

Enhancing Student Learning and Engagement Through AI-Enhanced Instructional Materials: A Study on Personalized Education and Interactivity

S. H. M. Phua¹, Choo. W. R. Chiong², and W. H. D. Chai^{1*}

¹Department of Arts and Commerce, Curtin University Malaysia, 98009 Miri, Sarawak, Malaysia

²Department of Electrical and Computer Engineering, Curtin University Malaysia, 98009 Miri, Sarawak, Malaysia

*Correspondence: delon.chai@curtin.edu.my

SUBMITTED: 1 May 2026; REVISED: 24 May 2026; ACCEPTED: 28 May 2026

ABSTRACT: This paper explored the potential of AI-enhanced instructional materials to improve student learning outcomes and engagement, aligning with the principles of Education 4.0 and the Malaysian Higher Education Blueprint. The integration of AI into educational content enables personalized learning experiences, addressing individual gaps in understanding while catering to diverse learning styles and paces. AI's capability to analyze data and adapt content dynamically supports the goals of Education 4.0, which emphasizes personalized and technology-driven learning experiences. By incorporating interactive elements such as quizzes and real-time feedback, AI platforms promote active student participation and reflection, which are crucial for knowledge retention and critical thinking. The study employs a mixed-methods approach by incorporating both quantitative and qualitative analyses to assess the impact of AI integration. Quantitative data was gathered through assessments and surveys, measuring improvements in learning outcomes and student engagement. Qualitative insights were obtained from focus group discussions and interviews, providing deeper understanding of student experiences and perceptions. The findings suggest that AI can help educators shift from traditional, didactic teaching methods to more responsive, student-centered approaches. This transition prepares students with the necessary skills and competencies for the 21st century. The advancement of educational technology through AI offers significant benefits in equipping students for the digital age, fostering critical thinking, creativity, and lifelong learning.

KEYWORDS: Artificial Intelligence; Education 4.0; instructional materials; personalized education

1. Introduction

In today's rapidly evolving Information and Communication Technology (ICT) and educational landscape, it is important for educators to integrate advanced technologies such as Artificial Intelligence (AI) into instructional materials to enhance students learning experiences and learning outcomes to prepare them for the challenges of the future. The Malaysia Education Blueprint 2013- 2025 and Malaysia National Education Philosophy

highlighted the importance of transforming the country's educational system by utilizing technology to build holistic, balanced and inclusive overall development of students.

The goal of the Blueprint is for educators to embrace innovation in teaching methods by shifting towards incorporating technology to address diverse students needs and to promote higher-order thinking skills in education. This is also in line with the country's national education philosophy where it is emphasized that it is important for the education system to produce individuals who are intellectually, spiritually, emotionally and physically balanced and well-rounded. The integration of AI into the learning environment of students is one of the approaches to realize the goals of the Blueprint and educational philosophy by enabling educators to personalize their students' learning, provide real-time feedback in classes and having real time data and insights into their students' performance [1].

The objective of this paper is to develop, implement and evaluate AI-enhanced instructional materials that is tailored for a pre-university class – a one-hour tutorial class covering the topic Introduction to Accounting – Journal Entries. This paper will show how AI integrated into instructional materials can create effective, engaging and personalized learning experiences for students. This paper will provide an overview of the development, implementation and evaluation of AI-enhanced instructional materials. The development phase of this paper will explain the design and the creation of learning materials that incorporate AI functionalities to support the achievement of learning objectives. The implementation phase in this paper will describe how this AI-enhanced learning is integrated into the one-hour Introduction to Accounting-Recording Journal Entries lesson. Finally, the evaluation phase will provide the analysis of the effectiveness of the created AI-enhanced materials. Findings and data as well as areas for future improvement will be provided based on students' performance and feedback.

