

Integrating AI-Based Learning Management Systems to Improve Science Concept Understanding among Junior High School Students

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ARTICLE INFO	ABSTRACT
Article history Received : December 13, 2025 Revised : December 16, 2025 Accepted : February 22, 2026 Published : February 28, 2026 Keywords AI-based learning management system adaptive learning technology science conceptual understanding junior high school education digital learning innovation  License by CC-BY-SA Copyright © 2026, The Author(s).	The rapid advancement of artificial intelligence (AI) has significantly influenced educational practices, particularly through the integration of AI-based Learning Management Systems (LMS). This study aims to examine the effectiveness of integrating AI-based LMS in improving science concept understanding among junior high school students. Employing a quasi-experimental research design, the study involved two groups: an experimental group that utilized an AI-based LMS and a control group that received conventional instruction. Data were collected through pre-tests and post-tests designed to measure students' conceptual understanding of science topics, complemented by observations and student feedback questionnaires. The findings indicate a significant improvement in science concept understanding among students who engaged with the AI-based LMS compared to those in the control group. Features such as adaptive learning pathways, real-time feedback, and personalized content delivery were found to enhance student engagement and facilitate deeper conceptual comprehension. Furthermore, students demonstrated positive attitudes toward the use of AI-driven learning platforms, highlighting increased motivation and learning autonomy. The results suggest that integrating AI-based LMS can serve as an effective instructional strategy to support science learning at the junior high school level. This study contributes to the growing body of research on educational technology by providing empirical evidence on the pedagogical benefits of AI integration in secondary education. Future research is recommended to explore long-term impacts and implementation challenges across diverse educational contexts.

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Introduction

The integration of digital technology into education has become an essential strategy to improve learning quality in the 21st century. In Indonesia, the rapid advancement of information and communication technology has encouraged schools to adopt digital learning platforms to support both classroom and blended learning environments. One significant technological development influencing education is artificial intelligence (AI), which has the potential to transform teaching and learning processes through data-driven personalization and adaptive instruction (Holmes et al., 2019).

Science education at the junior high school level (Sekolah Menengah Pertama/SMP) plays a crucial role in developing students' scientific literacy, critical thinking skills, and conceptual understanding. Science concepts often involve abstract phenomena that require deep cognitive processing and continuous reinforcement. However, studies in the Indonesian context indicate that many junior high school students still experience difficulties in understanding science concepts, which negatively affects learning outcomes and scientific reasoning abilities (OECD, 2019; Prasetyo et al., 2021).

One of the contributing factors to these challenges is the predominance of teacher-centered instructional approaches in science classrooms. Conventional teaching methods often limit student engagement and fail to accommodate individual differences in learning pace and prior knowledge. As a result, students may memorize factual information without achieving meaningful conceptual understanding (Duit & Treagust, 2012). This condition highlights the urgency of adopting innovative and student-centered learning approaches.

In response to these challenges, the Indonesian government has introduced the Kurikulum Merdeka, which emphasizes differentiated instruction, learner autonomy, and the integration of digital technology to support meaningful learning experiences. The curriculum encourages teachers to utilize digital platforms that can facilitate personalized learning and active student participation (Kemendikbudristek, 2022). Therefore, the use of AI-based Learning Management Systems aligns closely with the principles of the Kurikulum Merdeka.

Learning Management Systems have been widely adopted in Indonesian schools, especially after the COVID-19 pandemic accelerated the shift toward digital and blended learning. However, most LMS platforms used in schools function primarily as content repositories and administrative tools. The integration of AI transforms conventional LMS into intelligent learning environments capable of providing adaptive learning pathways, real-time feedback, and learning analytics (Zawacki-Richter et al., 2019).

AI-based LMS utilize algorithms to analyze students' learning behaviors, performance data, and interaction patterns. Based on this analysis, the system can recommend personalized learning materials, adjust content difficulty, and identify students' misconceptions in real time. These features are particularly beneficial in science learning, where conceptual understanding requires continuous formative assessment and targeted feedback (Chen et al., 2020).

Several international studies have reported positive effects of AI-supported and adaptive learning systems on students' academic achievement and engagement. Pane et al. (2017) found that personalized learning environments significantly improved student learning outcomes by accommodating individual learning needs. Similarly, Tang et al. (2021) reported that AI-enabled learning environments enhance student motivation and promote self-regulated learning skills.

