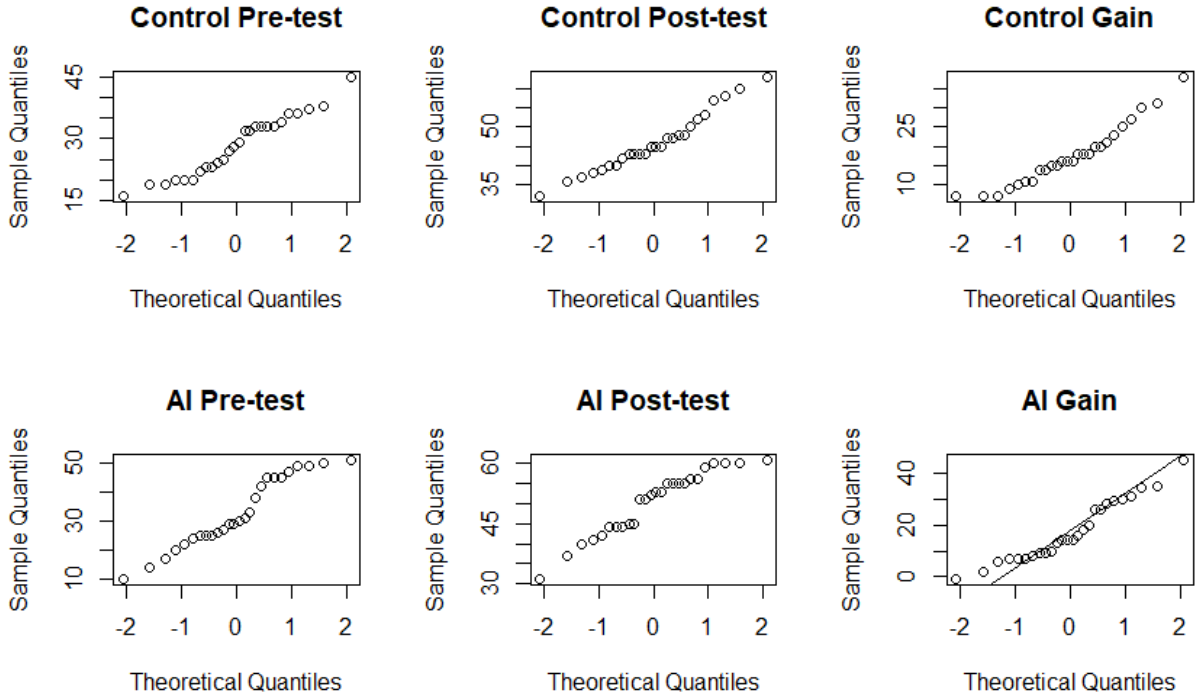
Table 4.2. Shapiro-Wilk Test of Normality

Variable	Group	W	p
Pre-test	Control	0.954	0.284
Post-test	Control	0.965	0.492
Gain	Control	0.943	0.157
Pre-test	AI-Supported	0.935	0.101
Post-test	AI-Supported	0.932	0.086
Gain	AI-Supported	0.945	0.174

Normality of Distributions. Prior to conducting inferential statistical analyses, the normality of score distributions was assessed using the Shapiro-Wilk test. The results are presented in Table 4.2.

As shown in Table 4.2, all p-values exceeded the significance level of .05, indicating that the distributions of pre-test, post-test, and gain scores did not significantly deviate from normality. For the control group, the distributions of pre-test scores (W = 0.954, p = .284), post-test scores (W = 0.965, p = .492), and gain scores (W = 0.943, p = .157) satisfied the assumption of normality. Similarly, for the AI-supported group, pre-test scores (W = 0.935, p = .101), post-test scores (W = 0.932, p = .086), and gain scores (W = 0.945, p = .174) were normally distributed.

Figure 4.2. Q–Q Plots for Pre-test, Post-test, and Gain Scores in the Control and AI-Supported Groups



Inspection of the Q–Q plots further supported the results of the Shapiro–Wilk tests, as the observed values closely followed the reference line with no substantial deviations. This suggests that the data were approximately normally distributed across both groups. These findings indicate that the assumption of normality was satisfied for all variables included in the study. Therefore, parametric statistical procedures were considered appropriate for subsequent analyses. The assumptions required for conducting t-tests were considered to be adequately met.

Homogeneity of Variance

Levene's test was conducted to examine the assumption of homogeneity of variance between the control and AI-supported groups. The results are presented in Table 4.3.

Table 4.3. Levene's Test of Homogeneity of Variance

Variable	F	p
Post-test Scores	0.277	0.601
Gain Scores	3.931	0.053

For post-test scores, Levene's test indicated no significant difference in variance between groups, $F(1,50) = 0.277$, $p = .601$. Similarly, although the test for gain scores approached statistical significance, $F(1,50) = 3.931$, $p = .053$, the p-value remained above the .05 threshold. Consequently, the assumption of homogeneity of variance was considered acceptable for both variables. The results support the use of independent-samples t-tests and ANCOVA for evaluating differences between instructional conditions.

4.1.4 Within-Group Changes in Academic Achievement

To evaluate whether students demonstrated significant improvement following the instructional intervention, paired-samples t-tests were conducted separately for the control and AI-supported groups. The results are presented in Table 4.4.

Table 4.4. Paired-Samples t-Test Results

Group	Mean Difference	t	df	p	95% CI
Control	- 17.58	-11.39	25	< .001	[-20.76, -14.40]
AI-Supported	- 17.58	-7.62	25	< .001	[-22.33, -12.82]

The results revealed statistically significant improvements in academic achievement for both instructional conditions. For the control group, post-test scores were significantly higher than pre-test scores, $t(25) = -11.39$, $p < .001$. The mean difference between pre-test and post-test scores was -17.58 points, with a 95% confidence interval ranging from -20.76 to -14.40. Similarly, students in the AI-supported group demonstrated a significant increase in achievement following the intervention, $t(25) = -7.62$, $p < .001$. The mean difference was also -17.58 points, and the 95% confidence interval ranged from -22.33 to -12.82. These findings indicate that students in both instructional conditions achieved substantially higher post-test scores compared to their pre-test performance. The results suggest that both traditional instruction and AI-supported learning contributed positively to students' understanding of nervous system anatomy.

4.1.5 Between-Group Comparisons

To determine whether AI-supported learning resulted in different levels of academic achievement compared to traditional instruction, independent-samples t-tests were conducted for pre-test scores, post-test scores, and gain scores. The results are presented in Table 4.5.

