The Role of Artificial Intelligence in Enhancing Digital and Data Literacy among Secondary School Students: A Systematic Literature Review

Peran Kecerdasan Buatan dalam Meningkatkan Literasi Digital dan Literasi Data pada Siswa Sekolah Menengah: Tinjauan Literatur Sistematis

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Abstrak

Kemajuan kecerdasan buatan (Artificial Intelligence/AI) telah membawa perubahan signifikan dalam paradigma pembelajaran di sekolah menengah, khususnya terkait pengembangan literasi digital, literasi data, dan keterampilan abad ke-21. Penelitian ini bertujuan meninjau secara sistematis peran AI dalam memperkuat kemampuan tersebut melalui metode Systematic Literature Review (SLR), dengan menganalisis artikel ilmiah yang diterbitkan antara tahun 2020 hingga 2025 dari berbagai basis data internasional. Hasil kajian menunjukkan bahwa penerapan AI mampu mendorong pembelajaran yang adaptif dan terpersonalisasi, sekaligus meningkatkan kemampuan berpikir kritis, kolaboratif, dan kreatif siswa. Meskipun demikian, terdapat sejumlah tantangan, seperti keterbatasan infrastruktur teknologi, kesiapan guru dalam menggunakan AI, serta isu etika dan privasi data yang perlu diperhatikan. Secara keseluruhan, AI memiliki potensi besar sebagai katalis transformasi pendidikan yang inklusif, efektif, dan berkelanjutan, asalkan diiringi oleh kebijakan yang tepat dan peningkatan kompetensi pendidik dalam memanfaatkan teknologi secara optimal.

Kata Kunci: *Kecerdasan Buatan; Literasi Digital; Literasi Data; Keterampilan Abad ke-21; Pendidikan Sekolah Menengah*

The advancement of artificial intelligence (AI) has brought significant changes to the learning paradigm in secondary schools, particularly in the development of digital literacy, data literacy, and 21st-century skills. This study aims to systematically review the role of AI in enhancing these competencies through a Systematic Literature Review (SLR), analyzing scholarly articles published between 2020 and 2025 from various international databases. The findings indicate that AI implementation can foster adaptive and personalized learning, while also improving students' critical thinking, collaboration, and creativity skills. However, several challenges remain, including limited technological infrastructure, teacher readiness to utilize AI, and ethical and data privacy concerns that need careful consideration. Overall, AI has great potential as a catalyst for inclusive, effective, and sustainable educational transformation, provided it is supported by appropriate policies and enhanced educator competencies to optimize the use of technology.

Keywords: Artificial Intelligence; Digital Literacy; Data Literacy; 21st-Century Skills; Secondary Education.

1.   INTRODUCTION

The rapid advancement of technology has positioned *Artificial Intelligence (AI)* as one of the most significant innovations influencing various aspects of human life, including education (Anggraeni et al., 2025; Kim et al., 2022; Sidik, Rozak, et al., 2025). The utilization of *AI* in the educational domain has brought fundamental changes to the learning process, ranging from how students access and manage information to how educators design more effective teaching strategies (Crawford et al., 2023; Fatqurhohman, Damayanti, et al., 2025; Sidik, Rozak, et al., 2025). Moreover, *AI* plays an essential role in analyzing and evaluating learning outcomes through the use of more accurate and comprehensive data (Sanusi et al., 2022; Sidik et al., 2023). The integration of this technology not only enhances efficiency and automation within the educational system but also opens opportunities for the implementation of more adaptive, collaborative, and student-centered learning approaches (Crompton & Burke, 2023; Fatqurhohman, Syam, et al., 2025; Huang et al., 2021).

Along with the rapid advancement of digital transformation, there has been an increasing demand for the mastery of new competencies known as *digital literacy* and *data literacy* (Fitriani et al., 2025; Kansa & Kansa, 2021; Sidik, Irawijayanti, et al., 2025). *Digital literacy* encompasses the ability to understand, use, and evaluate information obtained through digital technologies effectively, critically, and ethically (Pangrazio & Selwyn, 2019; Reddy et al., 2023). Meanwhile, data literacy focuses on the ability to comprehend, analyze, interpret, and make decisions based on data accurately and responsibly (Akman et al., 2023; Michos et al., 2023; Yates & Carmi, 2020). Both forms of literacy serve as essential elements in developing *21st-century* skills that students must possess in order to adapt, actively participate, and think critically in navigating the dynamics of an information- and technology-based society.