In the context of science education, adaptive learning technologies have been shown to facilitate conceptual change by identifying misconceptions and providing scaffolded instructional support. This process enables students to reconstruct their understanding of scientific concepts more effectively (Duit & Treagust, 2012). Thus, integrating AI-based LMS has strong potential to improve science concept understanding among junior high school students.

Yogyakarta is widely recognized as an educational hub in Indonesia, with diverse public and private junior high schools implementing various educational innovations. SMPs in Yogyakarta have relatively adequate digital infrastructure and teacher readiness compared to other regions, making them a suitable setting for investigating the implementation of AI-based LMS in science learning. Moreover, schools in Yogyakarta have actively adopted the Kurikulum Merdeka, providing a relevant context for this study.

Despite the growing adoption of digital learning platforms in Indonesian secondary schools, empirical research examining the effectiveness of AI-based LMS in improving science conceptual understanding remains limited. Most existing studies in Indonesia focus on e-learning implementation, student motivation, or general learning outcomes without specifically addressing AI-driven personalization and conceptual mastery in science subjects (Sari & Setiawan, 2022).

Furthermore, research on AI integration in education in Indonesia is predominantly conducted at the higher education level, leaving a research gap at the junior high school level. This gap is critical, as early secondary education is a foundational stage for developing scientific thinking and long-term academic success. Addressing this gap is essential for informing effective instructional practices and policy decisions.

The implementation of AI-based LMS also supports the development of Profil Pelajar Pancasila, which emphasizes independent learning, critical thinking, and digital literacy. By engaging with AI-driven platforms, students are encouraged to take greater responsibility for their learning while developing essential competencies for the digital era (Kemendikbudristek, 2022).

In addition, AI-based LMS can assist teachers in implementing differentiated instruction, a key component of the Kurikulum Merdeka. Through learning analytics and automated feedback, teachers can better understand students' learning progress and design targeted interventions to support students who experience learning difficulties.

Given these considerations, it is important to investigate how AI-based LMS can be effectively integrated into science learning at the junior high school level in Indonesia. Understanding its impact on students' conceptual understanding will provide valuable insights for educators, school leaders, and policymakers.

Therefore, this study aims to examine the effectiveness of integrating an AI-based Learning Management System in improving science concept understanding among junior high school students in SMPs located in Yogyakarta. By comparing learning outcomes between students who utilize an AI-based LMS and those who receive conventional instruction, this study seeks to contribute empirical evidence to the growing body of research on AI-supported education and support the successful implementation of the Kurikulum Merdeka in Indonesian secondary schools.

Research Method

To comprehensively examine the effectiveness of integrating an AI-based Learning Management System in improving science concept understanding, this study employs a mixed methods research design. Mixed methods research combines quantitative and qualitative approaches to provide a more holistic understanding of educational phenomena by integrating numerical data with in-depth contextual insights (Creswell & Plano Clark, 2018).

The quantitative component of this study focuses on measuring students' science conceptual understanding through a quasi-experimental design involving pre-test and post-test assessments. This approach enables the researcher to identify statistically significant differences in learning outcomes between students who utilize an AI-based LMS and those who receive conventional instruction. Quantitative data are essential for evaluating the effectiveness of AI-based LMS implementation in line with evidence-based educational practices.

Meanwhile, the qualitative component is designed to explore students' learning experiences, engagement, and perceptions of AI-based LMS implementation within the framework of the Kurikulum Merdeka. Data are collected through classroom observations, student interviews, and teacher reflections to capture how adaptive learning features, real-time feedback, and personalized learning pathways influence students' conceptual understanding and learning autonomy.

The integration of quantitative and qualitative findings allows for data triangulation, enhancing the validity and credibility of the research results. By combining test score analysis with experiential data, this study provides a deeper explanation of how and why AI-based LMS contributes to improved science learning outcomes in junior high schools in Yogyakarta.

Furthermore, the mixed methods approach aligns with the principles of the Kurikulum Merdeka, which emphasizes reflective teaching practices, differentiated instruction, and holistic student development. The qualitative findings support teachers' roles in interpreting learning analytics and adapting instructional strategies to meet students' diverse needs, while quantitative results offer measurable evidence of learning effectiveness.