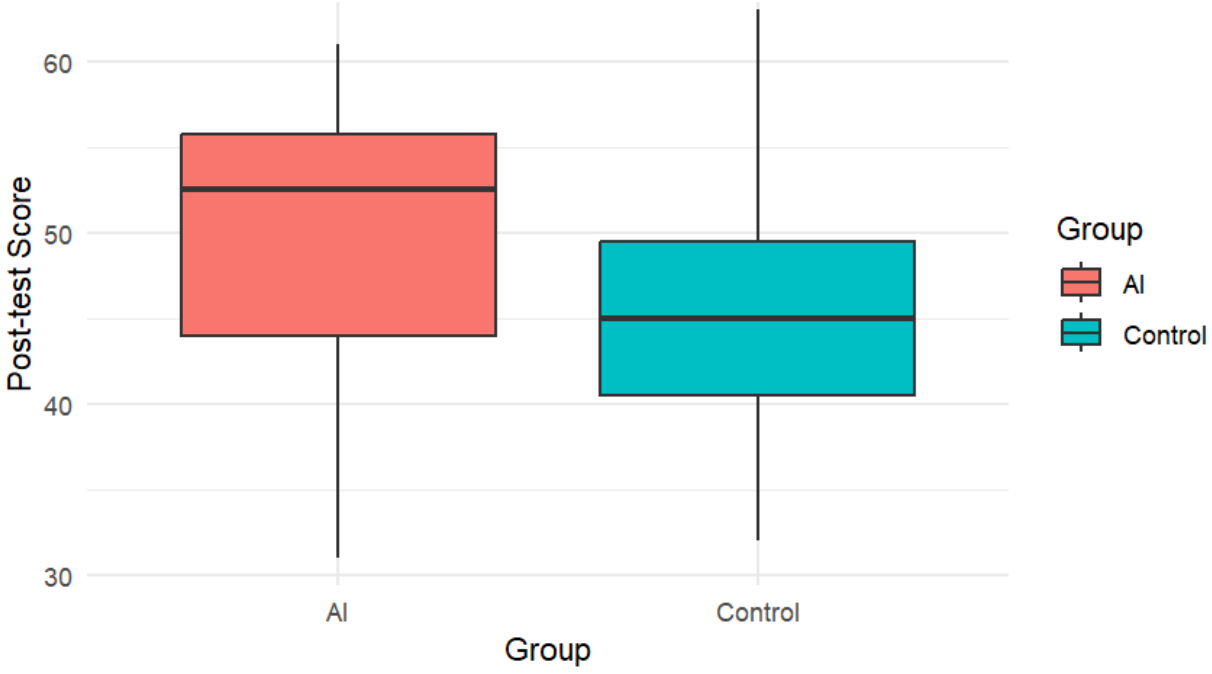
Table 4.5. Independent-Samples t-Test Results

Variable	t	df	p	95% CI
Pre-test Scores	1.53	41.34	0.134	[-1.37, 9.91]
Post-test Scores	1.95	50	0 .057	[-0.12, 8.66]
Gain Scores	0.00	50	1.000	[-5.58, 5.58]

The comparison of pre-test scores revealed no statistically significant difference between groups prior to the intervention, $t(41.34) = 1.53$, $p = .134$. Although the AI-supported group obtained a slightly higher mean pre-test score (M = 32.62) than the control group (M = 28.35), this difference was not statistically significant. Therefore,

the two groups were considered broadly comparable with respect to baseline knowledge of nervous system anatomy. Following the instructional intervention, students in the AI-supported group achieved a higher mean post-test score (M = 50.19) than students in the control group (M = 45.92). However, the difference did not reach statistical significance, $t(50) = 1.95$, $p = .057$. Although the result approached the conventional significance threshold, it does not provide sufficient evidence to conclude that AI-supported learning produced significantly higher post-test achievement than traditional instruction. Similarly, no statistically significant difference was observed in gain scores between groups, $t(50) = 0.00$, $p = 1.000$. Both groups demonstrated identical average learning gains of 17.58 points, indicating comparable levels of improvement throughout the intervention.

Figure 4.3. Distribution of Post-test Scores in the Control and AI-Supported Groups



Visual inspection (Figure 4.3) of the boxplot indicates that the AI-supported group achieved a higher median post-test score than the control group. However, substantial overlap between the distributions is evident, suggesting that students in both instructional conditions achieved broadly comparable levels of academic performance. This observation is consistent with the independent-samples t-test results, which indicated that the difference between groups approached but did not reach statistical

significance. Overall, the independent-samples t-test results suggest that both instructional approaches were effective in supporting student learning, although no statistically significant differences were identified between instructional conditions.

4.1.6 ANCOVA Results

To further investigate the effect of instructional condition while controlling for differences in prior knowledge, an analysis of covariance (ANCOVA) was conducted. Post-test score served as the dependent variable, instructional group was entered as the fixed factor, and pre-test score was included as a covariate.

Table 4.6. ANCOVA Results for Post-test Scores

Source	SS	df	F	p
Pre-test	494.20	1	9.27	0.004
Group	107.10	1	2.01	0.163
Residuals	2613.70	49	—	—

The ANCOVA results indicated that pre-test performance significantly predicted post-test achievement, $F(1,49) = 9.27$, $p = .004$. This finding suggests that students' initial level of knowledge contributed substantially to their final academic performance. In contrast, the effect of instructional group was not statistically significant after controlling for pre-test differences, $F(1,49) = 2.01$, $p = .163$.

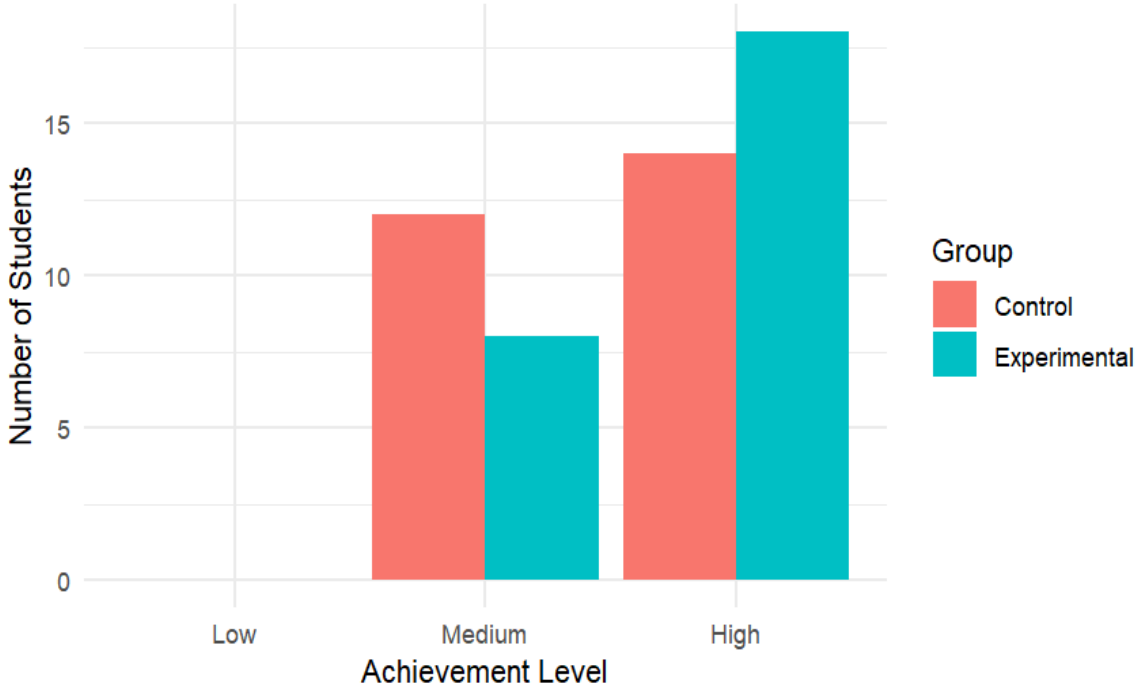
Although the AI-supported group achieved a higher mean post-test score than the control group, the observed difference was not sufficient to reach statistical significance when baseline achievement was taken into account. These findings indicate that prior knowledge was a stronger predictor of post-test performance than instructional condition. Consequently, the higher post-test scores observed in the AI-supported group appear to be partially explained by differences in students' initial levels of understanding rather than by the instructional intervention alone. Overall, the ANCOVA results support the conclusion that both instructional approaches were

effective in improving students' understanding of nervous system anatomy. However, no statistically significant advantage of AI-supported learning over traditional instruction was identified after controlling for baseline knowledge.