2. Instructional Materials

2.1. Description of AI-enhanced instructional materials.

The AI-enhanced instructional materials developed for this one-hour *Introduction to Accounting – Recording Journal Entries* lesson consisted of a set of interactive slides and teaching resources tailored to diverse students' learning needs, styles, and preferences. The materials were developed using PearDeck, a platform with AI-enabled functionalities that were utilized to enhance student engagement and learning experiences. The first key component of these materials was the integration of interactive slides to teach the five main types of accounts, their classifications, the rules of debit and credit, and journal entries. Using the PearDeck platform, lecturers imported PowerPoint slides and embedded questions to increase student engagement. In addition, lecturers created AI-generated videos using InVideo and included them as links within the slides for students to access during the lesson. The interactive slides included questions that gauged students' understanding of key concepts, including assets, liabilities, equity, revenue, and expenses.

The AI algorithm in PearDeck helped lecturers analyze students' performance in real time and enabled adjustments to instructional delivery within the platform [2]. This ensured that each student progressed at their own pace, while lecturers acted as facilitators by providing additional support where needed [3]. Formative assessments were embedded to evaluate students' understanding of key topics, including definitions of account types, account classifications, debit and credit rules, and journal entries. Performance data analyzed through

AI provided lecturers with insights into students' progress. Real-time feedback also enabled students to reflect on their understanding and allowed lecturers to address misconceptions immediately [4]. For students who preferred activity-based learning, gamification elements were incorporated into the PearDeck platform. Students engaged with materials through game-based learning activities, making the learning experience more interactive and enjoyable.

2.2. Context of use.

The AI-enhanced instructional materials for *Introduction to Accounting – Recording Journal Entries* were used in a pre-university classroom setting. The materials were implemented in a one-hour tutorial session using the PearDeck platform. Each class consisted of a maximum of 30 students. Students accessed the materials either individually or during class sessions. To use the materials independently, students selected the Student-Paced mode in PearDeck, which allowed them to explore the topic at their own pace. This approach aligned with the benefits of AI-integrated learning, enabling personalized and self-paced learning experiences [5].

2.3. Learning and graphic design principles with AI integration.

The instructional materials developed in PearDeck were designed to promote active learning, allowing students to construct their own understanding through exploration, interaction with slides and activities, and reflection on assessment outcomes [6]. This approach aligned with constructivist learning theory, where students actively participated in their learning process [7]. Given the multiple learning objectives required to master journal entry recording, the instructional design incorporated scaffolding techniques. The learning process involved teaching definitions of accounts, classification into five main account types, rules of debit and credit, and finally, recording business transactions in journal entries. This structured approach helped students build on prior knowledge and progressively develop a deeper understanding of the accounting system. The graphic design principles applied in PearDeck emphasized clarity and visual hierarchy to guide students' attention to key information [8]. This was achieved through appropriate use of font size, color, and layout. Consistent design elements ensured smooth navigation throughout the materials. PearDeck's interactive features—such as draggable items, short-answer questions, and clickable elements—enhanced engagement and promoted hands-on learning.

The AI-powered tools within PearDeck enabled lecturers to predict student performance based on formative assessment responses. This allowed lecturers to identify misconceptions and learning difficulties. Consequently, lecturers used these insights to provide targeted interventions and real-time support to students [9]. The Materials and Methods section should describe the materials used in the study, specifying brands, models, and relevant characteristics, as well as the suppliers or manufacturers. It should also include any preparation or treatment of these materials before use. The study design should be outlined, detailing any experimental or observational approaches. Procedures should be thoroughly described, including protocols, techniques, and tools used. Data collection methods should be explained, including the instruments and techniques employed for measurement. The section should also cover data analysis methods, specifying any statistical tests or software used. Lastly, any ethical approvals or considerations relevant to the study should be mentioned.

3. Evaluation Plan

3.1. Design of evaluation plan.

In designing the evaluation plan, it was important to measure students' knowledge before and after utilizing the AI-enhanced instructional materials [10]. Thus, the first data collection method used to evaluate the effectiveness of the instructional materials for the one-hour class session was to embed assessments of topic knowledge, including definitions of accounts, classification of accounts, rules of debit and credit, and recording of journal entries. These assessments were administered before students were exposed to the AI-enhanced instructional materials and again after the one-hour lesson. The assessments were embedded within the PearDeck platform to determine whether there was a significant difference in students' scores following the lesson.

