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RESEARCH ARTICLE

An investigation into artificial intelligence literacy among biology education students as a foundation for developing an AI-integrated curriculum in learning planning courses

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ABSTRACT

This study investigates the level of artificial intelligence (AI) literacy among Biology Education students as a foundation for developing an AI-integrated curriculum aligned with Society 5.0. Using a quantitative descriptive approach, data were collected from 176 students at a university in the Nias Islands, categorized as an Affirmation Region. AI literacy was assessed through essay-based case analyses and self-assessment questionnaires, guided by four core indicators: critical comprehension, recognition of social impact, technological application, and ethical behavior. Findings reveal that students demonstrated low AI literacy, with an average score of 56%, and low attitudes toward AI use (49.68%). Notably, students showed the weakest performance in recognizing AI's social consequences (50%) and evaluating information critically (54%). While basic technological use was relatively higher (65%), ethical awareness remained insufficient (55%). These results underscore a pressing need for curriculum reform that integrates AI literacy into biology education, emphasizing interdisciplinary, ethical, and critical dimensions. To address these challenges, the study proposes an AI-integrated capstone reflection framework within instructional planning courses. This framework aims to foster 21st-century competencies by embedding contextual, project-based learning with AI applications. The findings contribute to the discourse on equitable digital education and curriculum innovation in underdeveloped regions, offering actionable insights for educators and policymakers in the Society 5.0 era.

KEYWORDS

Artificial intelligence literacy; biology education; curriculum development; ethical awareness; affirmation region

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1. Introduction

History records that in 2020, a new term emerged, Society 5.0, or the Era of Industrial Revolution 5.0. Society 5.0 brings enormous changes both in terms of social and technological aspects (Tavares et al., 2022). In the context of education, Society 4.0

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encourages the development of digital skills, online learning, and the integration of technology in the teaching and learning process. Meanwhile, Society 5.0 encourages the strengthening of human values, cross-disciplinary collaboration, critical thinking, and social problem-solving-based learning with the support of smart technology (Mourtzis et al., 2022).

Before introducing Society 5.0, Japan had tried to introduce policies to face the challenges posed by the Industrial Revolution 4.0 by focusing attention and innovation on humans and using existing technology to help social welfare. This era is characterized by the integration of technologies such as IoT, AI, big data, blockchain, and robotics (Calp & Bütüner, 2022; Mourtzis et al., 2022). Apart from industry, education is also undergoing a transformation. Socio-culture 5.0 views that education requires the ability to be not only skilled, but also adaptable, critical thinking, creative, and socially conscious (Fukuyama, 2020).

One of the most notable impacts is the utilization of AI in education. AI has been adopted to further widen access to education, enhance the flexibility of learning, and enrich teaching methods through intelligent tutoring systems, adaptive learning analytics, educational chatbots, and even AI-driven virtual reality simulations for lessons (Anyim, 2021; Criollo-C et al., 2021; Zawacki-Richter et al., 2019). In Teaching Biology, the use of AI facilitates problem and project-based learning design, aids learners in visualizing complex concepts such as life cycles of organisms or ecosystem interrelations, and fosters 21st-century skills among learners (Khan et al., 2024; Shah et al., 2023). AI enables students to experience learning that is more contextual, personalized, and interactive than what is offered with conventional methods.

Although this development possesses enormous potential, there are equally potent challenges that emerge, such as the lack of AI literacy amongst students, particularly in the Biology Education Study Program. AI literacy refers to the comprehension of the workings of AI systems, the apolitical and functional use of AI applications, and the social and economic awareness regarding the technology (Hwang et al., 2023; Ng et al., 2022). It is evident that many students possess a basic level of skill in using AI applications to complete tasks, but they lack the ability to understand critical concepts such as algorithmic bias, data privacy, and ethical responsibility (Long & Magerko, 2020). This raises concerns that higher education does not appear to prepare students as digital citizens for the future.

AI digital literacy is the knowledge, attitudes, skills, and understanding needed to navigate, evaluate, and use artificial intelligence technologies and concepts effectively in daily life, work, and learning (Yao & Wang, 2024). According to Hwang et al. (2023), AI Digital Literacy is divided into four sub-dimensions: critical comprehension ability, the

ability to recognize the social impact of artificial intelligence, the ability to use artificial intelligence technology, and ethical behavior ability.