4.1.7 Achievement Level Distribution

To provide an additional perspective on student performance following the instructional intervention, post-test scores were categorized into achievement levels and compared across instructional groups.

Figure 4.4. Distribution of Achievement Levels After the Intervention



As shown in Figure 4.4, no students in either group remained within the low-achievement category following the intervention. Most students were classified within the medium and high achievement levels. In the control group, 12 students were classified as medium achievers and 14 students as high achievers. In the AI-supported group, 8 students were classified as medium achievers and 18 students as high achievers. The distribution suggests that a greater proportion of students in the AI-supported group achieved high levels of academic performance compared to students in the control group. Although inferential statistical analyses did not reveal significant differences between groups, the achievement-level distribution indicates a positive

tendency toward higher performance among students who participated in AI-supported learning. Overall, the results demonstrate that both instructional approaches were effective in promoting student achievement, with the AI-supported group showing a slightly greater concentration of students within the highest achievement category.

4.2 Student Perceptions of AI-Supported Learning

The second and third research questions examined students' perceptions of AI-supported learning and the extent to which AI contributed to engagement and independent learning. To address these questions, descriptive statistics were calculated for questionnaire responses collected from students in the AI-supported group following the instructional intervention.

To provide an overview of students' perceptions of AI-supported learning, mean scores were calculated for each questionnaire item using a five-point Likert scale. Higher mean values indicate more positive perceptions of the usefulness of AI in supporting learning, engagement, and independent study. The results are presented in Figure 4.5 and summarized in Table 4.7.

Figure 4.5. Mean Scores for Student Perceptions of AI-Supported Learning

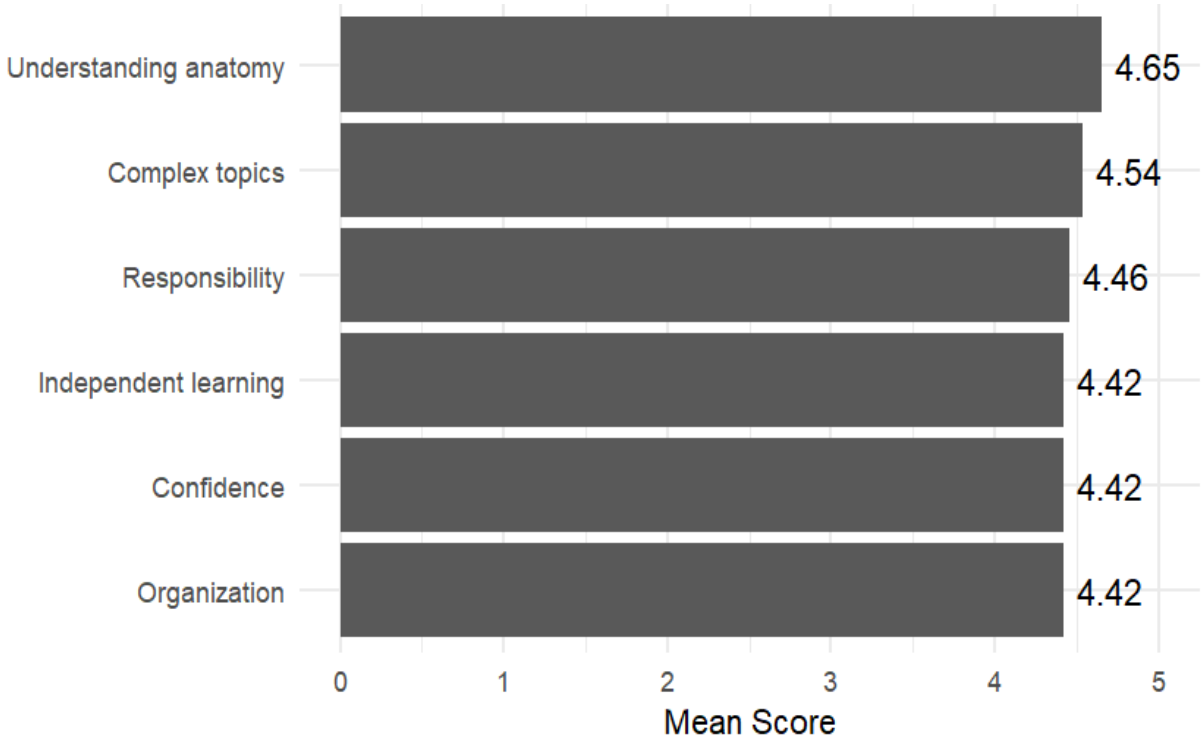


Table 4.7. Student Perceptions of AI-Supported Learning

Statement	Mean
AI helped me understand anatomy concepts more effectively	4.65
AI helped me understand complex biology topics	4.54
AI improved my confidence in learning biology	4.42
AI helped me organize my learning process	4.42
AI helped me identify gaps in my knowledge	4.38
AI encouraged greater responsibility for learning	4.46
AI explanations were clear and understandable	4.27
AI helped me review difficult concepts	4.31
AI supported independent learning	4.42
AI increased my motivation to learn biology	4.15
AI should be used in other university courses	4.19

As shown in Table 4.7 and Figure 4.5, students reported highly positive perceptions of AI-supported learning. All questionnaire items received mean scores above 4.0 on a five-point scale, indicating generally favorable attitudes toward the use of AI in biology education. The highest-rated statement was “AI helped me understand anatomy concepts more effectively” (M = 4.65), followed by “AI helped me understand complex biology topics” (M = 4.54). These findings suggest that students perceived AI as particularly valuable for learning conceptually challenging content within the nervous system anatomy unit. Students also reported that AI encouraged greater responsibility for learning (M = 4.46), supported independent learning (M = 4.42),

improved confidence in learning biology (M = 4.42), and helped organize the learning process (M = 4.42). Additionally, students indicated that AI helped them identify gaps in their knowledge (M = 4.38) and review difficult concepts (M = 4.31).

Although slightly lower than other items, the statement "AI increased my motivation to learn biology" received a positive mean score (M = 4.15), suggesting that students generally perceived AI as contributing positively to learning engagement. Participants also expressed support for the wider use of AI technologies in higher education, as reflected by the statement "AI should be used in other university courses" (M = 4.19). Overall, the questionnaire findings indicate that students viewed AI-supported learning as an effective educational tool that enhanced conceptual understanding, promoted independent learning, and contributed positively to their overall learning experience.

4.3 AI Literacy, Benefits, and Challenges of AI-Supported Learning

The fourth and fifth research questions examined students' perceptions of AI literacy as well as their evaluation of the benefits and challenges associated with AI-supported learning. To address these questions, students were asked to evaluate several statements related to the accuracy, reliability, and responsible use of AI technologies in educational settings.

