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Analysis of Digital Literacy Implementation and Challenges of Ethics-Based AI Integration in Biology Learning

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ABSTRACT

The transformation of learning in the era of artificial intelligence requires students to develop strong digital literacy skills accompanied by ethical awareness in technology use. This study examines the implementation of digital literacy and the challenges of integrating AI ethics in Biology learning at MAN 2 Kota Malang. A descriptive approach was employed, with data collected through interviews with a Biology teacher and an AI digital literacy questionnaire administered to 60 tenth-grade students. The questionnaire assessed students' critical understanding, awareness of social impacts, ability to use AI, and ethical behavior. The findings indicate that students demonstrate relatively strong proficiency in using digital technologies and AI for learning. However, they still encounter difficulties in higher-order skills, such as critically evaluating information, identifying bias, and reflecting on the ethical implications of AI use. Teachers have introduced instructional innovations involving AI, augmented reality, and virtual reality, yet challenges remain in pedagogical integration, ethical guidance, and students' readiness. These findings highlight the need to strengthen value-based AI digital literacy in order to foster reflective awareness, ethical judgment, and academic integrity, thereby enabling Biology learning to move beyond technological efficiency toward more meaningful and responsible educational practices.

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1. INTRODUCTION

Technological advancement driven by globalization has brought significant changes to various aspects of human life, including education (Syaleha et al., 2025). In the context of biology education, the use of digital technology offers important opportunities to overcome conventional learning barriers, such as difficulties in visualizing abstract concepts, low student interest in learning, and limited access to instructional media and learning resources. This is particularly relevant because biology deals with complex life phenomena and therefore requires creative and innovative learning approaches to make abstract concepts more accessible and understandable to students (Bongard, 2021; Oktavia & Hardinata, 2021).

Alongside these developments, digital literacy has become an essential competency that students must acquire in order to adapt to and compete in an increasingly globalized world. Digital literacy refers not only to the ability to operate digital devices, but also to the capacity to use them effectively as learning tools that integrate technological and pedagogical dimensions (Simbolon, 2022). This competency is also consistent with the orientation of the Merdeka Curriculum, which promotes student-centered learning through flexible and differentiated approaches aimed at developing higher-order thinking skills (HOTS).

The mastery of digital literacy has been shown to play an important role in improving the efficiency of the learning process, enhancing learning outcomes, and supporting students' cognitive, affective, and psychomotor development (Yu, 2022; Yuan et al., 2025). One technological innovation that is highly relevant to these demands is Artificial Intelligence (AI), which offers considerable potential to advance biology education while strengthening the role of prospective educators within broader educational transformation efforts (Abimanto, 2023; Sallam, 2023). AI not only supports the automation of certain teaching tasks, but also enables the creation of personalized, interactive, and more in-depth learning experiences (Dini, 2023; Syaleha et al., 2025).

Moreover, the integration of AI is increasingly reinforced by the development of technologies such as Augmented Reality (AR) and Virtual Reality (VR), which can visually represent complex biological structures and processes, thereby helping students understand abstract concepts more clearly (Aripin et al., 2024). These technologies make learning more immersive and engaging, which in turn can enhance students' understanding of content that requires strong visualization skills.

Several studies have shown that ChatGPT, as an AI-based application, has considerable potential to support academic activities, although its use also presents several challenges, including limited contextual understanding and the risk of user dependency (Suharmawan, 2023). The use of ChatGPT is also considered capable of improving learning quality, provided that both teachers and students possess adequate digital literacy and a sound understanding of the ethical dimensions of technology use (Dempere et al., 2023; Montenegro-Rueda et al., 2023). However, research by Heeg and Avraamidou (2023) indicates that AI systems also pose risks related to algorithmic bias, misinformation, and potential copyright violations. If the use of AI is not accompanied by ethical and reflective guidance, it may weaken students' analytical and reasoning abilities while increasing the risk of plagiarism and academic dishonesty. Therefore, the integration of AI in education must be accompanied by ethical awareness and moral grounding so that learning does not focus solely on cognitive achievement, but also contributes to students' character development and spirituality.