The second evaluation approach involved analyzing student engagement within the PearDeck platform. Data were collected on the time students spent on tasks, their interaction patterns with the learning materials, and their completion rates for activities and assessments. This analysis was important because engagement with AI-enhanced learning materials was expected to support knowledge acquisition and achievement of learning outcomes [11].

The third evaluation method involved collecting qualitative data from students and lecturers regarding their experiences, satisfaction, and perceived effectiveness of the instructional materials. This was conducted through focus group discussions with selected participants to gain deeper insights into their experiences with advanced technology integration in classroom learning and to identify areas for improvement [12].

The fourth evaluation approach involved peer review of teaching practices. Observers evaluated classroom implementation of the AI-enhanced instructional materials and collected data on how the materials were used, as well as their impact on student behavior and interactions with peers and lecturers.

3.2. Justification of the evaluation design on AI aspects.

The design of the evaluation plan was intended to ensure that educators gained meaningful insights into the impact of their teaching practices on student learning and engagement. This section provides justification for the evaluation design, particularly the incorporation of AI tools for data collection and analysis of learning outcomes and engagement.

3.2.1. Pre- and post-assessment using PearDeck AI capabilities.

The first evaluation method involved assessing students' knowledge before and after using the AI-enhanced instructional materials. This approach directly measured the impact of the materials on students' attainment of learning outcomes. Previous studies have shown that pre- and post-assessments are effective in measuring knowledge gains resulting from specific interventions [13]. By embedding these assessments within the PearDeck platform, educators were able to quantitatively measure improvements in students' understanding of key topics, including account definitions, classifications, debit and credit rules, and journal entry recording. The rationale for using PearDeck was based on its AI-enabled data analytics capabilities. These features allowed educators to receive real-time feedback on students' understanding both before and after the lesson. This enabled timely adjustments to instructional

strategies based on pre-assessment results [14]. Additionally, the data collected through PearDeck allowed educators to determine whether there was a statistically significant difference in student performance before and after the intervention, thereby supporting the effectiveness of AI-enhanced instructional materials.

3.2.2. Analysis of student engagement using AI in PearDeck.

The second evaluation method incorporated AI to analyze student engagement data. The PearDeck platform enabled the collection of detailed engagement metrics, including time spent on tasks, interaction patterns, and completion rates. Higher levels of engagement are associated with improved knowledge retention and learning outcomes [15]. Therefore, analyzing these metrics provided valuable insights into how AI-enhanced instructional materials influenced student behavior and engagement. The use of AI to track and analyze engagement patterns provided a more comprehensive understanding of student learning compared to traditional observation methods. This justified the inclusion of AI-based analytics in evaluating the effectiveness of the instructional materials.

3.2.3. AI-enhanced focus group feedback analysis.

The third evaluation method involved collecting qualitative data from students and lecturers regarding their experiences, satisfaction, and perceptions of the instructional materials. Focus group discussions were conducted to gain deeper insights into their experiences with advanced technology integration in the classroom. AI-powered survey tools were also used to collect responses related to ease of use, accessibility, and inclusivity of the instructional materials. Additionally, ChatGPT was utilized to categorize and analyze qualitative responses, enabling identification of key themes and critical issues raised by participants. This approach enhanced the efficiency and depth of qualitative data analysis.

4. Implementation of Instructional Materials

4.1. Procedure for implementing AI-enhanced instructional materials.

The implementation procedure was divided into three phases to ensure that the instructional materials were effectively integrated into the learning environment and that data collection for analysis was conducted smoothly. Since some lecturers teaching the *Introduction to Accounting* course were not technologically proficient, they attended training on AI-enhanced instructional materials and the PearDeck platform. The training covered the use of various AI tools for teaching, methods of integrating these tools into classroom practices, and techniques for interpreting data generated by AI systems. Lecturers also received specific training on using PearDeck, including setting up interactive presentations, creating AI-generated videos using InVideo, developing AI-driven assessments, and managing interactive activities. The training included guidance on administering pre- and post-assessments and interpreting engagement data from PearDeck analytics tools.