Figure 4.6. Mean Scores for AI Literacy and Perceived Challenges

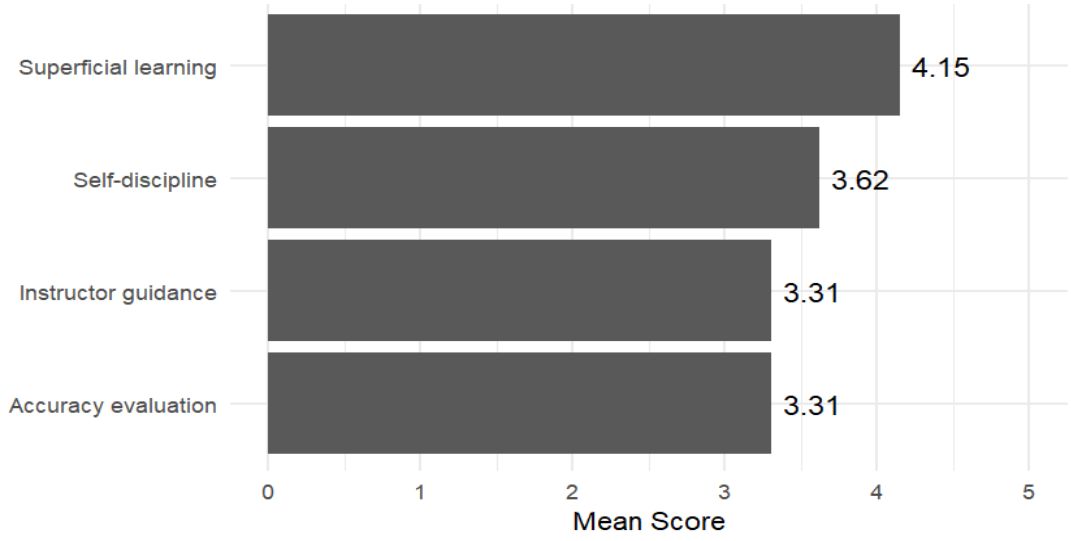


Table 4.8. AI Literacy and Challenges of AI-Supported Learning

Statement	Mean
It can be difficult to evaluate the accuracy of AI-generated information	3.31
I need instructor guidance when using AI tools for learning	3.31
Excessive reliance on AI may reduce independent thinking	4.15
Students should verify information generated by AI	4.23
AI-generated responses may sometimes contain errors	4.08

The findings indicate that students were generally aware of both the benefits and limitations of AI-supported learning. The highest level of agreement was observed for the statement "Students should verify information generated by AI" (M = 4.23), indicating strong recognition of the importance of critically evaluating AI-generated content. Students also agreed that excessive reliance on AI may reduce independent thinking (M = 4.15) and acknowledged that AI-generated responses may occasionally contain errors (M = 4.08). These findings suggest that participants understood that AI technologies are not infallible and require careful use within educational contexts. Moderate levels of agreement were observed for the statements "It can be difficult to evaluate the accuracy of AI-generated information" (M = 3.31) and "I need instructor guidance when using AI tools for learning" (M = 3.31).

Although students generally viewed AI positively, these results indicate that they continued to value teacher support and recognized the challenges associated with evaluating AI-generated information. Taken together, the findings suggest that students approached AI-supported learning with a balanced perspective. While they appreciated the educational benefits of AI, they also demonstrated awareness of potential limitations, including inaccuracies, overreliance, and the need for information verification. These findings indicate the development of emerging AI literacy skills and responsible attitudes toward the use of artificial intelligence in higher education.

4.4 Summary of Findings

The purpose of this study was to investigate the impact of AI-supported learning on academic achievement and student perceptions in a university biology course focusing on nervous system anatomy. The findings presented in this chapter addressed the five research questions guiding the study. With respect to academic achievement, both the control and AI-supported groups demonstrated substantial improvement following the six-week instructional intervention. Paired-samples t-tests revealed statistically significant increases in post-test performance for both groups. The control group improved from a mean pre-test score of 28.35 to a mean post-test score of 45.92, whereas the AI-supported group improved from 32.62 to 50.19. These findings indicate that meaningful learning occurred under both instructional conditions.

Between-group analyses showed that the AI-supported group achieved a higher average post-test score than the control group. However, independent-samples t-tests indicated that the difference did not reach statistical significance. Similarly, ANCOVA results demonstrated that instructional condition was not a significant predictor of post-test performance after controlling for baseline knowledge. Instead, pre-test achievement emerged as the strongest predictor of academic outcomes. The questionnaire findings revealed highly positive student perceptions of AI-supported learning. Students reported that AI helped them understand anatomy concepts more effectively, facilitated understanding of complex biology topics, improved confidence, and supported independent learning. High levels of agreement were also observed for statements related to learning organization, responsibility for learning, and identification of knowledge gaps.

The results further suggest that AI-supported learning contributed positively to student engagement and independent learning. Students reported increased motivation, improved ability to review difficult concepts, and greater autonomy in managing their learning activities. These findings indicate that AI technologies may support active participation in the learning process and encourage independent study behaviors.

In relation to AI literacy and responsible AI use, students demonstrated awareness of both the advantages and limitations of AI technologies. Participants acknowledged that AI-generated information should be verified, recognized that AI responses may contain inaccuracies, and expressed concern regarding excessive reliance on AI. Students also indicated that instructor guidance remains important when using AI-supported learning tools. Overall, the findings suggest that AI-supported learning represents a valuable educational supplement within university biology education. Although statistically significant differences in achievement between instructional conditions were not identified, students reported numerous educational benefits associated with AI use, including improved conceptual understanding, enhanced engagement, greater independence, and increased awareness of responsible AI practices.

DISCUSSION

5.1 Overview of Findings

The present study investigated the impact of AI-supported learning on academic achievement in a university biology course focusing on nervous system anatomy. In addition, the study examined students' perceptions of AI-supported learning, its contribution to engagement and independent learning, as well as students' views regarding AI literacy, benefits, and challenges associated with the use of artificial intelligence in higher education.

The findings yielded several important observations. First, both traditional instruction and AI-supported learning resulted in significant improvements in academic achievement. Second, although students in the AI-supported group achieved higher post-test scores than students in the control group, the difference between groups was not statistically significant after controlling for pre-test performance. Third, students reported highly positive perceptions of AI-supported learning and indicated that AI contributed positively to understanding complex biological concepts, independent learning, and learning engagement. Finally, students demonstrated awareness of both the educational benefits and limitations of AI technologies, indicating a relatively high level of AI literacy.

5.2 AI-Supported Learning and Academic Achievement

The first research question examined whether AI-supported learning influences students' academic achievement in a university biology course. The results demonstrated that both instructional approaches were effective in improving students' knowledge of nervous system anatomy.

Descriptive statistics revealed substantial improvement in both groups. The control group improved from a mean pre-test score of 28.35 (SD = 7.41) to a mean post-test score of 45.92 (SD = 7.69), whereas the AI-supported group improved from 32.62 (SD = 12.16) to 50.19 (SD = 8.07). Paired-samples t-tests confirmed that these improvements were statistically significant in both groups. For the control group, t(25)

= -11.39, $p < .001$, whereas for the AI-supported group, $t(25) = -7.62$, $p < .001$. These findings indicate that meaningful learning occurred under both instructional conditions. The results suggest that structured instruction, regardless of instructional format, contributed positively to students' understanding of nervous system anatomy. Such findings are consistent with previous research reporting that both traditional and technology-enhanced instruction can improve academic achievement when supported by clear learning objectives and active engagement with course content. The independent-samples t-test showed no significant difference between groups at baseline, $t(41.34) = 1.53$, $p = .134$, indicating that the groups were broadly comparable before the intervention. Following instruction, the AI-supported group achieved a higher mean post-test score than the control group. However, this difference did not reach statistical significance, $t(50) = 1.95$, $p = .057$. Similarly, gain scores did not differ significantly between groups, $t(50) = 0.00$, $p = 1.000$.

To further examine instructional effects while controlling for prior knowledge, ANCOVA was conducted using post-test score as the dependent variable and pre-test score as a covariate. The results indicated that pre-test performance significantly predicted post-test achievement, $F(1,49) = 9.27$, $p = .004$. In contrast, instructional condition was not a significant predictor of post-test performance, $F(1,49) = 2.01$, $p = .163$. Unlike several previous studies that reported statistically significant improvements in academic achievement, the present study did not identify a significant between-group difference.