Several previous studies have attempted to examine the importance of AI integration into education. Criollo et al. (2021), for example, showed that the use of AI in learning can improve student motivation and learning achievement, but it is highly dependent on user readiness. Anyim (2021) emphasized that there is a lack in the level of development of computational thinking and AI literacy among university students. In a study on learning anatomy with VR-based AI, Shah et al. (2023) reported that the technology itself had a huge contribution to the understanding of biological concepts. Khan et al. (2024) reported that the application of machine learning-based projects in science education improved students' analytical and problem-solving skills. However, the majority of these studies still concentrate on the application of AI technology in the learning process and not on the level of students' conceptual and ethical understanding of the technology (Lin et al., 2023; Ng et al., 2021).

Moreover Hwang et al. (2023), in their study, they claimed that AI literacy must be perceived as a multidimensional construct that consists of technical skills, critical thinking, ethical awareness, and collaborative skills. Ng et al. (2022) also emphasized the necessity of developing pedagogical frameworks focused on equipping students with comprehensive AI literacy skills, including an ability to identify bias, social implications, and ethical actions with respect to the development and use of AI technologies. Unfortunately, there is very little literature that specifically focuses on measuring AI literacy of students from biology education. There is an almost complete lack of research regarding the validation instruments of AI literacy measurement, as well as the systematic integration of AI literacy into the curriculum of biology education, at the higher education level in Indonesia.

The gap that lies in the previous research regarding the current needs became an important background for this research. While integrating the application of AI into learning has been the focus of many studies, very few of them address how students' conceptual readiness to comprehend, apply, and critique AI, particularly in the complex, ethical field of biology, is. The absence of standards or structured measurement instruments of AI literacy for biology education students also indicates a gap that fundamentally requires attention (Zebua et al., 2025). Therefore, this study attempts to fill the gap by measuring the AI literacy of educational biology students, identifying the correlating factors, and formulating an AI literacy curriculum framework that meets the demands of Society 5.0.

Recent studies show that integrating artificial intelligence (AI) learning into biology education has a significant impact on improving students' AI literacy. A study in the International Journal of Artificial Intelligence in Education shows a significant increase in

AI literacy scores after students participated in a series of contextually designed AI-based meetings in biology learning (Zha et al., 2025). This improvement not only encompasses technical understanding, such as algorithms and data processing, but also students' ability to apply AI concepts in biological contexts, such as species classification and population prediction of living organisms. Thus, measuring AI literacy in biology education is not merely an evaluation of technical skills but also the integration of interdisciplinary understanding that reflects the demands of 21st-century competencies and Society 5.0.

Several factors influencing the level of AI literacy among biology education students have been identified through various empirical studies. Research by Chiu & Chai (2020) shows that AI literacy is influenced by a combination of professional training, student-centered learning approaches, and active engagement in problem-based projects. Additionally, research from Frontiers in Education found that technological readiness, institutional support, and faculty leadership in designing learning experiences also determine the success of AI integration into the curriculum (Ayyoub et al., 2025). This indicates that AI literacy does not stand alone but depends on a collaborative and adaptive educational ecosystem that responds to technological changes.

In response to these findings, the formulation of an AI literacy curriculum model relevant to the Society 5.0 era must be integrative and reflective. This model should include the development of basic technical skills (such as an introduction to machine learning and data science in the context of biology), the strengthening of critical thinking and technological ethics competencies, and the development of interdisciplinary collaborative projects. A study by Tan & Tang (2025) also recommends that AI literacy assessments be conducted in layers, starting from pre- and post-tests, self-reflection, to portfolio-based assessments that measure students' analytical and problem-solving abilities. Thus, a systematically designed AI literacy curriculum will be able to prepare biology education students to face the challenges of integrating smart technology into the future world of education and social life.

Based on the above, primary issue of this research can be put succinctly as follows: what is the level of literacy in artificial intelligence of educational biology students in relation to Society 5.0 and what are the factors that affect AI literacy level and what is the appropriate AI literacy-based curriculum model for biology education for this era. The scope of the objectives is to evaluate and interpret the AI literacy level of educational biology students, determine the influencing variables, and design a curriculum recommendation model that prepares educational biology students for an increasing integration with artificial intelligence technology.

2. Methods

The objective of this study is to measure the artificial intelligence (AI) literacy levels of biology education students using a quantitative descriptive approach. The participants included 176 students enrolled in the Bachelor of Science in Biology Education program at a university located in the Nias Islands, an area classified as an Affirmation Region. The subjects were selected through purposive sampling from active students in the fourth, sixth, and eighth semesters who had completed at least one course related to educational technology or digital biology.