At the beginning of the class, the 30 students were required to complete a pre-assessment to evaluate their prior knowledge of accounting concepts. This assessment was conducted within the PearDeck platform to provide lecturers with insights into students' baseline understanding. Following the pre-assessment, the lecturer delivered a one-hour lesson using the developed AI-enhanced instructional materials. Throughout the session, students engaged

with interactive slides and activities within PearDeck and received real-time feedback on their performance through embedded AI tools. At the end of the session, students completed a post-assessment similar to the pre-assessment. This allowed lecturers to directly compare students' knowledge before and after the lesson. After the session, lecturers analyzed data from the pre- and post-assessments to evaluate the effectiveness of the instructional materials. Additionally, engagement data from PearDeck—such as time spent on activities, interaction patterns, and completion rates—were analyzed to assess student participation and engagement.

4.2. Use of instructional materials by students.

The 30 students used the AI-enhanced instructional materials in an interactive learning environment facilitated by PearDeck. During the tutorial session, students engaged with interactive slides, viewed AI-generated videos created using InVideo, and participated in activities such as draggable and clickable tasks designed to support their understanding of accounting concepts. Throughout the session, students completed interactive assessments that provided immediate feedback. This enabled them to identify and correct errors and misconceptions in real time, thereby reinforcing their learning.

4.3. Data collected during implementation.

Data were collected during the implementation of the AI-enhanced instructional materials through the PearDeck platform. Pre- and post-assessment results were collected to evaluate knowledge gains after the one-hour tutorial session. In addition, student engagement metrics—including time spent on tasks, interaction patterns, and completion rates—were collected and analyzed to better understand how students interacted with the AI-enhanced learning materials.

5. Data Analysis

5.1. Knowledge gain analysis.

The data collected during the implementation of the AI-enhanced instructional materials were analyzed using the AI analytics tools available in the PearDeck platform. The analysis aimed to evaluate the effectiveness of the instructional materials in improving student learning outcomes and engagement. The pre- and post-assessment scores were compared to measure the knowledge gained by students before and after the implementation of the instructional materials. Data were collected from 30 students in a tutorial session, which typically consisted of a small group. In this study, the entire cohort of 30 students was included. The average pre-assessment score was 65% (SD = 10%), while the post-assessment score increased to 80% (SD = 8%). To determine the statistical significance of this improvement, a paired *t*-test was conducted using IBM SPSS Statistics. The results showed a *t*-value of 7.5 and a *p*-value < 0.001, indicating a highly significant improvement in students' knowledge after the implementation of the AI-enhanced instructional materials. Further analysis using AI tools identified specific areas where students showed the greatest improvement. The pre- and post-assessment scores for different accounting subtopics are presented in Table 1. As shown in Table 1, the greatest improvement was observed in *accounts definition*, indicating that the AI-enhanced instructional materials were particularly effective in strengthening students' conceptual understanding of this topic.

Table 1. Pre- and post-assessment average marks by subtopic.

Subtopics	Pre-assessment (%)	Post-assessment (%)
Accounts definition	60	85
Accounts classification	68	78
Rules of debit and credit	62	79
Recording of journal entries	70	78

5.2. Engagement analysis.

Engagement metrics collected from the PearDeck platform provided valuable insights into how students interacted with the instructional materials. On average, students spent 45 minutes on tasks during the 60-minute tutorial session. The completion rate for activities was 92%. The most engaging activity was identified as the interactive quiz on account classification into the five main account types. The AI algorithm in PearDeck identified patterns in student engagement and revealed a positive relationship between time spent on tasks and knowledge gain. Students who spent more than 40 minutes on the instructional materials achieved an average post-assessment score of 85%, whereas those who spent less than 40 minutes achieved an average score of 75%. This finding highlighted the importance of sustained engagement in achieving better learning outcomes.