This issue is particularly relevant to the empirical context of MAN 2 Kota Malang. Interview findings indicate that the school has initiated a transformation in biology learning through the strengthening of digital literacy, the implementation of 21st-century learning

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models, and the use of technology-based media such as AI, AR, and VR in classroom practice. The integration of religious values has also been emphasized as an ethical foundation for the use of technology. Nevertheless, several challenges remain, including teachers' readiness to implement AI, their understanding of AI-related ethics, and the need to maintain a balance between scientific and technological advancement, spiritual values, and students' character formation (Ayanwale et al., 2022; Yue et al., 2024; Wang et al., 2023).

Despite the growing integration of digital technologies in education, limited research has specifically examined how digital literacy and ethics-based AI integration are implemented in biology learning within school contexts that also emphasize religious and moral values. This gap is particularly important in the context of the Merdeka Curriculum, which promotes flexible, student-centered, and competency-oriented learning. Therefore, this study aims to analyze the implementation of digital literacy and identify the challenges of ethics-based AI integration in biology learning at MAN 2 Kota Malang. The findings are expected to contribute to the discourse on technology-enhanced biology education by offering insights into how AI can be integrated in ways that are pedagogically meaningful, ethically grounded, and responsive to students' cognitive and character development.

2. METHOD

2.1 Research Design

This study employed a descriptive approach to analyze the implementation of digital literacy and the challenges of integrating ethics-based artificial intelligence in Biology learning at MAN 2 Malang City. This approach was selected because the study aimed to obtain an in-depth understanding of how digital technology and artificial intelligence were used in classroom practice, how ethical considerations were addressed, and how these practices aligned with the principles of the Merdeka Curriculum. Although the primary orientation of the study was qualitative, quantitative descriptive data were also incorporated through a student questionnaire to provide additional support for the interpretation of the findings.

2.2 Data Collection Techniques

The study was conducted at MAN 2 Malang City. The participants consisted of one Biology teacher and 60 tenth-grade students. The Biology teacher served as the primary informant because the teacher was directly involved in planning and implementing learning activities that integrated digital literacy and artificial intelligence. Meanwhile, the students participated in the questionnaire stage to provide information regarding their level of digital and artificial intelligence literacy. The inclusion of both teacher and student participants enabled the study to capture the issue from instructional as well as learner perspectives.

Data collection was carried out in two stages. The first stage involved an in-depth interview with the Biology teacher. This interview was intended to explore the implementation of digital literacy in Biology learning, the integration of artificial intelligence in instructional activities, the challenges encountered during this process, and the teacher's perceptions of ethical issues related to academic integrity and responsible technology use.

The second stage involved the distribution of a digital literacy questionnaire to the students. The purpose of this stage was to obtain descriptive data regarding students' competencies in digital literacy and artificial intelligence literacy. The results from the interview and questionnaire were then combined to provide a more comprehensive understanding of the implementation of digital literacy and the ethical challenges of AI.

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2.3 Data Analysis

Two instruments were used in this study. The first instrument was a structured interview guide consisting of 15 questions. These questions were designed to examine the teacher's perspectives on digital literacy implementation, the use of artificial intelligence in Biology instruction, the challenges faced during integration, and the application of ethical considerations in the learning process.

The second instrument was an artificial intelligence digital literacy questionnaire consisting of 20 items. This questionnaire was developed based on the indicators proposed by Hwang et al. (2023) and was intended to measure students' abilities to access, understand, evaluate, and use digital technology and artificial intelligence ethically and productively. The interview was conducted face-to-face to ensure depth and flexibility in capturing the teacher's responses, whereas the questionnaire was distributed to students to obtain structured descriptive data from a larger number of participants.

The data analysis followed the interactive model of Miles and Huberman (2014), which includes data reduction, data display, and conclusion drawing. The qualitative data obtained from the teacher interview were reduced by organizing the responses into key themes related to digital literacy implementation, artificial intelligence integration, instructional challenges, and ethical concerns. These themes were then presented in the form of descriptive narratives to allow a detailed interpretation of the teacher's experience and perspective.