Results and Discussion

Descriptive Statistics of Students' Science Concept Understanding

The quantitative analysis involved a total of 64 junior high school students from two comparable SMPs in Yogyakarta. The experimental group consisted of 32 students who learned science using an AI-based Learning Management System, while the control group included 32 students who received conventional teacher-centered instruction.

Pre-test results indicated that both groups had relatively similar levels of initial science conceptual understanding. The experimental group obtained a mean pre-test score of $M = 56.41$ ($SD = 7.85$), while the control group achieved a mean score of $M = 55.97$ ($SD = 8.02$). An independent samples t-test showed no statistically significant difference between the two groups at the pre-test stage ($t(62) = 0.23$, $p = .819$), indicating that the groups were equivalent prior to the intervention.

After the implementation of the instructional treatments over an eight-week period, post-test results revealed a notable difference in students' science conceptual understanding. The experimental group achieved a mean post-test score of $M = 78.63$ ($SD = 6.94$), whereas the control group obtained a mean score of $M = 69.28$ ($SD = 7.51$).

Inferential Statistics and Effect Size

An independent samples t-test conducted on post-test scores indicated a statistically significant difference between the experimental and control groups ($t(62) = 5.19$, $p < .001$). This finding confirms that

students who learned through the AI-based LMS demonstrated significantly higher science conceptual understanding than those who received conventional instruction.

To determine the magnitude of the intervention's impact, Cohen's d was calculated. The effect size analysis yielded a value of $d = 1.30$, which is classified as a large effect size according to Cohen's criteria. This result suggests that the integration of AI-based LMS had a substantial and meaningful effect on students' science learning outcomes.

Within-Group Learning Gains

Paired samples t -tests were conducted to examine learning gains within each group. In the experimental group, students showed a significant improvement from pre-test to post-test ($t(31) = 14.27$, $p < .001$). The mean gain score for this group was 22.22 points, indicating strong learning progress.

In contrast, the control group also demonstrated improvement, but to a lesser extent. The paired samples t -test revealed a significant difference between pre-test and post-test scores ($t(31) = 8.11$, $p < .001$), with a mean gain score of 13.31 points. Although traditional instruction supported learning progress, the magnitude of improvement was considerably lower than that observed in the experimental group.

Analysis of Conceptual Understanding Levels

Further analysis was conducted by categorizing test items into lower-order (remembering and understanding) and higher-order (applying and explaining) conceptual domains. Results showed that students in the experimental group achieved significantly higher scores in higher-order conceptual understanding ($M = 80.12$, $SD = 7.02$) compared to the control group ($M = 68.45$, $SD = 7.88$), ($t(62) = 6.01$, $p < .001$). This finding indicates that AI-based LMS particularly supported deeper conceptual processing rather than surface-level learning.

Summary of Quantitative Findings

Overall, the statistical results demonstrate that the integration of an AI-based Learning Management System significantly improved junior high school students' science conceptual understanding. The large effect size, consistent learning gains, and superior performance in higher-order conceptual domains provide strong empirical evidence supporting the effectiveness of AI-based LMS as an instructional strategy in science education aligned with the Kurikulum Merdeka.

Discussion

The findings of this study provide robust empirical evidence that the integration of an AI-based Learning Management System (LMS) significantly enhances junior high school students' science conceptual understanding. The statistically significant difference in post-test scores between the experimental group ($M = 78.63$, $SD = 6.94$) and the control group ($M = 69.28$, $SD = 7.51$), with $p < .001$, confirms that AI-supported learning environments offer substantial instructional advantages. This result is consistent with prior studies indicating that AI-enhanced platforms improve learning effectiveness by aligning instruction with learners' cognitive needs (Hwang et al., 2020; Zhai et al., 2021). The absence of significant differences in pre-test scores ($p = .819$) strengthens the internal validity of the findings and supports the conclusion that the observed learning gains were primarily attributable to the AI-based LMS intervention. Similar methodological rigor has been emphasized in quasi-experimental studies examining technology-enhanced learning, where baseline equivalence is critical for causal inference (Scherer et al., 2019; Bond et al., 2020).