Nevertheless, students reported highly positive perceptions of AI-supported learning and indicated that AI supported engagement, independent learning, and understanding of complex biological concepts. These findings suggest that the primary benefits of AI-supported learning in the present study were related to the learning process rather than measurable differences in academic achievement. These findings partially support previous research suggesting that AI technologies can enhance learning outcomes through personalized learning, adaptive support, and immediate feedback (Almasri, 2024; Usak, 2024; Cotton, 2023). Although statistically significant

advantages were not identified, the higher mean post-test performance observed in the AI-supported group suggests that AI may provide additional educational support for some learners.

One possible explanation for the absence of significant between-group differences is the relatively short duration of the intervention. The study was conducted over six weeks and focused on a single biology topic. Previous studies have suggested that the educational benefits of innovative instructional approaches often become more evident after prolonged implementation.

Another explanation may be that both groups received high-quality instruction, identical learning objectives, and equivalent learning activities, thereby reducing the likelihood of large performance differences. The nature of nervous system anatomy itself may also be relevant. Nervous system anatomy is widely regarded as one of the most conceptually demanding areas of biology because students must integrate anatomical structures, physiological mechanisms, neural pathways, and functional relationships simultaneously.

According to Cognitive Load Theory (Sweller, 1988), learning may be hindered when students must process large amounts of interconnected information. AI-supported learning may reduce extraneous cognitive load by providing simplified explanations, additional examples, and immediate clarification of difficult concepts. The slightly higher post-test performance observed in the AI-supported group may therefore reflect the ability of AI tools to support conceptual processing in cognitively demanding learning environments.

5.3 Student Perceptions, Engagement, and Independent Learning

The second and third research questions explored students' perceptions of AI-supported learning and the extent to which AI contributed to engagement and independent learning. The questionnaire results revealed highly positive perceptions of AI-supported learning. All questionnaire items received mean scores above 4.0 on a five-point scale. The highest-rated item was AI support for understanding anatomy concepts (M = 4.65), followed by understanding complex biology topics (M = 4.54).

Students also reported that AI encouraged greater responsibility for learning (M = 4.46), supported independent learning (M = 4.42), and helped organize the learning process (M = 4.42). These findings are consistent with previous research indicating that AI technologies can improve conceptual understanding and provide personalized learning opportunities (Almasri, 2024). The ability to obtain explanations on demand, request alternative examples, and review difficult concepts may explain why students perceived AI as particularly useful when studying nervous system anatomy. The findings also suggest that AI-supported learning contributed positively to student engagement. Students reported increased motivation to learn biology (M = 4.15) and expressed support for implementing AI technologies in other university courses (M = 4.19). These findings align with previous studies reporting that AI-supported learning environments can increase learner engagement, curiosity, and participation in educational activities (Hu, 2024; Tlili et al., 2024).

The results further support theoretical perspectives on independent learning. According to Zimmerman (2002) and Pintrich (2004), successful learners actively monitor their understanding, identify knowledge gaps, and regulate their learning behavior. Students in the present study reported that AI helped them identify gaps in their knowledge (M = 4.38), review difficult concepts (M = 4.31), and organize their learning activities (M = 4.42). These findings suggest that AI-supported learning may facilitate important aspects of independent learning by providing learners with immediate access to educational support whenever needed. Importantly, students did not simply use AI as a source of answers.

Rather, the questionnaire findings suggest that AI functioned as a learning companion that supported understanding, revision, and knowledge organization. This observation supports contemporary educational perspectives emphasizing that AI is most effective when used as a supplement to active learning rather than as a substitute for student effort. These results indicate that AI-supported learning encouraged students to take a more active and autonomous role in their own learning process in biology education.

5.4 AI Literacy, Benefits, and Challenges of AI-Supported Learning

The fourth and fifth research questions examined students' perceptions of AI literacy as well as their evaluation of the benefits and limitations associated with AI-supported learning. The findings indicate that students generally possessed a balanced understanding of AI technologies. On the one hand, students recognized numerous educational benefits. AI was perceived as useful for understanding anatomy concepts, learning difficult topics, supporting independent learning, reviewing course materials, and increasing learning efficiency. These findings correspond with previous studies highlighting the educational potential of generative AI systems in higher education (Kasneci et al., 2023; Holmes et al., 2022). On the other hand, students also demonstrated awareness of the limitations of AI. The statement that students should verify AI-generated information received a high level of agreement (M = 4.23). Participants also agreed that AI-generated responses may sometimes contain errors (M = 4.08) and that excessive reliance on AI could reduce independent thinking (M = 4.15).

These findings are particularly important because recent literature has emphasized the growing importance of AI literacy in educational contexts. Researchers such as Kasneci et al. (2023) and Tlili et al. (2024) argue that students must learn not only how to use AI technologies but also how to evaluate their outputs critically. The present findings support this perspective by demonstrating that students were aware of the need to verify AI-generated information and recognized the possibility of inaccuracies. Interestingly, students also reported that instructor guidance remained important when using AI technologies (M = 3.31). This finding reinforces the conclusion that AI should not be viewed as a replacement for teachers. Instead, the most effective educational use of AI appears to occur when artificial intelligence functions as a supplementary resource within a structured learning environment guided by instructors.

Overall, the findings suggest that students approached AI-supported learning with a balanced perspective. While they recognized its benefits for learning and

independent study, they also demonstrated awareness of potential risks, limitations, and ethical considerations. Such attitudes are encouraging because they indicate the development of responsible AI use and critical evaluation skills that are increasingly important in contemporary higher education.

CONCLUSION

The purpose of this study was to investigate the impact of AI-supported learning on academic achievement in a university biology course and to examine students' perceptions of artificial intelligence in biology education. The study specifically focused on nervous system anatomy and explored the influence of AI-supported learning on academic performance, student engagement, independent learning, AI literacy, and students' perceptions of the benefits and limitations associated with AI technologies.

The findings demonstrated that both traditional instruction and AI-supported learning resulted in significant improvements in academic achievement. Students in the control group improved from a mean pre-test score of 28.35 to a mean post-test score of 45.92, whereas students in the AI-supported group improved from 32.62 to 50.19. Paired-samples t-tests confirmed statistically significant improvements in both groups.

However, independent-samples t-tests and ANCOVA indicated that the differences between instructional conditions were not statistically significant after controlling for baseline knowledge. These findings suggest that AI-supported learning can effectively support student learning, although its advantage over traditional instruction was not statistically confirmed within the context of the present study. The study also revealed highly positive student perceptions of AI-supported learning.

Students reported that AI helped them understand anatomy concepts more effectively, facilitated understanding of complex biological topics, supported independent learning, and improved organization of the learning process. These findings indicate that students perceived AI as a valuable supplementary educational tool capable of enhancing learning experiences in biology education.

Furthermore, the results suggest that AI-supported learning contributed positively to student engagement and independent learning. Students reported increased responsibility for learning, improved ability to identify gaps in knowledge, and greater autonomy during the learning process. These findings support the view that

AI technologies can facilitate learner-centered educational environments by providing immediate access to explanations, feedback, and learning support.

An important contribution of the study was the examination of AI literacy and students' awareness of the challenges associated with AI-supported learning. Participants recognized that AI-generated information may contain inaccuracies and emphasized the importance of verifying AI-generated responses. Students also expressed concerns regarding excessive reliance on AI and its potential influence on independent thinking. These findings demonstrate that students generally approached AI technologies critically and understood both their educational potential and limitations.

Overall, the findings suggest that AI-supported learning represents a promising complement to traditional biology instruction. While AI did not produce statistically significant improvements in achievement compared to traditional instruction, students perceived substantial benefits related to conceptual understanding, engagement, independent learning, and academic support. The results indicate that the educational value of artificial intelligence depends not only on the technology itself but also on how effectively it is integrated into teaching and learning practices.