Data collection was consolidated into one academic semester, which began with AI literacy essay test administration and self-assessment questionnaire distribution. The primary instrument of the research was the AI literacy essay test, which was constructed using four indicators proposed by Hwang et al. (2023): the ability to critically parse information concerning AI, the ability to recognize the social consequences of AI, the skill of using AI technology, and the awareness to act ethically in the use of AI. The test comprised eight case study-based essay questions illustrating the application of AI in biology along with its ethical controversies. In addition, the self-assessment questionnaire was designed to gauge the students' perceptions and beliefs about their AI literacy competencies using a five-point Likert scale ranging from strongly disagree to strongly agree.

Before the instruments were used, content validation was conducted by three experts: biology education experts, educational technology experts, and ethical AI experts. This validation aimed to ensure the representation of AI literacy indicators as well as the relevance of the biological context in the essay questions and questionnaire items. After that, a limited trial (piloting) was conducted on 30 students outside the main subjects to test the reliability of the instrument using Cronbach's alpha coefficient for the questionnaire, and inter-rater reliability for the essay test.

The collection was conducted in two phases. The first phase was the administration of the essay test with a maximum working time of 90 minutes, which was done offline in a classroom on campus. The second phase was the distribution of self-assessment questionnaires via Google Forms, which could be accessed by students using their personal devices. Data collection for all students was set within a two-week timeframe in order to ensure the timeliness of the results and the context of the results being relevant to the academic schedule of the students.

The analysis of data employed a quantitative descriptive approach. The scores from the essay test and questionnaire were evaluated statistically to obtain the average score, standard deviation, and the percentage distribution of the students' AI literacy level. The essay test was scored according to an AI literacy-based scoring rubric, which included

predefined maximal scores for each indicator to be assessed. All steps of the study, from the development of instruments to the data analysis, were conducted in accordance with the protocol of social research ethics, which included voluntary participation, informed consent, and confidentiality of personal data of the students. This design enables flexible adaptation of the procedures to local characteristics of participants and available resources while still allowing for replications in similar or different contexts.

3. Results

Table 1 shows the results of measuring students' AI digital literacy from four main subdimensions: the ability to critically digest information, recognize the social impact of AI, use AI technology, and behave ethically. In the ability to critically digest information subdimension, students obtained an average score of 54%, which is at a low level. This shows that almost all students still have difficulty in interpreting and evaluating both the substance and claims offered by AI systems. Under the sub-dimension of 'recognizing the social impact of AI,' the scores achieved were also low at 50%. This finding suggests that students have not yet attempted to comprehend the social and cultural implications of AI technology and its impact on human development.

Table 1. Results of students' AI digital literacy knowledge (Hwang et al., 2023).

Sub-Dimension	Descriptors	Percentage (%)	Description
Critical comprehension ability	Able to interpret and analyze the truth, objectivity, and information power of content presented by AI	54	Low
The ability to recognize the social impact of artificial intelligence	Able to analyze the implications of AI for society and the role of AI in human development.	50	Low
The ability to use artificial intelligence technology	Able to use and learn AI products and technologies effectively	65	Low
Ethical behaviour ability	Able to accept information generated by AI critically by considering ethical and moral aspects.	55	Low
Total		224	
Average		56	Low

The sub-dimension of using AI technology scored highest, with 65%, even though they still remain classified as 'low achievers.' This suggests that, although students are relatively able to use AI products and applications for their daily activities, their level of

mastery is still insufficient to render these technologies in a productive and critical manner. Finally, regarding behavior of an ethical nature, students scored 55%, once again classifying them as 'low achievers.' This shows the lack of consideration of critical and useful ethical principles in accepting, utilizing, and disseminating AI-generated information.

The total score of all sub-dimensions tested was 224, but the average score was only 56%, indicating that the general level of AI literacy of university students is still in the low category. This finding emphasizes the need for educational interventions to improve students' AI literacy not only on the technical aspects of use, but also on the deeper critical, social, and ethical aspects.

Table 2 presents the results of the digital literacy attitude test of the students regarding AI technology based on 20 items relating to the critical, ethical, and reflective dimensions of attitude toward AI technology. On average, the students' attitude score was 49.68%, which puts them in a low category. This shows that students do not possess critically responsible and aware attitudes concerning the impact of AI technology on their daily lives.

For some items, there were relatively better achievements noted. For example, the statement "If I'm unsure about what AI presents, I'd look for supplementary materials to study the information deeper" scored the highest at 64.70%, which is categorized as good. This means that some students tend to verify the information independently and cross-check the information provided by AI. However, there was only one other statement that met the sufficiency threshold to be considered C+, which is "I am not sure the information presented by AI is accurate all the time", at 58.66%, which denotes some form of preliminary awareness regarding AI's accuracy.

