Artificial Intelligence and Industrial Revolution 4.0: Their Impact on 21st-Century Pedagogy among Pre-Service History Education Teachers

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ABSTRACT

This study was conducted to examine the impact of Artificial Intelligence (AI) and Industrial Revolution 4.0 (IR 4.0) on 21st-century pedagogy among pre-service History subject teachers. AI and IR 4.0 are two elements that are highly emphasised in the teaching and learning process in schools, particularly in enhancing digital transformation and innovative pedagogical practices. However, the findings indicate that pre-service History teachers' mastery of these elements remains at a foundational level, reflecting limited exposure to the functional and pedagogical applications of AI and IR 4.0 technologies in teaching and learning practices. This study used the Technology Acceptance Model (TAM), Technological Pedagogical Content Knowledge (TPACK), and 21st Century Skills Framework as the main theoretical foundations of the study. This study employed a quantitative approach and a non-experimental design by collecting data using questionnaires. A total of 71 samples were selected using simple random sampling techniques. The data were analysed using descriptive analysis and inferential statistics using the Statistical Package for the Social Sciences software. The results of the study show that the level of AI (M = 4.393, SD = 0.287), IR 4.0 (M = 4.450. SD = 0.233), and 21st-century pedagogy (M = 4.497, SD = 0.249) among pre-service History teachers is at a high level. AI ($\beta = 0.195$, $t = 1.762$, $p > 0.083$) does not act as a significant predictor of 21st-century pedagogy, while IR 4.0 ($\beta = 0.359$, $t = 3.254$, $p < 0.002$) is a significant predictor. The study highlights the need to strengthen teacher education programmes by enhancing structured exposure to AI and IR4.0 applications in pedagogy. These efforts are essential to support sustainable educational transformation and to ensure more effective, innovative, and future ready teaching and learning environments.

Keywords— Artificial Intelligence, Industrial Revolution 4.0, Pre-service History Teachers, 21st Century Pedagogy

INTRODUCTION

In the era of rapid globalization and digital transformation, education systems worldwide are undergoing profound structural and pedagogical changes, particularly in teaching and learning practices. The IR 4.0, characterized by automation, the Internet of Things (IoT), big data analytics, and AI, has significantly reshaped the educational landscape toward more technology enhanced, data-driven, and personalized learning environments (Xu & Ouyang, 2022; Zawacki-Richter et al., 2019). Recent systematic reviews confirm that AI integration in education has expanded rapidly across multiple domains, including intelligent tutoring systems, automated assessment, adaptive learning environments, learning analytics, and conversational agents such as chatbots (Chen et al., 2023; Holmes & Tuomi, 2022). These developments demonstrate that AI is no longer an emerging tool but an increasingly embedded component of modern educational ecosystems. In particular, generative AI technologies such as large language models have further accelerated transformation by enabling real time content creation, feedback generation, and personalized instructional support (Kasneci et al., 2023; Tlili et al., 2023).

Within this context, AI literacy has become a critical component of 21st-century pedagogical readiness. For pre-service teachers, especially those enrolled in History Education programs at higher education institutions such as Universiti Malaysia Sabah (UMS), the ability to understand and apply AI tools is essential in ensuring effective instructional delivery aligned with contemporary educational demands. Studies have shown that AI supported learning systems enhance student engagement, improve conceptual understanding, and support differentiated instruction tailored to learners' cognitive levels and learning pace (Chen et al., 2023; Xu & Ouyang, 2022). Moreover, AI technologies provide significant pedagogical value through data-driven insights that allow educators to monitor learner progress, identify knowledge gaps, and implement timely interventions. Learning analytics systems powered by AI enable more precise decision making processes in instructional design and assessment strategies, thereby improving educational outcomes and efficiency (Holmes & Tuomi, 2022; Zawacki-Richter et al., 2019).However, despite these advantages, the integration of AI in education also presents critical challenges. Systematic reviews highlight concerns related to ethical considerations, data privacy, algorithmic bias, and the readiness of educators and students to adopt AI technologies effectively (Zawacki-Richter et al., 2019; Kasneci et al., 2023). In addition, overreliance on generative AI tools may weaken critical thinking skills and reduce deep cognitive engagement if not properly integrated within pedagogical frameworks (Tlili et al., 2023).