As artificial intelligence continues to become increasingly accessible within higher education, educators should consider its use as a pedagogical support tool that complements instructor guidance and promotes active learning. Future research involving larger samples, longer intervention periods, and additional biology topics may provide further insight into the long-term educational impact of AI-supported learning in higher education.

LIMITATIONS

Several limitations should be considered when interpreting the findings of the present study.

First, the study was conducted with a relatively small sample consisting of 52 third-year university students from a single higher education institution. Although the sample size was sufficient for the statistical analyses performed, larger samples would increase statistical power and improve the generalizability of the findings.

Second, the intervention was limited to a six-week instructional period and focused exclusively on the topic of nervous system anatomy. Consequently, the results may not be fully representative of other biological disciplines such as genetics, physiology, molecular biology, or ecology. Longer interventions may reveal stronger effects of AI-supported learning on academic achievement and learner development.

Third, the study employed a quasi-experimental design using intact classroom groups rather than random assignment. Although pre-test comparisons and ANCOVA were used to control for baseline differences between groups, the possibility of unmeasured differences among participants cannot be completely excluded.

Fourth, student perceptions were measured through self-report questionnaires. While questionnaire data provide valuable insights into students' experiences, responses may be influenced by individual attitudes, interpretation of questionnaire items, or social desirability bias.

Finally, the study primarily examined short-term learning outcomes. Other important educational variables, including long-term knowledge retention, critical thinking skills, problem-solving abilities, and transfer of learning, were not directly measured and therefore remain areas for future investigation.

Recommendations for Future Research

Future research should investigate the impact of AI-supported learning using larger and more diverse student populations across multiple universities. Such studies would improve the generalizability of findings and provide a broader understanding of the educational potential of artificial intelligence in higher education.

Longitudinal studies are also needed to examine the long-term effects of AI-supported learning on knowledge retention, conceptual understanding, and academic achievement. Extended interventions may help determine whether the benefits of AI become more pronounced over time. Future studies should explore the implementation of AI-supported learning across different areas of biology, including genetics, physiology, ecology, biotechnology, and molecular biology. Comparing outcomes across multiple scientific disciplines may provide a more comprehensive understanding of where AI technologies are most effective.

Additional research should investigate factors that may influence the effectiveness of AI-supported learning, including digital literacy, AI literacy, prior academic achievement, learning strategies, prompting skills, and learner motivation. Such factors may help explain why some students benefit more from AI-supported learning than others. Future investigations should also examine the relationship between AI-supported learning and student engagement, independent learning, self-regulation, critical thinking, and responsible AI use. As artificial intelligence becomes increasingly integrated into educational environments, understanding how students interact with AI technologies will remain an important area of educational research.

Finally, future studies should continue to explore strategies for integrating AI into biology education while maintaining scientific accuracy, promoting critical evaluation of information, and preserving the important role of instructors in the learning process.

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APPENDICES

Appendix 1. Nervous system achievement test

The same assessment instrument was administered as both the pre-test and post-test for students in the control and AI-supported groups.

Instructions: Please answer all questions. The assessment includes multiple-choice questions, clinical reasoning questions, diagram-identification tasks, and open-ended questions.

Part I. Multiple-Choice Questions

1. Which structure is part of the central nervous system?

a) Dorsal root ganglion
b) Cranial nerve V
c) Brainstem
d) Spinal nerve root

2. Which glial cell forms myelin in the CNS?

a) Schwann cell
b) Oligodendrocyte
c) Microglia
d) Satellite cell

3. Which embryonic structure gives rise to the cerebrum?

a) Mesencephalon
b) Telencephalon
c) Metencephalon
d) Myelencephalon

4. Damage to the dorsal column–medial lemniscus pathway would impair:

a) Pain and temperature sensation
b) Fine touch and vibration sensation
c) Motor reflexes
d) Hearing

5. Rods in the retina are responsible for:

a) Color vision
b) Sharp central vision
c) Low-light vision
d) Accommodation

6. Salty taste transduction occurs primarily by:

a) H^+ influx
b) Na^+ influx
c) GPCR activation
d) Chloride channels

7. The organ of Corti contains:

a) Photoreceptors
b) Hair cells
c) Taste buds
d) Olfactory cilia

8. Sympathetic preganglionic neurons originate from:

a) Brainstem nuclei
b) Sacral spinal cord
c) Thoracolumbar spinal cord
d) Dorsal horn

9. Which neurotransmitter is released by most sympathetic postganglionic neurons?

a) Acetylcholine
b) Norepinephrine
c) Dopamine
d) Glutamate

10. Parasympathetic ganglia are usually located:

a) In the sympathetic chain
b) Far from target organs
c) Close to or within target organs
d) In the dorsal root ganglia

11. A lesion of CN III results in:

a) Loss of smell
b) Down-and-out eye with ptosis
c) Facial paralysis
d) Tongue deviation

12. Upper motor neuron damage typically causes:

a) Flaccid paralysis
b) Hyperreflexia
c) Fasciculations
d) Loss of ankle reflex only

13. A positive Romberg test indicates impairment of:

a) Vestibular reflexes
b) Motor strength
c) Proprioception
d) Vision

14. The baroreceptor reflex primarily controls:

a) Hearing
b) Pupil constriction
c) Blood pressure
d) Taste sensation

15. Which sensory receptor detects vibration?

a) Merkel disk
b) Pacinian corpuscle
c) Free nerve ending
d) Ruffini ending

16. Brown-Séquard syndrome is caused by:

a) Total transection of the spinal cord
b) Damage to one half of the spinal cord
c) Loss of only the dorsal columns
d) Loss of only the spinothalamic tract

17. A patient with left posterior cerebral artery (PCA) stroke most likely has:

a) Right visual field loss
b) Left leg paralysis
c) Aphasia
d) CN III palsy

18. Which cranial nerve controls lateral eye movement?

a) CN III
b) CN IV
c) CN VI
d) CN XII

19. Which fibers are characterized by long preganglionic neurons and short postganglionic neurons?

a) Sympathetic
b) Parasympathetic
c) Somatic
d) Enteric

20. Taste buds are found in all papillae EXCEPT:

a) Circumvallate
b) Fungiform
c) Foliate
d) Filiform

21. Which structure controls autonomic homeostasis?

a) Cerebellum
b) Hypothalamus
c) Basal nuclei
d) Hippocampus

Part II. Multiple-response questions

21. A sound wave enters the cochlea. Which sequence correctly describes the process?

a) The basilar membrane vibrates, displacing hair cells
b) The tympanic membrane vibrates, moving ossicles
c) Ion channels open in stereocilia, causing depolarization
d) The oval window receives mechanical energy from the stapes

22. A patient has impaired pain sensation but preserved vibration sensation below T8 on theright side. Which processes explain this pattern?

a) Dorsal column fibers remain intact
b) Spinothalamic fibers are damaged contralaterally
c) Pain fibers cross 1–2 segments above entry
d) Vibration fibers cross immediately in the spinal cord

23. Light hits the retina. What happens in the correct phototransduction cascade?

a) Cis-retinal → trans-retinal
b) Photoreceptor hyperpolarizes
c) Bipolar cell depolarizes
d) Ganglion cell fires action potentials

24. Which events occur during sympathetic activation?

a) Pupils constrict
b) Heart rate increases
c) Bronchi dilate
d) Gastrointestinal motility increases