The development of *digital literacy* and *data literacy* at the secondary education level has become an increasingly important and urgent aspect (Michos et al., 2023). Learners at this stage are in a phase of cognitive and social development that allows for the strengthening of critical thinking skills, problem-solving abilities, and ethical awareness in the use of technology (Fatqurhohman, 2025). Secondary schools play a strategic role in building a strong foundation of digital and *data literacy*, as students at this level begin to engage intensively with technology, both in learning activities and in daily life (R. Lin et al., 2023; Michos et al., 2023; Pangrazio & Selwyn, 2019). The integration of *Artificial Intelligence (AI)* into the learning process has the potential to serve as an effective strategy for enhancing both forms of literacy through approaches that are more adaptive, contextual, and oriented toward the development of *21st-century* competencies.

Various studies have shown that *Artificial Intelligence (AI)* holds great potential in supporting the learning process through a wide range of applications, such as adaptive learning systems, virtual assistants (*chatbots*), learning analytics, and automated assessment (Chen et al., 2020). These technologies enable the realization of personalized learning tailored to each student's abilities, needs, and learning styles (Su et al., 2023; Zhang & Aslan, 2021). Moreover, *AI* can provide real-time feedback and assist educators in identifying and addressing student's learning difficulties more effectively. Nevertheless, the implementation of *AI* in efforts to enhance digital and data literacy at the secondary school level still faces several challenges (Xu & Ouyang, 2022). Some of these include teachers' limited

understanding of AI concepts and applications, uneven school infrastructure readiness, and emerging issues related to ethics and student data privacy protection, all of which require serious attention in its implementation(Abulibdeh et al., 2024; Chen et al., 2020; Huang et al., 2021).

In addition, there remain differences in approaches and understandings regarding the contribution of *Artificial Intelligence (AI)* to the development of *digital* and *data literacy* (Asnawati et al., 2023). Some studies emphasize the role of *AI* as a technological tool that functions to enhance the efficiency and effectiveness of the learning process (Ouyang & Jiao, 2021; Zahara et al., 2023). Meanwhile, other studies view *AI* as a medium that can promote critical reflection, ethical awareness, and a deeper understanding of the dynamics of the digital world among students (Su et al., 2023). These differing perspectives indicate the need for a more comprehensive review to examine various viewpoints, empirical findings, and research gaps that still exist within the related literature.

Based on the aforementioned background, this study aims to conduct a systematic literature review (SLR) on the role of *Artificial Intelligence (AI)* in enhancing *digital literacy* and *data literacy* among secondary school students. This review focuses on identifying current research trends, applied approaches, as well as the challenges and opportunities that arise in the implementation of *AI* within secondary education settings. Through the analysis and synthesis of previous research findings, this article seeks to provide a comprehensive understanding of *AI's* potential in supporting the development of digital and data literacy competencies. Furthermore, the results of this review are expected to offer strategic and practical recommendations for educators, policymakers, and education researchers to optimize the use of *AI* in improving learning effectiveness in the era of *21st-century digital transformation*.

2.   METHOD

This study employs a *systematic literature review (SLR)* approach to obtain an in-depth and comprehensive understanding of the role of *Artificial Intelligence (AI)* in enhancing digital and data literacy among secondary school students. This approach was selected because it allows researchers to identify, evaluate, and synthesize previous research findings in a structured, objective, and transparent manner (Hiebl, 2023). The method also serves to minimize potential researcher bias and ensure that the conclusions drawn are based on valid and accountable empirical evidence. The review procedure follows the general principles of the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)* framework (Page et al., 2021), which includes four main stages: identification, screening, eligibility assessment, and inclusion of literature relevant to the research focus.