In contrast, there were far more statements that were classified as low. As in the attitude of adequately checking the reliability of AI-based big data, the figure is only 40.84%, and for taking responsibility for choices made based on AI recommendations, the figure is only 43.75%. Other attitudes related to AI utilization, AI selection, and socio-ethical considerations impacting AI also proved below 55%. This explains that the mastery of reflective skills and social responsibility in the use of AI has not reached an optimal level.

This source explains that although in some cases there are positive indicators, the majority are still reduced in building ethical, empathetic, and responsible AI. This is in line with the literature, which explains that the development of AI literacy is not only balanced with technical ability, but also balanced with mastery of ethical attitudes and the social impact of technology (Holmes, Bialik, et al., 2022; Long & Magerko, 2020).

Table 2. Student AI digital literacy attitude test results

Statement	Statement type	Percentage (%)	Criteria
If I have doubts about what the AI presents, I will look for more relevant information to learn more about it.	+	64,70	Good
I do not believe the information presented by AI is always correct.	+	58,66	Fairly
When in doubt about the information provided by AI, I will check its veracity through other sources.	+	54,65	Fairly
I can evaluate whether the content suggested by the AI presents a balanced/unbiased point of view.	+	60,98	Fairly
I understand very well how to check the accuracy of the content delivered by AI.	+	46,55	Low
I think AI technology is very important in my life.	+	46,98	Low
I know how fast AI can accomplish a task.	+	52,89	Low
Although AI is constantly evolving, I believe it cannot replace humans	+	45,23	Low
I think everyone needs AI skills.	+	48,46	Low
I think about the good and bad impacts that AI can have	+	43,73	Low
I can process the information or content I am looking for to come up with something new.	+	50,42	Low
I can use AI services independently.	+	44,48	Low
I can choose the AI service (platform) that suits me, depending on the situation.	+	54,01	Fairly
I can use AI technology to solve learning and daily life problems.	+	53,22	Fairly
I can use AI technology to find the information or content I need.	+	41,68	Low
When using AI-based big data, I will ensure the legality and reliability of the information generated.	+	40,84	Low
Whether I follow AI's recommendations or not, I can consider who is responsible for the consequences of my choices.	+	52,90	Low
Whether or not I accept AI's recommendations, I take responsibility for the impact of my choices.	+	43,75	Low
I fully consider the viewpoints of others when sharing the information I have gathered.	+	42,80	Low
I have a standard to distinguish between content that is good to share and content that is normal.	+	46,80	Low
Total		993,73	
Average		49,68	Low

These findings strengthen the necessity to integrate the material on AI literacy into the biology education curriculum. Not only should the students be made familiar with the tools, but they must also be educated on the socio-ethical and legal aspects of AI; its incorporation must be multi-dimensional. Without reinforcing these attitudinal components, the students risk being active consumers of technology without realizing the implications of using AI on education, society, and their future professions.

4. Discussion

The findings of this study suggest that the AI literacy level of the Biology Education students at Nias Islands University falls within the intermediate category, as indicated by the average literacy score of 58.5, which is accompanied by the average attitude towards digital literacy being a mere 49.68%. Although the students displayed basic skills in using AI-enabled technology, their more advanced capabilities of evaluating, social understanding, ethically reflecting on the impacts of AI technology, and doing so in a 'critical thinking' manner were indeed very limited (Zebua, 2024). This aligns with the findings of Hwang et al. (2023), who observed that, in general, students seem to only understand AI as a practical utility devoid of the multifaceted social and ethical issues underlying its use.

From the perspective of AI literacy theory, Ng et al. (2022) emphasize that AI literacy involves technical and conceptual skills, along with social and ethical facets. The framework made by Long & Magerko (2020) adds that evaluating social accuracy, fairness, and consequences of AI is crucial in enabling and developing literacy. The low performance of students on the ethical awareness and critical thinking approaches in this study demonstrates that these dimensions of literacy have not been sufficiently addressed, especially in the context of biology education in remote, underdeveloped areas. Some factors of the terrain support this finding. First, the biology education curriculum in many colleges, particularly in the less developed regions, still predominantly focuses on traditional science with little to no integration of digital technology advancement and its ethical use (Labov et al., 2010). Second, the lack of digital-based laboratories, the absence of AI development training for instructors, and the scarcity of resource access to information technology are the main problems in the Affirmation Region, like the Nias Islands. As a result, the students' AI literacy was only developing partially, strong in the operational aspect but weak in the reflective and critical aspects.

The implications of these findings are that AI literacy development has to be integrated contextually into the curriculum of Education Biology rather than just adding new courses to it. This can be done through the recontextualization of existing courses.