25. A patient fails to perceive graphesthesia (cannot recognize traced numbers on the skin). Which statements are true?

a) The cortical sensory area may be damaged
b) Dorsal column pathways are intact
c) The spinothalamic tract is damaged
d) The thalamus may be involved

26. Which processes occur during the baroreceptor reflex when a person suddenly stands up?

a) Baroreceptor firing decreases
b) Sympathetic activity increases
c) Vasoconstriction occurs
d) Parasympathetic tone increases

27. Which cranial nerves carry taste information?

a) CN V
b) CN VII
c) CN IX
d) CN X

28. Upper motor neuron lesions typically produce which combination of signs?

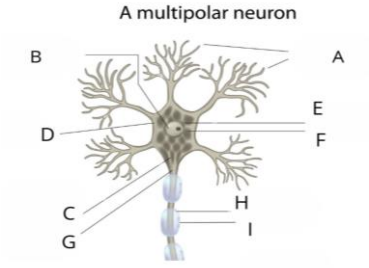
a) Spasticity
b) Hyperreflexia
c) Fasciculations
d) Babinski sign

29. In diabetes mellitus, loss of vibration and proprioception occurs because:

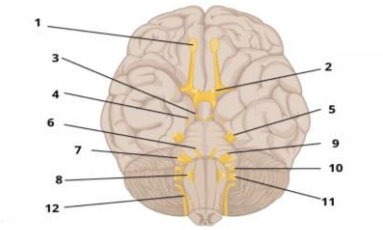
a) Small sensory fibers degenerate first
b) Large myelinated sensory fibers are damaged
c) Dorsal root ganglia may degenerate
d) Sympathetic ganglia are destroyed

Part III. Diagram Identification Tasks

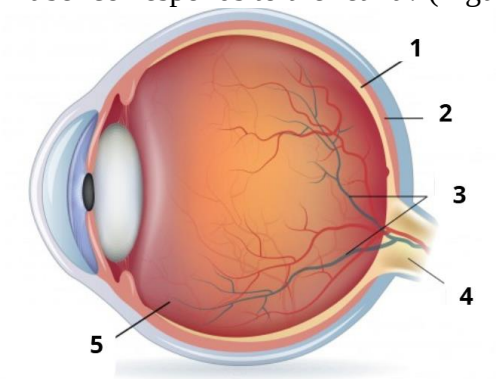
30. Diagram of a multipolar neuron labeled A–I. Which label corresponds to the axon hillock?(Figure C1)



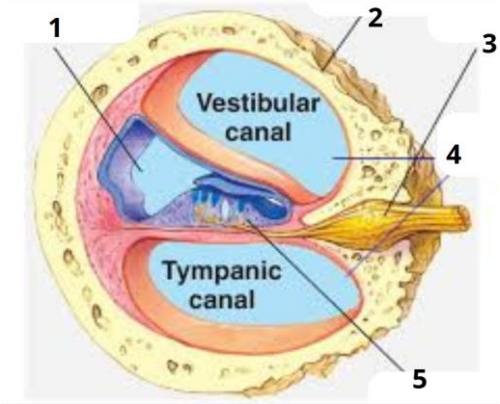
31. Brainstem with cranial nerves labeled 1–12. Which number points to CN VI (abducens)? (Figure C2)



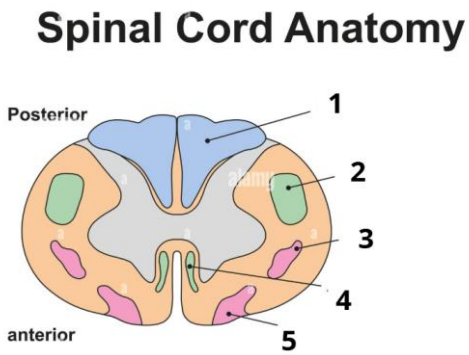
32. Which label corresponds to the retina? (Figure C3)



33. Which label corresponds to the Organ of Corti? (Figure C4)



34. Which label corresponds to the dorsal column? (Figure C5)



Part IV. Open-Ended Questions

36. What is the main function of the nervous system?
37. What is a neuron and why is it important?
38. Name two major divisions of the nervous system.
39. What role do hormones play in the body?
40. How does the endocrine system differ from the nervous system in signaling?

Appendix 2. Control group questionnaire

Instructions: Please indicate the extent to which you agree with each statement using the following scale:

1 = Strongly Disagree

2 = Disagree

3 = Neutral

4 = Agree

5 = Strongly Agree

Section A. Understanding of Nervous System Anatomy

1. The learning activities helped me better understand the anatomy of the nervous system.
2. I was able to understand complex topics (e.g., CNS, PNS, neural pathways, reflex arcs).
3. The learning format helped me connect theoretical knowledge with practical examples.
4. After the lessons, I felt confident about my knowledge of the covered topics.

Section B. Independent Learning Skills

5. I was able to organize my learning process effectively.
6. I regularly monitored my understanding of the material.
7. I could identify gaps in my knowledge and work on them independently.
8. The learning process encouraged me to take responsibility for my own learning.

Section C. Challenges and Critical Perception

9. I sometimes found it difficult to evaluate the accuracy of the information I received.
10. I needed additional guidance from the instructor during the learning process.
11. The learning format required more self-discipline than I am used to.
12. The use of digital tools can lead to superficial learning if not used properly.

Appendix 3. AI supported learning questionnaire

Instructions: Please indicate the extent to which you agree with each statement using the following scale:

1 = Strongly Disagree

2 = Disagree

3 = Neutral

4 = Agree

5 = Strongly Agree

Section A. Understanding of Nervous System Anatomy

1. The learning activities helped me better understand the anatomy of the nervous system.
2. I was able to understand complex topics (e.g., CNS, PNS, neural pathways, reflex arcs).
3. The learning format helped me connect theoretical knowledge with practical examples.
4. After the lessons, I felt confident about my knowledge of the covered topics.

Section B. Independent Learning Skills

5. I was able to organize my learning process effectively.
6. I regularly monitored my understanding of the material.
7. I could identify gaps in my knowledge and work on them independently.
8. The learning process encouraged me to take responsibility for my own learning.

Section C. AI-Supported Learning

9. The use of AI tools helped me learn more efficiently.
10. AI explanations were clear and easy to understand.
11. AI tools helped me review and reinforce complex topics in nervous system anatomy.
12. Using AI increased my motivation to study the subject.
13. AI supported my independent learning outside the classroom.
14. I would like AI tools to be used in other anatomy or biology courses.

Section D. Challenges and Critical Perception

15. I sometimes found it difficult to evaluate the accuracy of the information I received.
16. I needed additional guidance from the instructor during the learning process.
17. The learning format required more self-discipline than I am used to.
18. The use of digital tools can lead to superficial learning if not used properly.

Section E. Open-Ended Feedback Questions

19. What aspects of the learning process did you find most helpful during the study?
20. What difficulties did you experience while studying the anatomy of the nervous system?
21. What suggestions do you have for improving the use of AI in future anatomy or biology courses?
22. How could AI tools be better integrated into classroom teaching to support learning?
23. What features or functions would you like AI tools to have to better support your learning in the future?

Appendix 4. Sample Traditional Lesson Materials (Control Group)

LESSON 1. Nervous System Basics

1. Learning Objectives

By the end of this lesson, students will be able to:

1. Describe the major divisions of the nervous system (CNS and PNS).
2. Explain the roles of sensation, integration, and response.
3. Differentiate gray and white matter.
4. Identify basic neuron structures and types.
5. Describe major glial cell types and their functions.