The quantitative data obtained from the student questionnaire were analyzed descriptively using spreadsheet software. The results were then presented in the form of bar charts to illustrate trends in students' levels of digital and artificial intelligence literacy. These descriptive results were used to support and complement the qualitative findings, thereby strengthening the overall interpretation of how digital literacy and ethics-based artificial intelligence were implemented in Biology learning.

3. RESULT AND DISCUSSION

3.1 Result

The integration of digital technology in learning has become a central concern in educational research, particularly in response to the rapid development of AI. This study examines the implementation of ethics-based AI digital literacy in Biology learning at MAN 2 Kota Malang and investigates its impact on classroom practices, teachers' and students' experiences, and the dynamics of AI use in relation to critical comprehension, social awareness, practical use, and ethical behavior. Through this analysis, the study seeks to understand how AI is perceived and utilized in Biology learning, while also identifying pedagogical challenges associated with integrating AI in a responsible and meaningful manner.

Based on the analysis of the self-assessment questionnaire data, the overall level of students' AI digital literacy at MAN 2 Kota Malang can be categorized as good (Figure 1). This is indicated by the predominance of responses in the agree (score 4) and strongly agree (score 5) categories across most questionnaire items developed based on the AI digital literacy indicators proposed by Hwang et al. (2023) and applied in this study (Table 1). For the critical comprehension indicator, more than half of the respondents demonstrated a relatively high level of awareness in evaluating the accuracy of information generated by AI. Responses in the score 4 and 5 categories ranged from 60% to 75% across several items (Table 1). These findings suggest that students have begun to recognize that digital information produced by AI is not always inherently valid. However, a proportion of respondents still selected score 3,

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with percentages ranging from 9% to 16% (Table 1). This distribution indicates that the critical evaluation of AI-generated information has not yet become a consistently embedded practice among all students. Interview data with Biology teachers support this finding, revealing that some students tend to accept AI-generated outputs without verification or further reflection, as reflected in their difficulty explaining submitted answers orally.