The literature search was conducted online through various reputable academic databases, including *Scopus, ERIC, SpringerLink, ScienceDirect,* and *Google Scholar*, to ensure a comprehensive and representative coverage of studies. The publication range used spans from 2018 to 2025, corresponding to the period of increasing adoption and utilization of *Artificial Intelligence (AI)* in the fields of education and digital learning (Asnawati et al., 2023; Diantama, 2023). The search strategy employed a combination of keywords such as "*artificial intelligence*," "*digital literacy*," "*data literacy*," "*secondary school*," and "*education*," applied in both English and Indonesian to broaden the scope of search results.

The initial search results were then systematically filtered based on their relevance to the research focus through the screening of titles, abstracts, and keywords, ensuring that only literature meeting the thematic and methodological criteria was included in the subsequent analysis.

The inclusion criteria of this review encompass articles that specifically discuss the application or role of *Artificial Intelligence (AI)* within the context of secondary education and highlight aspects of *digital literacy*, *data literacy*, or other relevant *21st-century skills*. The selected articles must be sourced from peer-reviewed academic journals or conference proceedings and published in either English or Indonesian. Conversely, non-academic articles, studies unrelated to the context of secondary education, or those that do not directly address the relationship between *AI* and the development of digital or data literacy were excluded from the analysis. The selection procedure was carried out gradually and systematically to ensure that only articles meeting the eligibility criteria and demonstrating significant academic contributions were included in the final stage of analysis.

After the selection process was completed, the articles that met the inclusion criteria were extracted to obtain relevant information and subsequently analyzed in depth. The collected data included the authors and year of publication, research objectives, forms of *Artificial Intelligence (AI)* implementation, literacy aspects examined, methodological approaches employed, as well as the main findings and their implications for educational practice. The data were then analyzed using a *thematic analysis* approach to identify patterns, trends, and research gaps emerging from the reviewed literature (Thompson, 2022). This approach enabled the researchers to organize the findings around key themes related to the role of *AI* in the development of digital and data literacy at the secondary school level, while also revealing the critical factors that influence the effectiveness and success of its implementation.

To ensure the validity and reliability of the review, the article selection process was carried out carefully and involved several stages of verification. Each article was independently reviewed by two researchers to minimize potential subjective bias in determining the relevance and eligibility of the analyzed literature. In cases where differing opinions arose, the final decision was reached through discussion until a consensus was achieved. Furthermore, the researchers utilized a standardized data extraction sheet to maintain consistency and accuracy in recording information from each article. The validated data were then synthesized narratively to develop a comprehensive understanding of the role of *Artificial Intelligence (AI)* in strengthening digital and data literacy among secondary school students.

3.   RESULTS AND DISCUSSION

This *systematic literature review* analyzed articles published between 2020 and 2025, focusing on the implementation of *Artificial Intelligence (AI)* in secondary education and its impact on student's *digital* and *data literacy*. The analyzed articles encompassed various types of research, including empirical studies, literature reviews, and reports on *AI* program implementations in secondary schools. The selection of articles was conducted systematically to ensure a representative coverage of diverse educational contexts, methodological approaches, and applied technological innovations.

The analysis revealed that *AI* implementation in secondary schools is not limited to technical aspects or the automation of learning processes but also plays a significant role in developing *21st-century skills*, *digital literacy*, and *data literacy* among students. From the thematic synthesis, five main themes regarding the role of AI emerged: (1) AI as a tool for *adaptive learning* and *personalized learning*, (2) *AI* in the development of *digital literacy*, (3) *AI* in enhancing *data literacy* and analytical thinking skills, (4) challenges and ethical implications of *AI* implementation, and (5) the impact of *AI* on strengthening *21st-century skills*.

These themes were identified through an in-depth analysis of research focus, methodologies employed, *AI* implementation contexts, and reported outcomes in each article. The findings underscore that *AI* use in secondary education is multidimensional, influencing students' cognitive, metacognitive, and ethical development. Based on the identification of these themes, the study's results are presented as follows.

3.1. Artificial Intelligence as a Tool for Adaptive Learning and Personalized Learning

The development of *Artificial Intelligence (AI)* technology in the field of education has opened up opportunities for the creation of more adaptive, targeted, and personalized learning systems. In the context of secondary education, the implementation of AI provides students with the opportunity to learn according to their individual abilities, interests, and learning pace. This technology operates by utilizing *machine learning* algorithms and *data analytics* to adjust learning materials, learning styles, and types of feedback that best meet each student's specific needs. Such an approach not only enhances the relevance and effectiveness of the learning process but also supports the development of students' learning autonomy and intrinsic motivation (Alenezi, 2024; C. C. Lin et al., 2023).