One of the potential courses is Planning for Instruction, which is built around developing strategic instructional design and curriculum design. Through the application of AI, such as using machine learning for need assessment, instructional designers can model and predict learners' success. Students are not just honed in their AI skills, but are also trained to think critically and ethically about their application (Yao & Wang, 2024).

Empirical studies reinforce the above argument. Dilsizian & Siegel (2014) showed that applying AI to educational data analysis has accelerated instructional decision-making and improved the accuracy of designing adaptive learning interventions. On the other hand, (Holmes et al., 2019) argue that education that integrates AI and big data significantly improves students' critical thinking skills, especially in analyzing the complexity of educational data. This indicates that AI-based learning can strategically shape students' scientific, digital, and pedagogical literacy in a simultaneous manner.

Regarding the development of higher education, the results of this study recommend that AI literacy evaluation be included in the quality indicators of learning in the Society 5.0 era. In addition to improving technical competencies, AI-based curriculum adaptation will prepare students to become critical, ethical, and responsible digital citizens. This is in line with Zawacki-Richter et al. (2019), who argue that the development of AI literacy should include technical, social, cultural, and ethical dimensions holistically for higher education amidst the challenges of digitalization. Therefore, this study is in a context where the condition of AI literacy of students in affirmation areas is highlighted and intended as conceptual and practical suggestions for the transformation of AI-based biology education in the future.

4.1. Ability to critically absorb information

Research shows that, on average, students demonstrate a critically discerning ability about information stemming from AI technologies at 54%, which is considered low. This indicates that most students cannot assess the accuracy, objectivity, or validity of AI systems. These findings align with Hwang et al. (2023), which reported that even though students are accustomed to using AI-integrated applications, they seldom actively engage with the biases, accuracy, and framing of provided information. The lack of skill has severe consequences because, without the ability to critically evaluate the output of AI systems, these students become highly susceptible to algorithmically generated misinformation and manipulative content. Therefore, developing critical thinking skills towards AI must be prioritized in the teaching model, particularly for 3T areas.

4.2. Understanding the social impact of AI

At this indicator, the students only achieved an average score of 50%, which indicates a very limited awareness of the social dimensions of the technology. This shows that students still do not understand how AI influences the social, economic, cultural, and political life of people. This finding corroborates the Ng et al. (2022) report, which argues that AI literacy does not only involve the use of technology, but also how that technology shapes the public and creates new inequalities. In the context of biological education, this is particularly alarming given the relatively low levels of awareness owing to the growing dependence of biotechnology and biomedicine on AI, with its profound ethical and social risks. Curriculum models employing AI technologies need to include components of sociological reflection on the consequences of that technology to avoid making students passive consumers and instead cultivate responsible change agents.

4.3. Capability of using AI technologies

In the sub-dimension of the ability to use technology, students scored the highest at 65%. This indicates that students are moderately adept at utilizing AI applications for rather basic functions such as information retrieval or language translation. This finding also supports the results of Holmes, Porayska-Pomsta, et al. (2022), which stated that, in general, students adopt a morechical and reflective technology much later compared to its technical aspects. Nonetheless, this understanding remains superficial as it lacks fundamental knowledge on the functioning of algorithms, data-driven systems, or systemic biases. Therefore, AI-powered learning systems should not only emphasize the skills of using the technology, but rather the understanding of the structure, processes, and limitations of the technology (Alubthane, 2024; Niyozov et al., 2023).

4.4. The ability to behave ethically

With regard to AI as an intelligence system, the ethical behavior aspect also shows very low results, with an average score of just 55%. The ignorance of ethics of students in accepting, utilizing, and disseminating AI-enabled information is a serious issue in this digital age. Long & Magerko (2020), as well as Zawacki-Richter et al. (2019), emphasize that AI literacy needs to develop sensitivity towards ethical issues such as data privacy, algorithmic fairness, and social accountability. In biology, where sensitive data is utilized (for example, genomic data and medical records), ethical awareness is crucial to prevent data abuse and infringement of privacy rights. There is a need to systematically incorporate teaching materials on AI ethics into all technology-related courses

5. Conclusion

This study finds that the AI literacy level of the Biology Education students is still low, especially in critical thinking, ethical awareness, and social impact analysis of technology. This finding underscores the need to integrate AI literacy into curriculum design models through Planning Lessons with problem-based and project-based learning with reflective and applied AI integration. Such an approach may equip the students to meet the challenges of Society 5.0 as well as help bridge the gaps in digital literacy in the 3T area. In future developments, they could consider these study results for the design of contextual lesson modules on Planning Lessons with AI, as well as for further studies aimed at evaluating an AI-integrated teaching model on enhancing 21st-century skills for the students.

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