5.3. Focus group data analysis.

Quantitative feedback indicated that 55% of respondents were satisfied and 20% were very satisfied with the integration of AI into their learning. Additionally, 75% of respondents found the use of the PearDeck platform beneficial, particularly the pre- and post-assessments, as these allowed them to evaluate their understanding in real time. Furthermore, 50% of respondents reported that AI-generated videos helped them better understand accounting concepts. Qualitative data were analyzed using ChatGPT to identify recurring themes. One common challenge identified was technical issues, such as “slow loading times of PearDeck integrated slides on personal devices.” Some students also reported difficulty navigating the platform, particularly those unfamiliar with AI-based learning environments. In terms of accessibility and inclusivity, several respondents highlighted limitations related to socioeconomic factors, such as lack of access to suitable devices or reliable internet connectivity. For example, some students noted that they did not have access to high-quality devices or stable internet connections. Regarding future improvements, respondents suggested providing more tutorials and support for using AI-enhanced technologies. They also recommended workshops for both students and lecturers, as well as ensuring equitable access to digital resources. Suggestions included offering alternative learning options for students with limited internet access and improving accessibility for students from lower-income backgrounds.

6. Discussion of Findings

6.1. Knowledge gain analysis.

The data analysis conducted provided significant insights into the effectiveness of the AI-enhanced instructional materials in improving students’ learning outcomes and engagement. The pre- and post-assessment scores from the 30 students showed a substantial improvement in students’ knowledge after the utilization of AI-enhanced instructional materials. The average

pre-assessment score was 65% (SD = 10%), while the post-assessment score increased to 80% (SD = 8%). The results of the paired t-test ($t = 7.5$, $p < 0.001$) indicated that the improvement in students' knowledge was statistically significant. This improvement suggested that AI-enhanced instructional materials effectively facilitated student learning. This outcome was likely attributed to the ability of AI tools to provide personalized feedback, adapt to individual learning pace, and offer interactive and engaging content through an AI-enhanced platform [16]. The data also revealed that students demonstrated the most significant improvement in understanding the definitions of accounts, highlighting the effectiveness of AI-enhanced materials in reinforcing fundamental concepts [17].

However, although the improvement in account definitions was substantial, other subtopics such as rules of debit and credit and recording of journal entries did not exhibit equally strong gains. This finding suggested that AI-enhanced materials were particularly effective in areas where students initially had lower baseline knowledge [18]. The notable gains in understanding account definitions could also be attributed to the interactive features within the PearDeck platform, which provided multiple examples and practice opportunities. Additionally, the immediate feedback feature enabled students to correct misconceptions in real time, thereby reinforcing learning and contributing to higher post-assessment scores.

6.2. Engagement analysis.

The engagement analysis indicated that the most engaging activity was the interactive quiz on account classification, demonstrating the importance of interactive elements in maintaining student engagement. The results also showed a positive correlation between time spent on instructional materials and knowledge gained. Students who spent more than 40 minutes on tasks achieved an average post-assessment score of 85%, whereas those who spent less than 40 minutes achieved an average score of 75%. This finding highlighted that sustained engagement was crucial for achieving better learning outcomes [19]. The high level of student engagement was attributed to the interactive and personalized nature of the AI-enhanced learning materials. Features such as interactive slides, quizzes, and real-time feedback helped maintain students' interest and contributed to achieving the intended learning outcomes [20].

6.3. Areas for improvement.

Based on the findings, several areas for improvement were identified. First, the AI tools within the PearDeck platform primarily provided generalized feedback, which might not have been sufficiently tailored to individual learning needs. Future improvements should focus on enhancing personalization capabilities to develop individualized learning pathways. Second, although interactive quizzes demonstrated high engagement, subtopics such as rules of debit and credit and journal entry recording showed lower knowledge gains. Educators should therefore incorporate additional instructional strategies, such as case-based learning and advanced gamification techniques [21]. For instance, AI-generated business scenarios could be used to allow students to practice journal entries in more applied contexts. Third, the current instructional design primarily focused on individual learning. Greater emphasis should be placed on collaborative learning approaches, such as group discussions and team-based problem-solving activities, to enhance critical thinking and communication skills. Finally, technical and accessibility challenges were highlighted in the focus group findings. Issues such as slow system performance, limited device access, and inadequate internet connectivity

needed to be addressed. Providing training workshops for both students and lecturers, improving user interface design, and ensuring equitable access to digital resources were essential steps to enhance inclusivity in AI-enhanced learning environments.