A study conducted by Alenezi (2024) in the *International Journal of Online and Smart Education* demonstrated that the implementation of *AI-based adaptive learning systems* at the secondary school level contributes significantly to improving students' learning outcomes and motivation, particularly among those with lower academic achievement. The system utilizes *real-time performance data analysis* to adjust the level of task difficulty, types of activities, and learning strategies most suitable to individual needs. The findings indicate that *AI-driven personalized learning* can help reduce learning outcome disparities among students while simultaneously enhancing their satisfaction and engagement in the learning process.

Singh (2024) in the *Asian Education and Learning Review*, emphasized that *Intelligent Tutoring Systems (ITS)* and *adaptive learning environments* supported by *Artificial Intelligence (AI)* are not intended to replace teachers' roles, but rather to strengthen their pedagogical functions. In *AI-based learning* models, teachers act as facilitators who guide the learning process, while AI is responsible for monitoring student progress, identifying learning difficulties, and automatically providing data-driven learning recommendations. This approach allows teachers to focus more on conceptual guidance, the development of critical and creative thinking skills, and the enhancement of meaningful interactions with students. Thus, AI serves as a supportive tool that helps reduce administrative and routine workloads while simultaneously improving teaching effectiveness in modern classrooms.

The systematic review conducted by (C. C. Lin et al., 2023) in *Smart Learning Environments (SpringerOpen)* affirmed that *Artificial Intelligence (AI)* makes a significant contribution to achieving the goals of sustainable education through the implementation of personalized learning. Based on an analysis of 47 publications, the study revealed that *AI-based Intelligent Tutoring Systems (ITS)* can enhance learning effectiveness by up to 25%, particularly in strengthening *self-regulated learning* abilities and metacognitive awareness. Through personalized learning systems, students are able to independently manage their learning strategies with the support of recommendations generated from learning data analysis. This approach not only reinforces learning autonomy but also encourages students to become more reflective and responsible for their own learning processes.

In the context of *digital literacy* and *data literacy*, *AI-supported adaptive learning systems* play an important role in encouraging students to develop analytical skills toward the personal data generated during the learning process. Through this process, students not only learn to use technology functionally but also gain an understanding of how digital data are utilized to support learning-related decision-making. Nevertheless, the effectiveness of implementing adaptive *AI* systems is highly dependent on contextual factors such as the readiness of school digital infrastructure, teacher competence and training, and ethical awareness in managing student data (Holmes et al., 2022; Sharples, 2023). (Holmes et al., 2022) emphasized that without adequate policy support and teacher capacity building, the use of *AI* may, in fact, widen the digital divide between schools with access to technology and those without. Therefore, *AI-based personalized learning* must be accompanied by comprehensive teacher training strategies, inclusive education policies, and evaluation systems that uphold the principles of equity and equal access to technology.

Overall, recent literature indicates that *Artificial Intelligence (AI)*, as an adaptive learning tool and a means of personalized learning, holds great potential in enhancing students' motivation, autonomy, and digital literacy at the secondary school level. This technology also contributes to supporting teachers in making more informed pedagogical decisions through the systematic and evidence-based use of learning data. Nevertheless, the effectiveness of *AI* implementation is determined not only by the sophistication of its technology but also by the synergy among technological, pedagogical, and educational policy aspects that promote an ethical, inclusive, and sustainable digital transformation. Such an integrative approach is essential to ensure that the use of AI truly supports humanistic and equitable educational goals in the digital learning era.

3.2. Artificial Intelligence in the Development of Digital Literacy

The role of *Artificial Intelligence (AI)* in developing students' digital literacy at the secondary school level has received growing attention in recent literature. In this context, *digital literacy* encompasses students' ability to access, evaluate, utilize, and create information using digital technologies in a critical, creative, and ethical manner (Akman et al., 2023; R. Lin et al., 2023). AI functions not merely as a technological tool but also as a catalyst for learning processes that foster active engagement and reflective thinking within digital environments (Diantama, 2023; Zahara et al., 2023).