2. Background Reading

Chapter 12 (Basic Structure and Function of the Nervous System)

https://openstax.org/books/anatomy-and-physiology-2e/pages/12-introduction

3. Background Text

The nervous system is the body's main communication network. It detects stimuli, processes information, and coordinates actions. Structurally it consists of the central nervous system (CNS)—the brain and spinal cord—and the peripheral nervous system (PNS), which includes all neural structures outside the CNS. The CNS integrates information and directs responses, while the PNS connects the CNS with organs, limbs, and sensory receptors. Nervous tissue contains gray matter, composed of neuronal cell bodies and dendrites, and white matter, made primarily of myelinated axons that transmit signals rapidly. The basic working units of the nervous system are neurons, specialized cells that conduct electrical impulses. A typical neuron contains dendrites, a soma, and an axon. Neurons vary in structure—unipolar, bipolar, and multipolar—and communicate through synapses. Glial cells support and protect neurons. In the CNS, astrocytes, oligodendrocytes, microglia, and ependymal cells maintain homeostasis and produce myelin. In the PNS, Schwann and satellite cells perform similar roles.

These components support the three essential functions of the nervous system:

- **Sensation**: detecting stimuli
  Integration: processing information
  Response: triggering motor or glandular activity

4. Illustrations

Students draw by hand:

Illustration 1: CNS & PNS diagram

Illustration 2: Neuron structure

Illustration 3: Gray vs white matter in spinal cord

Each drawing must include labels.

5. Tasks

Task 1. Draw and Explain

Draw the CNS and PNS and write:

- What is included in each division
- Their roles
- Difference between gray and white matter

Task 2. Create a Functional Table

Create in your notebook:

| Function | Definition | Structures | Example |

Fill manually using the textbook.

Task 3. Define Neuron Structures

Write textbook-based definitions of:

- Axon hillock
- Initial segment
- Node of Ranvier
- Synaptic end bulb

Task 4. Glial Cells Matching Exercise

Match cell types to functions:

Astrocyte – _____

Oligodendrocyte – _____

Microglia – _____

Ependymal cell – _____

Schwann cell – _____

Satellite cell – _____

Task 5. Written Reflection

Short paragraph (8–10 sentences):

"How does the nervous system coordinate sensation, integration, and response? Provide one real-life example."

Assessment

1. Three hand-drawn diagrams
2. Completed functional table
3. Written definitions
4. Glial matching answers
5. Reflection paragraph

Appendix 5. Sample AI-Supported Lesson Materials (Experimental Group)

LESSON 1. Nervous System Basics

1. Learning Objectives

By the end of this lesson, students will be able to:

1. Describe the major divisions of the nervous system (CNS and PNS).
2. Explain the roles of sensation, integration, and response.
3. Differentiate gray and white matter.
4. Identify basic neuron structures and types.
5. Describe major glial cell types and their functions.

2. Background Reading

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The nervous system is the body's main communication network. It detects stimuli, processes information, and coordinates actions. Structurally it consists of the central nervous system (CNS)—the brain and spinal cord—and the peripheral nervous system (PNS), which includes all neural structures outside the CNS. The CNS integrates information and directs responses, while the PNS connects the CNS with organs, limbs, and sensory receptors.Nervous tissue contains gray matter, composed of neuronal cell bodies and dendrites, and white matter, made primarily of myelinated axons that transmit signals rapidly. The basic working units of the nervous system are neurons, specialized cells that conduct electrical impulses. A typical neuron contains dendrites, a soma, and an axon. Neurons vary in structure—unipolar, bipolar, and multipolar—and communicate through synapses. Glial cells support and protect neurons. In the CNS, astrocytes, oligodendrocytes, microglia, and ependymal cells maintain homeostasis and produce myelin. In the PNS, Schwann and satellite cells perform similar roles. These components support the three essential functions of the nervous system:

- **Sensation**: detecting stimuli
- **Integration**: processing information
- **Response**: triggering motor or glandular activity

4. Illustrations

Illustration 1 "Divisions of the Nervous System"

AI prompt: "Create a clean labeled diagram that shows the central nervous system (brain + spinal cord) and the peripheral nervous system (nerves and ganglia). Use simple colors and clear labels."

Illustration 2 "Neuron Structure"

AI prompt: "Generate a minimalistic diagram of a neuron showing dendrites, soma, axon hillock, myelin sheath, nodes of Ranvier, and synaptic end bulbs."

Illustration 3 "Gray vs White Matter"

AI prompt: "Produce a simple cross-section diagram of the spinal cord highlighting gray matter in the center and white matter surrounding it."

5. Tasks & Activities

Task 1. Annotate a Diagram Using AI

1. Generate the diagram using one of the prompts above.
2. **Write your own explanation:**
   What is the CNS?What is the PNS?
   Why is gray matter different from white matter?
   AI may only help you visualize. Explanations must be hand-written.

Task 2. Create a Function Table

AI prompt: "Generate an empty table with columns: Sensation – Integration – Response. Leave all cells blank." Fill in definitions, structures, and an example (e.g., touching hot water).

Task 3. Simplify Neuron Structures

AI prompt: "Explain axon hillock, node of Ranvier, and synaptic end bulb in simple everyday language." Rewrite final definitions in academic biology style.

Task 4. Glial Cells Quiz

AI prompt: "Create 5 quiz questions (without answers) about the roles of astrocytes, oligodendrocytes, Schwann cells, microglia, and satellite cells." Provide correct answers based on the reading.

Task 5. Reflection

AI prompt: "Generate 3 reflection questions about how AI tools helped me learn in this lesson." Answer the 3 questions.

Assessment

1. Three generated diagrams + written interpretations
2. Completed function table
3. Neuron definitions
4. Glial cell quiz answers
5. Reflection answers

Scientific Supervisor Report

Student Names: Bizhanova Assel

The Theme: The role of AI-powered technology in enhancing biology education

The Content of Conclusion: This thesis investigates the pedagogical integration of Artificial Intelligence (AI) into university-level biology, specifically focusing on the instruction of nervous system anatomy—a cognitively demanding domain requiring high levels of visualization and conceptual integration. Theoretically, the work is grounded in constructivism, social constructivism (Vygotsky's Zone of Proximal Development), and self-directed learning theory, positioning AI as a supplementary "pedagogical scaffold" rather than a replacement for traditional instruction. The author utilized a mixed-methods quasi-experimental design involving 52 third-year university students. The experimental group utilized AI-generated explanations, adaptive review, and diagrammatic assistance, while the control group followed a traditional teacher-led curriculum. Quantitative analysis through paired-samples t-tests revealed that both groups achieved statistically significant academic gains ($p<0.001$) over the six-lesson intervention. Notably, the AI group demonstrated a numerically higher final post-test mean ($M=50.38$) compared to the control group ($M=45.96$). While ANCOVA analysis indicated that the instructional group effect approached but did not reach formal statistical significance ($p=0.076$), the data revealed that AI integration served as an equalizing scaffold, reducing initial knowledge disparities within the experimental cohort. Qualitative findings from reflective questionnaires highlighted major pedagogical advantages in visualization, immediate feedback, and independent learning. However, the study also identifies critical challenges, including concerns over AI "hallucinations" (misinformation) and the risk of cognitive dependency, emphasizing that for AI to be effective, it must be implemented under guided educational conditions.

Decision: The diploma work meets all the institutional, academic, and empirical requirements of the School of Education and Humanities at SDU University. The student has shown strong capabilities in processing data, implementing a pedagogical experiment, and applying statistical models to educational contexts. Therefore, it is decided that this work is fully approved and recommended for a formal defense for the degree of Master of Educational Sciences in Biology.

Scientific Supervisor_____ Assistant Professor , Satayev Malik