7. Conclusion

This study demonstrated that the integration of AI-enhanced instructional materials significantly improved students' learning outcomes and engagement in an Introduction to Accounting course. The findings confirmed that AI-driven tools, particularly those embedded within the PearDeck platform, effectively supported personalized learning, real-time feedback, and interactive engagement. The statistically significant improvement in post-assessment scores indicated that AI-enhanced instructional materials could bridge knowledge gaps, especially in foundational topics. Additionally, the strong relationship between engagement and learning outcomes highlighted the importance of sustained interaction with instructional content in achieving academic success. However, the study also identified several limitations and challenges, including uneven learning gains across subtopics, limited personalization of AI feedback, and issues related to accessibility and technological infrastructure. These findings suggested that while AI holds substantial potential in education, its implementation must be carefully designed to ensure inclusivity, adaptability, and pedagogical effectiveness. Future research should explore the long-term impact of AI-enhanced learning, the integration of more advanced adaptive learning systems, and the role of collaborative AI-supported learning environments. Furthermore, expanding the sample size and applying the framework across different disciplines would enhance the generalizability of the findings. Overall, AI-enhanced instructional materials represent a promising direction in educational innovation. When effectively implemented, they can transform traditional teaching approaches into more dynamic, personalized, and inclusive learning experiences, thereby better preparing students for the demands of a rapidly evolving digital landscape.

Author Contributions

All authors contributed equally to this study. This includes conceptualization, methodology design, data collection, data analysis, writing of the original draft, and revision of the manuscript. All authors have read and approved the final version of the manuscript.

Competing Interests

The authors declare no competing interests.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and ethical considerations related to student participation.

References

- [1] Owan, V.J.; Abang, K.B.; Idika, D.O.; Etta, E.O.; Bassey, B.A. (2023). Exploring the potential of artificial intelligence tools in educational measurement and assessment. *Eurasia Journal of*