AI makes a significant contribution by enhancing interactivity and personalization in digital learning activities that strengthen digital literacy. A study by Jantakun et al. (2025),

through a bibliometric analysis published by the *Canadian Center of Science and Education (CCSE)*, revealed a notable increase in the number of studies related to "*AI for digital literacy*" during the period 2015–2024, with "*integration of AI tools in digital education*" identified as one of the main research focuses. In practice, AI-based learning applications and digital media enable students to interact with adaptive and contextual content, thereby providing learning experiences that are more relevant to their needs and digital competencies.

Second, *digital literacy* enhanced through the application of *Artificial Intelligence (AI)* also encompasses evaluative and ethical dimensions in technology use. A study conducted Bećirović et al. (2025) examined *AI literacy* among secondary school students and found that students' level of understanding and ability to use *AI* positively correlated with their learning outcomes, self-efficacy, and academic achievement. These findings indicate that digital literacy is not limited to technical skills in accessing or utilizing technology but also involves critical awareness of the functions, limitations, and ethical implications of the technologies being used. Thus, the integration of *AI* in learning serves a dual function: helping students use technology effectively while fostering reflective awareness of how technology shapes thinking, learning, and interaction within digital.

Third, the literature emphasizes that the development of *AI-based digital literacy* does not solely depend on students as end-users but also on the readiness of teachers and the overall education system. A study Traga Philippakos & Rocconi (2025), published in *MDPI Education Sciences*, revealed that secondary school teachers who utilized *AI* tools in lesson planning, assessment, and digital interaction demonstrated higher levels of digital literacy awareness and utilization compared to those who did not use *AI*. However, the study also highlighted an urgent need for structured professional training and policy support to help teachers understand how *AI* works, its ethical implications, and its pedagogical potential. Therefore, strengthening digital literacy through *AI* occurs not only at the individual learner level, but also within the broader educational ecosystem, encompassing teacher capacity, institutional support, and policies that foster sustainable and responsible technology integration.

Fourth, the integration of *Artificial Intelligence (AI)* in the development of *digital literacy* still faces various structural and practical challenges. Limitations in digital infrastructure, unequal access to technology across schools, and teachers' low competency in effectively utilizing *AI* are recurring issues identified in multiple studies. Zheng (2025), in a study published in the *International Journal of Education and Sustainable Development (IJESD)*, examined the state of digital literacy among secondary school teachers in China during the *AI* era. The findings revealed that although awareness of *AI's* potential is increasing, there remains a degree of resistance toward adopting new technologies, along with constraints in resources and professional training. These results underscore that the successful implementation of *AI* in enhancing digital literacy cannot be separated from the overall readiness of the education system. Therefore, strategies for strengthening *AI-based digital literacy* must consider contextual factors such as continuous teacher training, infrastructure investment, and policies that ensure equitable access to technology across all educational institutions.

Overall, the literature indicates that the integration of *Artificial Intelligence (AI)* within secondary education holds significant potential to strengthen students' *digital literacy*. This potential is reflected through the implementation of adaptive learning, the enhancement of critical awareness of technology, the active involvement of teachers equipped with *AI literacy* competencies, and the establishment of educational policies that promote systemic and inclusive approaches. Nevertheless, optimizing AI's role in developing *digital literacy* requires strong synergy among the technological, pedagogical, and policy dimensions. These three components must function cohesively to ensure that the integration of *AI* not only enhances students' technical abilities in using digital tools but also fosters their critical, ethical, and reflective thinking regarding the use of technology in learning and in society.