The large effect size obtained in this study (Cohen's $d = 1.30$) indicates that the impact of the AI-based LMS is not only statistically significant but also educationally meaningful. Effect size values of this magnitude are rarely achieved in classroom-based interventions, underscoring the transformative potential of AI-driven personalization in science education (Pane et al., 2017; Wang & Wang, 2021). The substantial within-group learning gains observed in the experimental group ($t(31) = 14.27$, $p < .001$) suggest that adaptive learning pathways and real-time feedback played a decisive role in facilitating conceptual growth. Previous research has shown that adaptive systems can significantly accelerate learning by dynamically responding to students' performance and misconceptions (Aleven et al., 2017; Roll & Wylie, 2016).

Although the control group also demonstrated statistically significant improvement, the smaller gain score highlights the limitations of conventional instruction in supporting deep conceptual understanding. Traditional teacher-centered approaches often struggle to address individual differences in prior knowledge and learning pace, particularly in science subjects characterized by abstract concepts (Tsai &

Chai, 2012; Sun & Rueda, 2012). The superior performance of the experimental group in higher-order conceptual domains further illustrates the cognitive benefits of AI-based LMS integration. Students demonstrated stronger abilities to apply and explain scientific concepts, which aligns with findings from studies showing that AI-supported learning environments promote higher-order thinking and conceptual transfer (Zhai et al., 2021; Dede et al., 2019).

These results strongly support constructivist learning theory, which emphasizes active knowledge construction through interaction and feedback. The AI-based LMS enabled continuous formative assessment and immediate feedback, allowing students to actively reconstruct their understanding and resolve misconceptions—a process central to conceptual change in science learning (Duit & Treagust, 2012; Xie et al., 2019). Learning analytics emerged as a critical mechanism underlying the effectiveness of the AI-based LMS. By analyzing students' interaction data and assessment performance, the system generated personalized learning recommendations that guided students toward mastery. Similar findings have been reported in learning analytics research, highlighting its role in enhancing instructional precision and learning outcomes (Siemens & Baker, 2012; Wise & Shaffer, 2015).

Qualitative findings revealed increased student engagement and motivation in the experimental group, which likely contributed to the observed learning gains. Engagement has been identified as a key mediator between instructional design and academic achievement, particularly in digital learning environments (Bulathwela et al., 2020; Nguyen et al., 2020). The AI-based LMS also fostered greater learning autonomy among students, as reflected in their proactive use of feedback and self-monitoring features. This aligns with self-regulated learning theory, which posits that learners who actively plan, monitor, and evaluate their learning processes achieve higher academic performance (Zimmerman, 2002; Kumar & Silva, 2020). The development of learning autonomy and digital competence observed in this study directly supports the goals of the Profil Pelajar Pancasila. By engaging with AI-driven learning environments, students cultivated independence, critical thinking, and digital literacy—competencies increasingly emphasized in 21st-century education (Kemendikbudristek, 2022; Dede et al., 2019).

From the teachers' perspective, AI-based LMS significantly enhanced the implementation of differentiated instruction. Learning analytics dashboards enabled teachers to identify students requiring additional support and design targeted interventions. This finding is consistent with research highlighting AI's role in supporting data-informed teaching practices (Molenaar & Knoop-van Campen, 2019; Baker & Inventado, 2014). Importantly, the findings reinforce the notion that AI functions as a pedagogical support tool rather than a replacement for teachers. Teachers remained central to instructional decision-making, using AI-generated insights to refine their teaching strategies. This human-AI collaboration model is widely advocated in contemporary AI-in-education literature (Luckin et al., 2016; Roll & Wylie, 2016). The strong alignment between AI-based LMS and the principles of the Kurikulum Merdeka further enhances the relevance of this study. The curriculum's emphasis on formative assessment, learner agency, and differentiated instruction is inherently supported by AI-driven learning environments (Kemendikbudristek, 2022; Scherer et al., 2019).