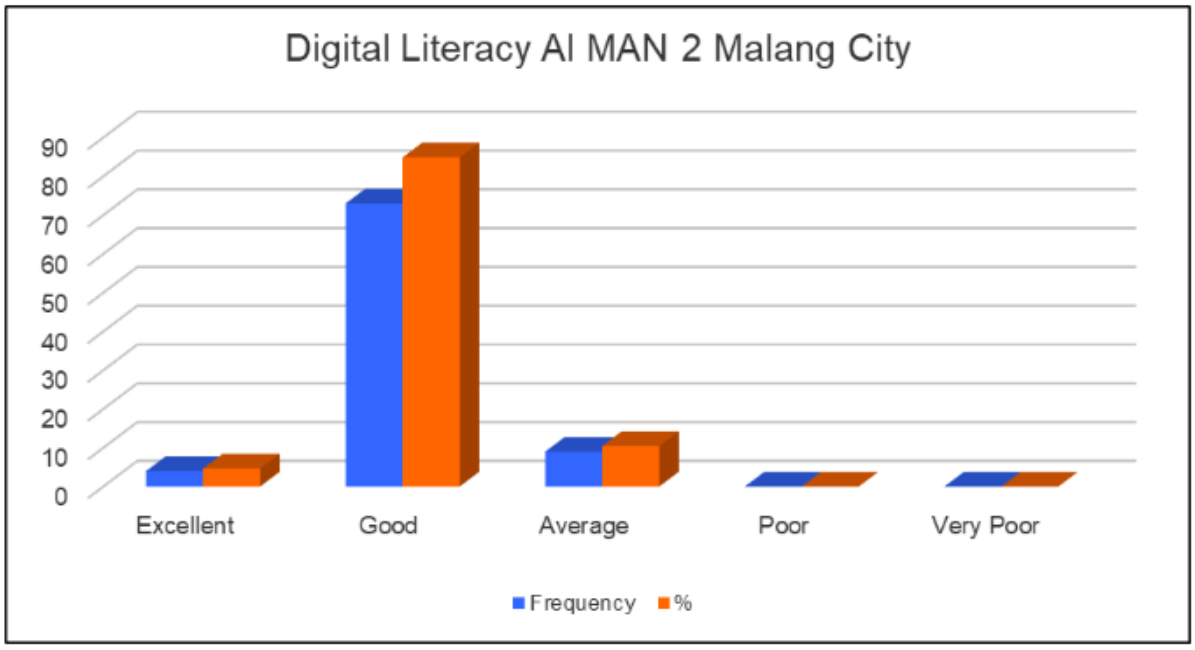

Figure 1. Categorization of AI digital literacy levels among students at MAN 2 Kota Malang

The indicator related to recognizing the social impact of artificial intelligence showed a more varied distribution of responses. Although score 4 remained dominant, with percentages ranging from 38% to 45% across several items, score 3 also appeared at relatively high levels, ranging from 29% to 37% (Table 1). These results indicate that students have begun to understand AI as a useful technology that cannot fully replace human roles. Nevertheless, awareness of the broader social implications and ethical issues associated with AI use remains uneven. The presence of lower-score responses (1%-4%) further indicates that sensitivity to the social and ethical dimensions of AI is still situational rather than deeply internalized. Interviews with Biology teachers revealed concerns that the use of AI as a shortcut may reduce the quality of students' thinking processes and increase the risk of academic dishonesty.

Table 1. Results of the AI Digital Literacy Self-Assessment Questionnaire of Students at MAN 2 Kota Malang

Category	Item	5	(%)	4	(%)	3	(%)	2	(%)	1	(%)
Critical Comprehension Ability	1	51	59,3	32	37,2	3	3,48	0	0	0	0
	2	16	18,6	58	67,44	12	13,95	0	0	0	0
	3	41	47,67	37	43,02	8	9,3	0	0	0	0
	4	20	23,25	52	60,46	13	15,11	1	1,16	0	0
	5	18	20,93	52	60,46	14	16,27	2	2,32	0	0

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Category	Item	5	(%)	4	(%)	3	(%)	2	(%)	1	(%)
The Ability to Recognize the Social Impact of Artificial Intelligence	6	8	9,3	49	56,97	25	29,06	4	4,65	0	0
	7	21	24,42	50	58,13	14	16,27	1	1,16	0	0
	8	34	39,53	33	38,37	15	17,44	1	1,16	3	3,48
	9	13	15,11	35	40,69	32	37,2	4	4,65	2	2,32
	10	41	47,67	38	44,19	5	5,81	0	0	2	2,32
	11	16	18,6	54	62,79	16	18,6	0	0	0	0
	12	14	16,27	60	69,76	10	11,62	1	1,16	1	1,16
	13	20	23,25	57	66,27	9	10,46	0	0	0	0
	14	11	12,79	52	60,46	19	22,09	3	3,48	1	1,16
	15	19	22,1	55	63,95	10	11,62	2	2,32	0	0
Ethical Behaviour Ability	16	16	18,6	56	65,11	12	13,95	1	1,16	1	1,16
	17	12	13,95	68	79,06	6	6,97	0	0	0	0
	18	17	19,76	63	73,25	6	6,97	0	0	0	0
	19	17	19,76	63	73,25	5	5,81	0	0	0	0
	20	25	29,07	55	63,95	6	6,97	0	0	0	0

Note. Scale: 5 = Strongly Agree; 4 = Agree; 3 = Less Agree; 2 = Disagree; 1 = Strongly Disagree.