3.3. Artificial Intelligence in Enhancing Data Literacy and Analytical Thinking Skills

In the increasingly data-driven landscape of education, *data literacy* has emerged as one of the key *21st-century* competencies that students must acquire (Ologbosere, 2023). *Data literacy* encompasses the ability to collect, comprehend, evaluate, and critically use data to make informed decisions. Within secondary education, the implementation of *Artificial Intelligence (AI)* plays a significant role in strengthening students' *data literacy* and analytical thinking skills (Pangrazio & Selwyn, 2019). This is achieved through two primary approaches: real-time data presentation and analysis, and the application of *project-based* and *simulation-based learning* (Salazar-Peña et al., 2023). Through *AI-supported learning systems*, students are not merely data consumers but also active participants in the process of interpreting and reflecting on the data they generate throughout their learning activities. Thus, *AI* serves as a catalyst for developing data analysis and critical thinking skills, while also encouraging students to understand the meaning and implications of data within broader and more applicable learning contexts.

Artificial Intelligence (AI) plays a crucial role in expanding students' access to data visualization and automated analysis, which were previously difficult to achieve at the secondary education level. Various studies have shown that the use of *AI-based learning* materials or worksheets can significantly enhance students' abilities in problem-solving, pattern recognition, and independent data interpretation (Agustiani et al., 2024; Sidik, Irawijayanti, et al., 2025). For instance, a study by Agustiani et al. (2024) conducted at a junior high school in Palembang revealed that the implementation of *AI-based worksheets* notably improved students' numeracy literacy, with learning outcomes reaching the high achievement category. These findings indicate that the integration of *AI* in learning processes extends beyond technological innovation substantively supports the development of analytical thinking and data literacy skills, which are essential components of *21st-century* education.

Through project- and simulation-based learning supported by *Artificial Intelligence (AI)*, students gain hands-on experience in analyzing data, testing hypotheses, and drawing conclusions based on empirical evidence. *AI-based learning systems* for the *K–12* level are capable of providing performance dashboards, activity recommendations, as well as real-time predictions and visualizations of learning progress. The Analytics at (Xiao et al., 2024) study titled "*ActiveAI: Enabling K-12 AI Literacy Education & Analytics at Scale*" revealed that large-scale *AI* learning platforms can effectively engage secondary school students in

the analysis of complex data, uncovering patterns related to prior knowledge and gender differences. These findings indicate that AI-based learning not only enhances data literacy, but also fosters students' awareness of scientific thinking processes and the ethical and meaningful use of data within the context of modern education.

A study by (Al-Abdullatif 2025) found that although the use of *AI* in *K–12* education is becoming increasingly widespread, there remain limited learning experiences that explicitly teach students about *AI* concepts, algorithmic transparency, and their ethical implications. Moreover, *AI* systems providing automated feedback can help students understand how their performance data are utilized to recommend subsequent learning activities transforming the learning process into an opportunity to explore data flows and evidence-based decision-making. However, several studies have also highlighted persistent challenges in implementing *AI* for *data literacy*, including the readiness of school technological infrastructure, limited teacher and student competencies in understanding and using *AI*, as well as issues related to data security and privacy. Without adequate policy support, infrastructure, and professional training, the application of *AI* risks widening the digital divide between schools with technological access and those without (Casal-Otero et al., 2023)

Overall, recent literature supports the view that the integration of *AI* in secondary schools can strengthen students' data literacy and analytical thinking, while simultaneously promoting a more reflective and *data-driven* learning culture. For optimal implementation, strategies are needed that include teacher training, provision of adequate devices and data access, and pedagogical designs that integrate data analysis as a core component of learning activities.

3.4.   Challenges and Ethical Implications of Artificial Intelligence Implementation

Although *Artificial Intelligence (AI)* offers significant potential for enhancing *digital literacy, data literacy,* and *personalized learning* at the secondary school level, its implementation presents various challenges and ethical implications. One major barrier is the readiness of infrastructure and technology access; schools with limited hardware, unstable internet connectivity, or inadequate data management systems may struggle to adopt *AI* effectively (Holmes et al., 2022). Additionally, teacher competency in using AI is a critical factor for successful implementation. Teachers who do not fully understand how *AI* systems operate or how to interpret student performance data risk underutilizing the technology, and may even misinterpret the data or recommendations generated by the system (Casal-Otero et al., 2023; Traga Philippakos & Rocconi, 2025). Therefore, successful *AI* integration requires adequate infrastructure support, professional capacity building for teachers, and educational policies that ensure equitable access and ethical use of technology.