Therefore, this study aims to examine the level of AI proficiency among students in the History Education program at UMS and to analyze how such proficiency influences their readiness for 21st-century pedagogical demands. It further explores enabling and inhibiting factors affecting AI integration in history education, particularly in relation to teaching effectiveness, student engagement, and instructional innovation. Understanding these dimensions is crucial for developing sustainable AI enhanced pedagogical strategies that align with Malaysia's aspiration to produce digitally competent, innovative, and globally competitive graduates. Ultimately, this study contributes to the growing body of literature on AI in education by providing empirical insights into the role of AI literacy in shaping pedagogical readiness in higher education contexts.

RESERCH BACKGROUND

The development of digital technology in the 21st- century has brought significant transformation to global education systems, including in Malaysia, particularly through advancements in Information and Communication Technology (ICT) and AI. AI is capable of simulating human intelligence through data analysis, information processing, and automated problem solving, thereby enabling teachers to deliver more creative, engaging, and effective instruction while enhancing student learning outcomes (Singh & Miah, 2019). According to Zawacki-Richteret al. (2019), the use of AI in higher education improves learning effectiveness through intelligent systems, learning analytics, and educational automation, while Holmes et al. (2019) suggest that AI can transform teaching and learning by enabling personalised learning environments that adapt instructional content, pacing, and feedback to learners' individual characteristics, thereby promoting more effective and learner-centred educational experiences.

AI also facilitates more interactive and flexible learning environments, while supporting teachers in developing digital instructional materials such as AI generated audio, video, and graphics. This is particularly significant in History education, which is often perceived as less engaging. The integration of AI and interactive multimedia can enhance students' interest, engagement, and conceptual understanding through immersive and interactive learning experiences (Abdul Rahman et al., 2024). Furthermore, technology-enhanced history instruction has been shown to foster higher-order thinking and critical thinking skills by encouraging students to analyse, evaluate, and interpret historical evidence (Dahalan et al., 2020). However, the level of AI proficiency among pre-service teachers remains limited and is often confined to basic operational use rather than pedagogically meaningful integration. Insufficient technical competence, inadequate professional training, and low self-confidence remain significant barriers to the effective integration of digital technologies into teaching practices (Ghavifekr & Rosdy, 2015). Furthermore, despite the rapid advancement of AI technologies, research examining their pedagogical applications remains relatively limited, particularly in teacher education, highlighting the need for further empirical investigation (Zawacki-Richter et al., 2019; Chen et al., 2023).

The Fourth IR 4.0 has further accelerated educational transformation through the integration of emerging technologies, including Artificial Intelligence (AI), the Internet of Things (IoT), big data, cloud computing, and virtual and augmented reality. These technological advancements require graduates to possess not only digital competence but also creativity, critical thinking, adaptability, and lifelong learning skills to remain competitive in an increasingly digital society (Schwab, 2016). Despite these developments, many pre-service teachers remain inadequately prepared for the demands of Education 4.0 because of limited exposure to emerging technologies and insufficient opportunities for authentic technology-integrated pedagogical training (Hussin, 2018).

In the context of History education, IR 4.0 technologies, including simulations, interactive multimedia, and AI-driven applications, have the potential to enhance teaching effectiveness by creating more immersive, engaging, and inquiry-based learning experiences. Nevertheless, many pre-service teachers continue to face challenges in integrating these technologies into their instructional practices because of limited technological pedagogical knowledge, insufficient training, and inadequate opportunities for authentic technology integration during teacher preparation programmes (Teo et al., 2021; Wilson et al., 2020). Furthermore, 21st-century pedagogy emphasises the development of communication, collaboration, creativity, and critical thinking, with teachers serving as facilitators who strategically integrate digital technologies to promote meaningful and student-centred learning (Partnership for 21st Century Learning, 2019).

Despite growing attention to Artificial Intelligence (AI) in education, a significant gap remains in teachers' readiness to effectively integrate these technologies into pedagogical practice. Many educators continue to rely on traditional instructional approaches and demonstrate limited confidence in using AI due to insufficient training, inadequate exposure, and underdeveloped professional competencies in AI-supported teaching. Recent frameworks emphasise that AI competence is multidimensional, requiring not only technical skills but also pedagogical, ethical, and reflective capabilities to ensure meaningful integration in educational contexts (Miao et al., 2024). However, evidence suggests that teacher education systems in many contexts are still in the early stages of systematically developing such competencies, resulting in uneven preparedness for AI-enhanced teaching and learning environments (UNESCO, 2024).

In addition, the ethical dimension of AI integration has become increasingly prominent. Concerns related to data privacy, algorithmic bias, transparency, and over-reliance on automated systems highlight the need for responsible and human-centred implementation of AI in education (Porayska-Pomsta et al., 2024). These issues underscore the importance of strengthening teachers' digital literacy and ethical awareness as essential components of AI readiness. Consequently, contemporary scholarship stresses that effective AI integration in education must be grounded in a balanced development of technical proficiency, pedagogical innovation, and ethical responsibility to ensure sustainable and trustworthy educational transformation.