In contrast, the indicator concerning the ability to use artificial intelligence technology demonstrated a high level of response stability. Students selected score 4, with percentages ranging from 60% to 70% across nearly all items (Table 1). This finding suggests that students generally feel confident in using AI to search for information and support learning activities, particularly in Biology. However, score 3 responses remained evident for items related to selecting appropriate AI tools and utilizing advanced features, ranging from 10% to 22% (Table 1). This pattern indicates that students' AI use skills are still primarily operational and have not yet developed into more strategic and reflective practices. Teachers also emphasized the importance of pedagogical guidance to ensure that AI use extends beyond task efficiency toward deeper conceptual understanding.

Regarding the ethical behavior indicator, students demonstrated relatively strong ethical awareness in using AI. This is reflected in the dominance of score 4 responses, with percentages ranging from 63% to 79% across several items assessing cautious attitudes toward sharing AI-generated information (Table 1). These findings are reinforced by teachers' instructional practices, including the emphasis on transparent rules, the use of oral assessments, and varied assignment formats to maintain academic integrity. Nevertheless, a proportion of respondents selected score 3, with percentages ranging from 5% to 14% (Table 1), indicating that ethical values related to AI use have not yet been consistently internalized in students' academic behavior.

Overall, the integration of quantitative findings with the literacy-level categorization shows that most students fall within the good category, while others are classified as fairly good or very good. The low and very low categories were rarely observed. These results suggest that the primary challenge of AI digital literacy at the school level no longer lies in basic access or technical ability, but rather in strengthening critical awareness and fostering the internalization of ethical values in AI use.

3.2 Discussion

Critical understanding is a fundamental dimension of AI-based digital literacy, particularly in Biology learning, which requires conceptual accuracy, evidence-based reasoning, and

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scientific verification. The findings indicate that most students have developed an initial awareness of the need to evaluate AI-generated information. The dominance of responses in the score 4 and 5 categories, ranging from 60% to 75% (Table 1), suggests that students generally recognize that AI outputs are not always accurate and therefore require verification. This finding is consistent with Nisa (2024), who emphasizes the importance of evaluating the credibility of digital information in an era increasingly shaped by generative technologies and misinformation. In this context, Biology learning at MAN 2 Kota Malang appears to be moving toward a more reflective use of AI, in which the technology is not merely treated as a functional tool but also as a medium for developing scientific thinking.

However, this awareness has not yet been fully translated into students' actual learning practices. The presence of score 3 responses, ranging from 9% to 16%, indicates that some students remain hesitant or inconsistent in verifying the scientific validity of AI-generated outputs. Interviews with the Biology teacher reinforce this pattern, revealing that some students still tend to accept AI-generated answers without cross-checking them against established biological concepts. This discrepancy between conceptual awareness and evaluative practice suggests that students' critical thinking skills are still emerging rather than firmly established. In Biology learning, such a condition may undermine the process of knowledge construction, since data accuracy, variable identification, and evidence evaluation are central components of scientific inquiry (Lederman, 2018; Windschitl et al., 2008).

These findings indicate that educational transformation is not solely a matter of expanding technological access, but also of strengthening students' metacognitive capacity. Although some students are already proficient in operating AI tools, they are not yet consistently able to assess the quality, potential bias, and limitations of the information they receive (Moșoi et al., 2025). Therefore, Biology learning needs to place stronger emphasis on the rationale and procedures for verifying AI outputs before they are used in scientific reasoning or problem-solving. This shift represents a core dimension of digital learning transformation, namely, movement from functional technology use toward reflective and scientifically grounded use.

To address this gap, systematic pedagogical intervention is required. Biology teachers need to integrate instructional strategies that encourage students to compare sources, identify potential algorithmic bias, and evaluate AI outputs against credible scientific references. Approaches such as guided inquiry, critical questioning, and source triangulation may help improve students' consistency in scientific reasoning. As argued by Pangrazio (2016), critical digital literacy should be embedded within the curriculum rather than treated as an additional or peripheral activity. In the context of MAN 2 Kota Malang, such reinforcement is also closely related to the cultivation of honesty, trustworthiness, and responsibility as ethical principles guiding technology use. Thus, the findings suggest that Biology learning at MAN 2 Kota Malang is undergoing a significant transformation, from viewing AI as a technical aid to using it as part of a broader framework of critical digital literacy that strengthens both scientific reasoning and ethical awareness.