- Mathematics, Science and Technology Education*, 19(8), em2307. <https://doi.org/10.29333/ejmste/13428>.
- [2] Morra, C.N.; Fultz, R.; Raut, S.A. (2022). A lesson from the pandemic: utilizing digital tools to support student engagement during instructional assistant-led sessions. *Journal of Microbiology and Biology Education*, 23(3). <https://doi.org/10.1128/jmbe.00143-22>.
- [3] Serrano, D.R.; Dea-Ayuela, M.A.; Gonzalez-Burgos, E.; Serrano-Gil, A.; Lalatsa, A. (2019). Technology-enhanced learning in higher education: How to enhance student engagement through blended learning. *European Journal of Education*, 54(2), 273–286. <https://doi.org/10.1111/ejed.12330>.
- [4] Runnalls, C.; Hong, D.S. (2020). “Well, they understand the concept of area”: pre-service teachers’ responses to student area misconceptions. Conference: 39th Annual Conference of the North American Chapter of the International Group for the Psychology of Mathematics Education, Indianapolis, Indiana, USA.
- [5] Mageira, K.; Pittou, D.; Papasalouros, A.; Kotis, K.; Zangogianni, P.; Daradoumis, A. (2022). Educational AI chatbots for content and language integrated learning. *Applied Sciences*, 12(7), 3239. <https://doi.org/10.3390/app12073239>.
- [6] Patil, S. (2023). Teaching and learning aids for blended learning. *The Online Journal of Distance Education and E-Learning*, 11(2), 1672–1677.
- [7] Mohammed, S.; Kinyo, L. (2020). Constructivist theory as a foundation for the utilization of digital technology in the lifelong learning process. *Turkish Online Journal of Distance Education*, 21(4). <https://doi.org/10.17718/tojde.803364>.
- [8] Harris, L.; Yearta, L.; Paolini, A. (2020). Using digital tools to foster student engagement within the universal design for learning framework. In: Handbook of Research on Fostering Student Engagement With Instructional Technology in Higher Education, Al Qurashi, Ed.; IGI Global: Hershey, PA, USA; pp. 411–428.
- [9] Wong, B.T.M.; Li, K.C. (2020). A review of learning analytics intervention in higher education (2011–2018). *Journal of Computers in Education*, 7(1). <https://doi.org/10.1007/s40692-019-00143-7>.
- [10] Kerres, M.; Buntins, K. (2020). Recommender in AI-enhanced learning: An assessment from the perspective of instructional design. *Open Education Studies*, 2(1), 101–111. <https://doi.org/10.1515/edu-2020-0119>.
- [11] Jia, X.-H.; Tu, J.-C. (2024). Towards a New Conceptual Model of AI-Enhanced Learning for College Students: The Roles of Artificial Intelligence Capabilities, General Self-Efficacy, Learning Motivation, and Critical Thinking Awareness. *Systems*, 12, 74. <https://doi.org/10.3390/systems12030074>.
- [12] Dinc, E. (2019). Prospective teachers’ perceptions of barriers to technology integration in education. *Contemporary Educational Technology*, 10(4), 381–398. <https://doi.org/10.30935/cet.634187>.
- [13] Little, T.D.; Chang, R.; Gorrall, B.K.; Waggenspack, L.; Fukuda, E.; Allen, P.J.; Noam, G.G. (2020). The retrospective pretest–posttest design redux: On its validity as an alternative to traditional pretest–posttest measurement. *International Journal of Behavioral Development*, 44(2). <https://doi.org/10.1177/0165025419877973>.
- [14] Tissenbaum, M.; Slotta, J. (2019). Supporting classroom orchestration with real-time feedback: A role for teacher dashboards and real-time agents. *International Journal of Computer-Supported Collaborative Learning*, 14, 1–27. <https://doi.org/10.1007/s11412-019-09306-1>.
- [15] Winn, A.S.; DelSignore, L.; Marcus, C.; Chiel, L.; Freiman, E.; Stafford, D.; Newman, L. (2019). Applying cognitive learning strategies to enhance learning and retention in clinical teaching settings. *MedEdPORTAL: The Journal of Teaching and Learning Resources*, 15, 10850. https://doi.org/10.15766/mep_2374-8265.10850.

- [16] 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>.
- [17] Meng, W.; Sumettikoon, P. (2022). The use of artificial intelligence to enhance teaching effectiveness in vocational education. *Eurasian Journal of Educational Research*, 2022(98), 266–283.
- [18] Meng, W.N.; Dhimolea, T.K.; Ali, Z. (2022). AI-enhanced education: Teaching and learning reimagined. In *Bridging Human Intelligence and Artificial Intelligence*; Albert, M.V., Lin, L., Spector, M.J., Dunn, L.S., Eds.; Springer International Publishing: Cham, Switzerland; pp. 107–124. https://doi.org/10.1007/978-3-030-84729-6_7.
- [19] Lee, J.; Song, H.D.; Hong, A.J. (2019). Exploring factors and indicators for measuring students' sustainable engagement in e-learning. *Sustainability*, 11(4), 985. <https://doi.org/10.3390/su11040985>.
- [20] Zainuddin, Z.; Shujahat, M.; Haruna, H.; Chu, S.K.W. (2020). The role of gamified e-quizzes on student learning and engagement: An interactive gamification solution for a formative assessment system. *Computers and Education*, 145, 10372. <https://doi.org/10.1016/j.compedu.2019.103729>.
- [21] Doney, I. (2019). Research into effective gamification features to inform e-learning design. *Research in Learning Technology*, 27. <https://doi.org/10.25304/rlt.v27.2093>.



© 2026 by the authors. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).