Overall, AI and IR 4.0 competencies are significantly associated with 21st-century pedagogical readiness among History education students at Universiti Malaysia Sabah. However, issues related to technological proficiency and pedagogical readiness remain, necessitating further investigation to ensure that future teachers are competent, innovative, and aligned with contemporary educational demands. This suggests that while students may possess basic awareness of emerging technologies, their ability to apply these tools effectively in instructional contexts is still developing. Strengthening AI literacy and digital pedagogy within teacher education programmes is therefore essential to bridge this gap. In addition, more structured and practice-based training opportunities are needed to enhance hands-on experience with educational technologies. Such efforts can support the transformation of theoretical knowledge into meaningful classroom practice. Ultimately, continuous improvement in both technical and pedagogical competencies is crucial to prepare future History educators for the evolving demands of 21st-century education

Research Objetives

This study aims to:

1. To examine the level of readiness to use AI among pre-service teachers in the History Education Program.

2. To examine the level of readiness to use IR 4.0 among pre-service teachers in the History Education Program.

3. To examine the level of mastery of 21st-century pedagogy among pre-service teachers in the History Education Program.

4. To investigate the effect between the readiness to use Artificial Intelligence and the mastery of 21st-century pedagog among pre-service teachers in the History Education Program.

THEORITICAL FRAMEWORK

This study is grounded in an integrated theoretical framework combining the Technology Acceptance Model (TAM) (Davis, 1989; Venkatesh & Davis, 2000)**,** the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006; Koehler & Mishra, 2009)**,** and the 21st- Century Skills Framework (Partnership for 21st Century Learning, 2019)**.** These three theories collectively provide a robust multi dimensional lens to explain how AI and R 4.0 technologies influence 21st-century pedagogical readiness among pre-service History education teachers.

Technology Acceptance Model (TAM)

The TAM, developed by Davis (1989), is widely used to explain individuals' acceptance and usage behaviour toward new technologies. TAM posits that two primary determinants which are Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). Within this study, TAM is employed to explain the psychological and behavioural readiness of pre-service History teachers in adopting AI and IR 4.0 technologies in teaching practice. If pre-service teachers perceive AI based tools as useful for improving instructional effectiveness, enhancing student engagement, and simplifying complex historical content, they are more likely to adopt and integrate these tools into their pedagogical practices. Similarly, perceived ease of use is critical, especially in the context of pre-service teachers who may have limited technical experience. AI systems that are user-friendly and require minimal technical effort are more likely to be accepted and used consistently in instructional settings. Venkatesh and Davis (2000) extended TAM by demonstrating that perceived usefulness has a stronger direct influence on behavioural intention than perceived ease of use, particularly in professional and educational contexts. In educational technology research, TAM has been widely validated as a strong predictive model of technology adoption among teachers and students (Teo, 2011). In this study, TAM functions as a behavioural foundation model that explains why pre-service teachers choose to accept or reject AI and IR 4.0 technologies in their teaching practice. It complements TPACK by addressing the motivational and attitudinal dimensions of technology integration.

Technological Pedagogical Content Knowledge (TPACK)

The TPACK framework conceptualises effective technology integration in teaching as the dynamic interaction between three primary knowledge domains: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK) (Mishra & Koehler, 2006). The intersection of these domains forms integrated knowledge structures, particularly TPACK, which represents a teacher's ability to meaningfully integrate technology into subject specific pedagogy to enhance student learning outcomes. In the context of this study, AI tools and IR 4.0 technologies represent advanced technological resources that require sophisticated pedagogical adaptation. For pre-service History teachers, TPACK is particularly crucial because History education requires not only factual understanding but also narrative construction, historical thinking skills, and critical interpretation of sources. Koehler and Mishra (2009) emphasise that effective technology integration is not merely about using digital tools but about transforming pedagogy in ways that are epistemologically aligned with subject matter. In History education, AI can support historical inquiry, source analysis, and immersive simulations of historical events, thereby enhancing conceptual understanding and historical empathy. Therefore, TPACK serves as the core pedagogical competency framework in this study to evaluate how pre-service teachers integrate AI and IR 4.0 technologies into meaningful instructional practices. Furthermore, prior research has demonstrated that

strong TPACK competencies are positively associated with innovative teaching practices, student engagement, and effective technology integration in classroom settings (Voogt et al., 2013). Thus, TPACK is positioned in this study as a mediating pedagogical construct that explains how technological knowledge (AI and IR 4.0) is translated into effective teaching practices.