The analysis of indicators related to students' awareness of the social impact of AI reveals a gap between operational understanding and deeper critical reflection. Students generally perceive AI as a useful instrumental technology, but not as something capable of fully replacing human roles and cognitive interaction. This is reflected in the dominance of score 4 responses, ranging from 38% to 45%, alongside a substantial proportion of score 3 responses, ranging from 29% to 37%. This pattern aligns with recent studies suggesting that AI should be positioned as a complementary tool rather than a substitute for the essential roles of

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teachers, peer interaction, and classroom dialogue, particularly in supporting more personalized forms of education (Gauseti et al., 2024; UNESCO, 2023; UNESCO, 2021).

Nevertheless, the relatively broad distribution of responses in this indicator, compared with the more stable patterns found in the technical capability indicators, suggests that students' awareness of the broader implications of AI remains inconsistent (MacLennan et al., 2025). A key weakness in AI digital literacy appears to lie in students' limited reflection on complex ethical and social issues. The presence of lower-score responses, although small in proportion, provides empirical evidence that students' consideration of issues such as algorithmic bias, data privacy, and the possible weakening of critical thinking due to overreliance on AI remains situational rather than deeply internalized. This points to an important pedagogical issue: educational practice must move beyond functional AI instruction toward the cultivation of evaluative and reflective capabilities (Zou et al., 2025).

The ability to understand AI appropriately involves more than simply knowing how to use the tool. It also requires the capacity to assess validity, identify bias, and critically question the reliability and implications of AI-generated outputs. Such ability is essential for making sound judgments within an increasingly complex digital ecosystem (Ma et al., 2025). Accordingly, these findings suggest the need for a curricular shift, particularly in Biology learning, where data interpretation and conceptual precision are crucial. Rather than positioning AI merely as a tool for improving academic performance, learning should focus on developing comprehensive and value-based AI digital literacy. In this regard, internalizing ethical values into consistent academic behavior becomes a key challenge, especially given the contrast between relatively strong technical ability and uneven social and ethical awareness (Priyanti & Wahyuni, 2022; Ryan et al., 2025). Value-based learning strategies that address cognitive, affective, and ethical dimensions are therefore essential for developing a generation of learners who are not only technologically competent but also responsible, ethically aware, and capable of maintaining academic integrity in the use of AI for scientific learning and everyday life (Khatri & Karki, 2023).

The findings indicate that most students demonstrate relatively strong technical capability in using AI for learning purposes. The dominance of score 4 responses, ranging from 60% to 70%, reflects a high degree of operational confidence in using AI, particularly for basic activities such as searching for information and using AI tools relevant to Biology content (Hidayat et al., 2024). This pattern is consistent with the increasing accessibility and user-friendliness of generative AI platforms, which have facilitated the early integration of such technologies into classroom learning (Priandani et al., 2025; Susilana & Rullyana, 2025). The consistency of these high scores also suggests that the basic barrier to technological adoption has largely been overcome, and that AI is beginning to function as a tool that supports learning efficiency.

However, a closer examination of the response distribution reveals a gap between operational competence and strategic competence. The presence of score 3 responses, ranging from 10% to 22% for items related to selecting AI services and using advanced features, indicates that some students have not yet reached a more analytical and reflective level of AI use. Strategic capabilities, such as choosing the most appropriate AI platform, combining different tools for complex tasks, and evaluating the quality and possible bias of AI-generated information, remain limited (Kasneci et al., 2023; Oktafia et al., 2025). In the context of Biology learning, which requires interpretation of evidence, conceptual analysis, and scientific reasoning, this limitation suggests that students' use of AI remains more functional than investigative.