From an ethical perspective, the implementation of *Artificial Intelligence (AI)* in secondary schools raises several critical questions regarding data privacy, algorithmic bias, and equitable access. *AI* systems that collect students' performance data in real time enable more adaptive and personalized learning, but they also pose risks of data breaches or unethical use of information (Jantakun et al., 2025; Zheng, 2025). Furthermore, non-transparent algorithms may introduce bias in assessments or learning recommendations, for example, favoring certain groups of students and creating inequities and disparities in

learning experiences (Sharples, 2023). Therefore, AI implementation in secondary education must be accompanied by data protection policies, algorithmic transparency, and bias mitigation efforts to ensure that the technology is used in an ethical, fair, and responsible manner.

Several studies have reported both similar and differing findings regarding the challenges and ethical implications of implementing *Artificial Intelligence (AI)* in secondary education. Akman et al. (2023) emphasized that algorithmic bias and data transparency are key issues that require attention, while (Jantakun et al., 2025) highlighted the importance of teacher readiness and AI literacy competencies as critical factors for successful implementation. On the other hand, Zheng (2025) provided a contextual perspective, showing that in some secondary schools in China, infrastructure limitations and social resistance constitute major barriers, unlike schools with more advanced technological capabilities. These findings underscore that the challenges of *AI* implementation are multidimensional, influenced by technological context, social factors, and prevailing educational policies. Therefore, *AI* implementation strategies must be tailored to the specific conditions of each school to ensure effectiveness and sustainability.

In addition to technical and infrastructure challenges, social and pedagogical resistance to new technologies also poses significant barriers to the integration of *Artificial Intelligence (AI)* in secondary education. Students, teachers, and parents often do not fully understand the role of *AI* or how their data are used, which can lead to distrust or concerns about the technology. Therefore, *AI* implementation requires a holistic approach that includes adequate infrastructure, professional training for teachers, and clear data usage policies and ethical procedures. Implementation strategies must also be inclusive to ensure that *AI* supports the learning process without negatively impacting students. Consequently, the success of *AI* integration depends not only on technological sophistication but also on good governance, fairness, and ethical awareness throughout the educational ecosystem. This approach allows *AI* to function as an effective, equitable, and sustainable learning support tool for all stakeholders involved.

3.5.   The Impact of Artificial Intelligence on Strengthening 21st-Century Skills

Artificial Intelligence (AI) has been recognized as a tool with significant potential to strengthen *21st-century skills*, including Critical Thinking, Creativity, Communication, and Collaboration commonly referred to as the 4C (Karakose & Tülübaş, 2023) . The impact of *AI* on these skills is complex and highly dependent on the interaction between students and teachers as well as the pedagogical design implemented. A literature study by (Trisnawati et al., 2023) indicated that the application of *AI* in education not only affects the *4C* but also enhances additional skills such as character and citizenship, forming a 6C framework (Character, Citizenship, Critical Thinking, Creativity, Collaboration, and Communication). The findings suggest that *AI* can support more personalized, interactive, and collaborative learning. However, excessive or uncontrolled use of this technology may potentially diminish students' critical and creative thinking abilities. Therefore, the integration of *AI* in secondary education must be balanced, ensuring that technology serves as a means to holistically strengthen *21st-century* skills, while maintaining the teacher's role as a facilitator and guide who directs students in using *AI* effectively and ethically.

The study conducted by Salhab & Aboushi (2025) examined the relationship between *Artificial Intelligence (AI) literacy, 21st-century skills*, and the level of *AI* acceptance among university students. The findings revealed that both *AI* literacy and *21st-century* skills have a moderate influence on students' acceptance of *AI* technology. This suggests that the higher the level of these literacies and skills, the more positive students' attitudes toward the use of *AI* in learning and academic life. However, the study also found that the overall level of *AI* literacy and *21st-century* skills among students remains moderate, indicating the need to strengthen higher education curricula to explicitly incorporate the development of *AI* literacy and *21st-century* competencies. This effort is crucial to ensure that students not only become users of technology, but also individuals who understand, manage, and adapt to the *AI* ecosystem in a critical and ethical manner.