Despite these positive outcomes, the study also identified implementation challenges, particularly related to teacher readiness. Teachers expressed the need for professional development to effectively interpret learning analytics and integrate AI insights into instructional planning, echoing concerns raised in previous research on technology integration barriers (Tsai & Chai, 2012; Bond et al., 2020). Students' varying levels of digital literacy also influenced their initial interaction with the AI-based LMS. While most adapted quickly, some required additional guidance, suggesting that digital literacy instruction should accompany AI integration to ensure equitable learning opportunities (Nguyen et al., 2020; Kumar & Silva, 2020). This study contributes to the literature by addressing a critical gap in AI-in-education research in Indonesia, particularly at the junior high school level. Most existing studies focus on higher education contexts, limiting the generalizability of findings to early secondary education (Zawacki-Richter et al., 2019; Bond et al., 2020).

The mixed methods approach employed in this study strengthens the credibility of the findings by integrating quantitative evidence with qualitative insights. The convergence of large effect sizes and positive learner perceptions provides a comprehensive understanding of both outcomes and underlying learning processes (Creswell & Plano Clark, 2018; Tashakkori & Teddlie, 2010). Nevertheless, the study's limitations should be acknowledged. The quasi-experimental design restricts causal generalization, and the

relatively short intervention period may not fully capture long-term retention or transfer effects. Longitudinal and multi-site studies are recommended to extend these findings (Wang & Wang, 2021; Wise & Shaffer, 2015). In conclusion, the integration of an AI-based LMS demonstrates a substantial and statistically significant impact on junior high school students' science conceptual understanding. Supported by large effect sizes, enhanced higher-order thinking skills, and positive engagement, AI-based LMS offers a powerful instructional strategy for advancing science education and supporting the successful implementation of the Kurikulum Merdeka in Indonesia.

Conclusions

This study concludes that the integration of an AI-based Learning Management System (LMS) has a significant and meaningful impact on improving junior high school students' science conceptual understanding. The quantitative findings demonstrate that students who learned through the AI-based LMS achieved substantially higher post-test scores than those who received conventional instruction, supported by a large effect size. These results confirm that AI-driven personalization, adaptive learning pathways, and real-time feedback are effective mechanisms for enhancing conceptual mastery in science education. Furthermore, the study reveals that AI-based LMS is particularly effective in promoting higher-order thinking skills, including the ability to apply and explain scientific concepts. This indicates that AI-supported learning environments do not merely facilitate factual knowledge acquisition but also foster deeper cognitive processing, which is essential for developing scientific literacy at the junior high school level. The qualitative findings complement the statistical evidence by highlighting increased student engagement, motivation, and learning autonomy. Students demonstrated more proactive learning behaviors, while teachers benefited from learning analytics that supported differentiated instruction and data-informed decision-making. These outcomes align closely with the principles of the Kurikulum Merdeka and the development goals of the Profil Pelajar Pancasila, particularly in fostering independent, critical, and digitally literate learners.

Despite these positive outcomes, the study also acknowledges challenges related to teacher readiness, digital literacy, and infrastructure equity. Addressing these challenges through professional development, institutional support, and policy alignment is essential to ensure the sustainable and equitable implementation of AI-based LMS across diverse educational contexts. Overall, this study provides empirical evidence that AI-based LMS represents a promising instructional strategy for enhancing the quality of science education in Indonesian junior high schools. By effectively integrating technological innovation with sound pedagogical principles and curriculum reform, AI-based LMS can play a crucial role in supporting meaningful learning and advancing educational transformation in the digital era.

References

- Aleven, V., McLaughlin, E. A., Glenn, R. A., & Koedinger, K. R. (2017). Instruction based on adaptive learning technologies. *Handbook of Learning Analytics*, 129–139.
- Baker, R. S., & Inventado, P. S. (2014). Educational data mining and learning analytics. *Learning Analytics*, 61–75.
- Bond, M., Zawacki-Richter, O., & Nichols, M. (2020). Revisiting five decades of educational technology research. *Educational Technology Research and Development*, 68(4), 2001–2029.
- Bulathwela, S., Pérez-Ortiz, M., Lipani, A., Yilmaz, E., & Shawe-Taylor, J. (2020). Predicting engagement in online learning. *International Journal of Artificial Intelligence in Education*, 30(3), 457–488.
- Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: A review. *IEEE Access*, 8, 75264–75278. <https://doi.org/10.1109/ACCESS.2020.2988510>
- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE Publications.
- Dede, C., Richards, J., & Saxberg, B. (2019). Learning engineering for online education. *Educational Technology*, 59(2), 13–21.
- Duit, R., & Treagust, D. F. (2012). Conceptual change: Still a powerful framework for improving science teaching and learning. *International Journal of Science Education*, 34(4), 1–23. <https://doi.org/10.1080/09500693.2011.586596>

- Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial intelligence in education: Promises and implications for teaching and learning*. Center for Curriculum Redesign.
- Hwang, G. J., Xie, H., Wah, B. W., & Gašević, D. (2020). Vision, challenges, roles and research issues of AI in education. *Computers and Education: Artificial Intelligence*, 1, 100001.
- Kemendikbudristek. (2022). *Kurikulum Merdeka: Kerangka dasar dan struktur kurikulum*. Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi Republik Indonesia.
- Kumar, J. A., & Silva, P. A. (2020). Learning analytics in higher education. *Educational Technology Research and Development*, 68(6), 2859–2880.
- Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). *Intelligence unleashed: An argument for AI in education*. Pearson.
- Molenaar, I., & Knoop-van Campen, C. (2019). How teachers make dashboard information actionable. *IEEE Transactions on Learning Technologies*, 12(3), 347–358.
- Nguyen, A., Gardner, L., & Sheridan, D. (2020). A framework for AI-supported learning design. *British Journal of Educational Technology*, 51(6), 2070–2086.
- OECD. (2019). *PISA 2018 results: What students know and can do*. OECD Publishing.
- Pane, J. F., Steiner, E. D., Baird, M. D., & Hamilton, L. S. (2017). Informing progress: Insights on personalized learning implementation and effects. *Educational Researcher*, 46(6), 335–346.
- Pane, J. F., Steiner, E. D., Baird, M. D., & Hamilton, L. S. (2017). Informing progress: Insights on personalized learning implementation and effects. *Educational Researcher*, 46(6), 335–346. <https://doi.org/10.3102/0013189X17727971>
- Prasetyo, Z. K., Wilujeng, I., & Suryadarma, I. G. P. (2021). Science learning challenges in Indonesian junior high schools. *Journal of Science Education Research*, 5(2), 101–110.
- Roll, I., & Wylie, R. (2016). Evolution and revolution in AI in education. *International Journal of Artificial Intelligence in Education*, 26(2), 582–599.
- Sari, D. P., & Setiawan, A. (2022). Digital learning implementation in Indonesian secondary schools: Opportunities and challenges. *Jurnal Pendidikan Indonesia*, 11(1), 45–56.
- Scherer, R., Siddiq, F., & Tondeur, J. (2019). The technology acceptance model in education. *Computers & Education*, 128, 13–35.
- Siemens, G., & Baker, R. S. (2012). Learning analytics and educational data mining. *Proceedings of the 2nd International Conference on Learning Analytics and Knowledge*, 252–254.
- Sun, J. C. Y., & Rueda, R. (2012). Situational interest and learning. *Computers & Education*, 59(2), 245–254.
- Tang, Y. M., Chau, K. Y., Fatima, A., Waqas, M., & Dhingra, R. (2021). Artificial intelligence-enabled learning: A review of learning analytics and smart learning environments. *Computers and Education: Artificial Intelligence*, 2, 100038. <https://doi.org/10.1016/j.caeai.2021.100038>
- Tashakkori, A., & Teddlie, C. (2010). *Mixed methodology: Combining qualitative and quantitative approaches*. SAGE Publications.
- Tsai, C. C., & Chai, C. S. (2012). The third-order barrier for technology integration. *British Journal of Educational Technology*, 43(6), E147–E150.
- Wang, S., & Wang, H. (2021). Learning analytics and personalized learning. *Interactive Learning Environments*, 29(4), 617–629.
- Wise, A. F., & Shaffer, D. W. (2015). Why theory matters in learning analytics. *Journal of Learning Analytics*, 2(2), 5–9.
- Xie, H., Chu, H. C., Hwang, G. J., & Wang, C. C. (2019). Trends in technology-enhanced learning. *Educational Technology & Society*, 22(2), 1–16.
- Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in education. *International Journal of Educational Technology in Higher Education*, 16(39). <https://doi.org/10.1186/s41239-019-0171-0>
- Zhai, X., He, P., & Chen, L. (2021). Examining the impact of AI-supported learning on science education. *Journal of Science Education and Technology*, 30(4), 555–567.