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This gap has important pedagogical implications. Technical competence that is not accompanied by critical and strategic thinking may encourage excessive dependence on AI-generated outputs, thereby constraining the development of higher-order thinking skills such as analysis, evaluation, and synthesis (Diantama, 2023; Yusuf et al., 2024). Such dependence may also reduce students' opportunities to engage in reflection, interaction, and independent knowledge construction, all of which are essential components of inquiry-based Biology learning (Papaneophytou & Nicolaou, 2025). These findings indicate that educational transformation requires not only technological familiarity, but also the ability to use technology critically, strategically, and meaningfully.

For this reason, the Biology curriculum needs to move beyond training students merely to operate digital tools. It should instead promote AI digital literacy that is oriented toward sensemaking, namely, the ability to evaluate, interpret, and integrate AI-generated information into students' own scientific understanding. Learning should be designed so that AI functions as a tool for cognitive support rather than as a substitute for intellectual effort. This requires pedagogical strategies such as guided inquiry, problem-based exploration, and reflective feedback, all of which can help students understand not only how AI works, but also why its outputs must be critically evaluated. Consistent with Nurdin et al. (2025), strengthening this strategic dimension is a crucial part of technology-based transformation in Biology learning, as it contributes not only to greater efficiency but also to the development of scientific competence and academic responsibility.

The findings also indicate that students' ethical awareness in using AI is relatively strong, as reflected in the dominance of score 4 responses, which range from 63% to 79%. This pattern suggests that students tend to be cautious when sharing digital information and generally comply with teachers' rules regarding technology use. Such findings are in line with broader discussions on the ethics of generative AI in education, which emphasize transparency, privacy protection, and vigilance against plagiarism and other forms of academic misconduct (He et al., 2023). At MAN 2 Kota Malang, Biology teachers' practices, including oral assessments, varied assignment formats, and explicit rules regarding AI use, appear to function as ethical scaffolding that helps support academic integrity in the classroom.

At the same time, the presence of score 3 responses, ranging from 5% to 14%, indicates that ethical internalization remains uneven. For some students, ethics still appears to be understood mainly as compliance with formal rules rather than as a reflective commitment to evaluating, justifying, and taking responsibility for AI-generated information. Rule-following without deeper reflection may produce behavior that is procedurally correct but morally fragile. This concern is consistent with He et al. (2023) and Ray (2023), who argue that without meaningful ethical internalization, AI can reinforce plagiarism, facilitate the spread of misinformation, and blur the boundary between human contribution and machine-generated content.

In the context of Biology learning, insufficient digital ethics carries particularly serious consequences. Biology is a discipline that depends heavily on conceptual precision, accurate terminology, and rigorous validation of information. Viewed through the AI4People framework, the position of students at MAN 2 Kota Malang appears to partially reflect the principles of beneficence and non-maleficence, but less fully those of autonomy, justice, and especially explicability, namely, the ability to explain the reasoning process and justification behind the use of AI (Floridi et al., 2018; Vieriu & Petrea, 2025). The principle of explicability is especially important in academic settings because it requires students not only to use AI

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but also to explain where the information came from, why it was considered trustworthy, and how it was verified. Without this capacity, scientific integrity becomes vulnerable.

In the madrasah context, the urgency of ethical internalization is even greater because education is expected to develop not only scientific competence but also moral character. Values such as amanah (trustworthiness), honesty, and responsibility should serve as the ethical foundation for AI use. However, the findings suggest that these values have not yet been fully translated into students' technology-related academic behavior. As noted by the Biology teacher at MAN 2 Kota Malang, some students still use AI to generate answers without adequately checking their accuracy. This directly contradicts the principles of trustworthiness and scientific responsibility that should characterize madrasah education.

The urgency of strengthening ethical internalization is further supported by the systematic review of He et al. (2023), which warns that AI use without a value-based framework may weaken critical thinking, reinforce bias, and reduce students' ability to interpret scientific information independently. Therefore, the transformation of Biology learning should move beyond technical proficiency toward positioning ethics as a core competency. A value-based learning approach is essential for integrating cognitive, affective, and ethical dimensions through strategies such as AI ethics case discussions, self-reflection activities, exploration of algorithmic bias, and authentic assessment that requires students to explain their reasoning process. In this sense, the internalization of ethical behavior is not simply about regulating the use of a tool, but about placing ethics at the center of learning so that AI genuinely strengthens academic integrity and the quality of students' scientific understanding.