A study conducted by (Krause et al., 2025) identified 14 essential skills that students need to interact effectively *with Artificial Intelligence (AI)*-based systems in educational contexts. These skills include *AI* literacy, critical thinking abilities, and the understanding and application of ethical *AI* practices. The study emphasizes that developing these competencies is not only important for maximizing the benefits of technology in learning but also crucial for ensuring that *AI* is used responsibly and ethically. Consequently, *21st-century* education needs to integrate curricula and teaching strategies that emphasize *AI* literacy, analytical skills, and ethical awareness, enabling students to use *AI* intelligently, critically, and sustainably across various learning contexts.

Although *Artificial Intelligence (AI)* holds great potential in supporting the development of *21st-century* skills, various studies have also highlighted concerns about its possible negative impacts. A study by Othmane (2024) revealed that most lecturers believe the use of *AI* may hinder the development of essential skills such as collaboration, communication, and critical thinking, as excessive dependence on automated systems can reduce human interaction and self-reflection. Similarly, Bauer et al. (2025) emphasized that while *AI* contributes to enhancing cognitive learning processes, there remain significant limitations related to algorithmic transparency, data bias, and the risk of technological overdependence. Both studies underline the importance of developing a comprehensive pedagogical framework and implementation strategies to ensure that AI functions as a supportive tool rather than a substitute in the cultivation of *21st-century* skills balancing cognitive, social, and ethical dimensions in the learning process.

Overall, various literature reviews indicate that *Artificial Intelligence (AI)* holds significant potential to enhance *21st-century skills*, particularly when applied wisely and in balance within learning contexts. Appropriate use of *AI* can strengthen students' critical thinking, creativity, collaboration, and communication through interactive, adaptive, and data-driven learning experiences. However, excessive reliance on *AI* without clear pedagogical guidance risks diminishing students' reflective capacity and independent thinking. Therefore, integrating *AI* into the education system should be accompanied by a comprehensive curriculum design oriented toward the holistic development of *21st-century* skills, encompassing cognitive, social, ethical, and digital dimensions. This approach ensures that *AI* serves as a supportive tool in the learning process not a replacement for human interaction and students' intellectual creativity.

4.   CONCLUSION

Based on a literature review covering studies published between 2020 and 2025, it can be concluded that *Artificial Intelligence (AI)* holds significant potential in strengthening *digital literacy, data literacy,* and *21st-century s*kills at the secondary education level. The implementation of *AI* not only enables more adaptive, responsive, and student-centered learning processes, but also creates opportunities for students to develop critical, analytical, and collaborative thinking through interactions with intelligent algorithm-based learning systems. Thus, *AI* serves as a catalyst for transformation in modern education, emphasizing the integration of technology and the development of higher-order cognitive competencies.

Artificial intelligence functions as an adaptive learning tool and a means of personalized education, allowing teachers to monitor student progress in real time, analyze individual needs, and adjust pedagogical strategies accordingly. In addition to improving learning effectiveness, *AI* contributes to the strengthening of digital and data literacy, particularly in developing students' abilities to interpret information, manage data, and make evidence-based decisions. Nevertheless, the success of AI implementation greatly depends on teacher readiness, the availability of digital infrastructure, and educational policies that promote innovation, collaboration, and equitable access to learning technologies.

On the other hand, the literature also indicates that the implementation of *AI* in secondary education faces a number of ethical and technical challenges that must be anticipated. Issues such as data privacy, algorithmic bias, and digital inequality among educational institutions may hinder the optimization of AI's potential in learning processes. Therefore, a clear ethical framework and regulatory standards are required to ensure student data security and algorithmic transparency within educational systems. Furthermore, teacher capacity building through continuous professional development is essential to ensure that educators can use *AI* technologies wisely, critically, and responsibly within *AI*-based learning contexts.

Overall, Artificial Intelligence holds great potential as a catalyst for 21st-century educational transformation when implemented in a balanced, contextual, and human-centered manner. The integration of AI into learning systems should aim to develop inclusive, ethical, and sustainable educational models, ensuring that technology functions not only as a supportive tool but also as a medium for fostering character, creativity, and social responsibility among learners. With a holistic and value-driven approach, AI can serve as a vital instrument in strengthening *21st-century* competencies, including critical thinking, communication, collaboration, and creativity.

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