The findings of this study also suggest that the changes in students' learning patterns and in teachers' roles in relation to AI can be understood through the lens of Mezirow's theory of transformative learning. According to Mezirow (1991), transformative learning begins with a problematic experience or disorienting dilemma that leads individuals to reexamine previously held assumptions. In this study, students' exposure to AI-generated outputs that are not always accurate can be seen as such a dilemma. Students are confronted with the fact that technology does not automatically provide correct answers, which challenges the earlier assumption that digital tools are inherently reliable. This experience encourages critical self-reflection, particularly in Biology learning, where conceptual precision and evidence-based reasoning are essential.

Consistent with Mezirow's concept of recognizing shared experience, both students and teachers appear to understand that the challenge of using AI critically is not an individual issue but a shared educational condition (Mezirow, 2009). This collective awareness opens space for the exploration of new roles within the learning process. Students begin to shift from being passive consumers of information to becoming critical evaluators who are responsible for assessing the validity, bias, and relevance of AI-generated content. At the same time, teachers experience a transformation in perspective as their role moves from content transmitter to facilitator of digital literacy and AI ethics, guiding students through critical and reflective learning processes. This shift reflects a broader reorientation in how technology is understood, from a mechanistic tool to a medium for cultivating scientific reasoning and reflective judgment (Gouseti et al., 2025).

The implementation of strategies such as guided inquiry, critical questioning, and source triangulation corresponds to Mezirow's phases of planning a course of action and acquiring new knowledge and skills (Mezirow, 1991). Through these approaches, students begin to engage in new learning practices that position AI as a tool for cognitive enhancement rather

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than as a substitute for thinking. When students are able to combine verification skills, bias recognition, and ethical reflection in their use of AI, they begin to enter the phase of reintegration, in which a new perspective is applied more consistently in everyday learning activities (Akgun & Greenhow, 2021). At this stage, Biology learning undergoes not only technological adaptation but also epistemic and moral transformation, with learning increasingly centered on sensemaking, academic integrity, and digital responsibility.

Thus, the integration of AI in Biology learning at MAN 2 Kota Malang does not merely produce technological innovation. It also initiates a transformative learning process in the sense described by Mezirow, beginning with a critical dilemma, followed by reflection and pedagogical dialogue, and leading to a shift in both students' learning practices and teachers' instructional roles. This transformation demonstrates that when AI use is supported by critical digital literacy and value-based ethics, it can contribute to a form of Biology learning that is more reflective, responsible, and relevant to the demands of the 21st century.

4. CONCLUSION

This study demonstrates that Biology learning at MAN 2 Kota Malang is undergoing a meaningful transformation through the implementation of digital literacy and the integration of AI ethics. The findings show that students have developed relatively strong technical competence in using AI, indicating that the focus of learning is shifting from basic access and operational use toward more critical, reflective, and ethically informed engagement. Nevertheless, gaps remain in students' ability to critically verify AI-generated information, identify potential bias, and consistently uphold academic integrity. In parallel, teachers have begun to incorporate AI, AR, and VR into Biology instruction as forms of pedagogical innovation, although challenges related to methodological preparedness and ethical understanding of AI use are still evident.

The study therefore confirms that transformative learning in the digital era cannot be reduced to technological proficiency alone. Rather, it requires the cultivation of metacognitive awareness, ethical values, and digital responsibility. For this reason, value-based learning strategies should become a central framework for fostering AI digital literacy in Biology education, so that the use of technology supports not only learning efficiency but also the development of students' scientific reasoning, moral awareness, and adaptive capacity. Accordingly, comprehensive and ethically grounded AI digital literacy should be regarded as an essential prerequisite for achieving transformative Biology learning that is aligned with the demands of the twenty-first century.

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