21st Century Skills Framework

The 21st Century Skills Framework, particularly the model developed by the Partnership for 21st-Century Skills (P21, 2019), emphasises the development of four core competencies known as the **"**4Cs": Critical thinking, Communication, Collaboration, and Creativity. These competencies are considered essential for preparing learners to succeed in a rapidly evolving, technology driven global environment. In the context of pedagogy, 21st-century teaching shifts the focus from teacher centred instruction to student centred, inquir based, and technology enhanced learning environments**.** Teachers are expected to act as facilitators who guide students in developing higher order thinking skills rather than merely transmitting knowledge.Recent scholarship highlights that 21st-century skills frameworks remain essential for aligning education systems with the demands of rapidly evolving digital and AI-driven societies. Contemporary studies emphasise that core competencies such as critical thinking, communication, collaboration, creativity, and digital literacy are consistently identified as fundamental outcomes of modern education, particularly in preparing learners for complex and technology-rich environments (Thornhill-Miller et al., 2023; Buasuwan et al., 2022). In this study, the 21st Century Skills Framework is conceptualised as the pedagogical outcome dimension, defining the intended learning transformation that should result from the integration of Artificial Intelligence (AI) and Fourth Industrial Revolution (IR 4.0) technologies in teaching and learning processes. It provides a structured lens for understanding how technology-enhanced instruction can foster the development of essential student competencies and support more adaptive, learner-centred educational experiences (Papagiannis & Pallaris, 2024). Accordingly, this framework serves as a benchmark for evaluating the extent to which AI and IR 4.0 integration contributes to meaningful pedagogical transformation in History education.

Integrated Theoretical Model

This study proposes an integrated theoretical model that synthesises TAM, TPACK, and the 21st Century Skills Framework to explain the relationships between AI, IR 4.0, and pedagogical readiness. Firstly, TAM explains the acceptance dimension, focusing on pre-service teachers' perceived usefulness and ease of use of AI and IR 4.0 technologies. These perceptions influence their willingness to adopt such technologies in teaching practices. Secondly, TPACK explains the competence dimension, focusing on how pre-service teachers integrate technological knowledge with pedagogical strategies and historical content knowledge. This determines the quality and effectiveness of technology-enhanced instruction. Thirdly, the 21st Century Skills Framework explains the outcome dimension, focusing on the development of student-centred pedagogical practices that foster critical thinking, creativity, collaboration, and communication. In this integrated model, AI and IR 4.0 technologies function as independent technological drivers**,** while TAM influences behavioural intention to adopt these technologies. TPACK acts as a mediating construct that translates technology adoption into pedagogical practice, while 21st-century skills represent the ultimate instructional outcomes of effective integration. This integrated framework is particularly significant because it bridges three levels of analysis:

1. Psychological level (TAM): Why teachers adopt technology
2. Pedagogical level (TPACK): How teachers use technology
3. Outcome level (21st-century skills): What students gain from technology-enhanced pedagogy

By combining these frameworks, this study provides a comprehensive explanation of how AI and IR 4.0 shape pedagogical readiness among pre-service History teachers in the context of contemporary educational transformation.

LITERATURE REVIEW

AI has become a major transformative force in education, reshaping teaching practices, learning environments, and assessment systems. AI in education is broadly defined as the application of computational systems capable of performing cognitive tasks such as prediction, adaptation, automation, and data-driven decision-making to enhance teaching and learning processes (Zawacki-Richter et al., 2019). Recent developments in generative AI, particularly large language models, have significantly expanded the role of AI in education. Kasneci et al. (2023) highlight that tools such as ChatGPT can support lesson planning, content generation, tutoring, and formative feedback, thereby improving teacher efficiency and instructional design quality. However, they also emphasise risks such as hallucinated content, bias, and academic integrity issues.

Similarly, Holmes et al. (2022) argue that AI enables personalised and adaptive learning systems that adjust content delivery based on learner performance and behaviour. This shifts education from standardised instruction toward learner-centred and data-driven pedagogies. In teacher education, Chan and Hu (2023) found that pre-service teachers commonly use generative AI for basic academic tasks, but lack deeper pedagogical integration skills. This indicates that AI adoption is increasing, but pedagogical transformation remains limited. In History education, AI has potential to support historical simulations, digital reconstruction, and interactive inquiry-based learning. However, UNESCO (2021) cautions that AI use in education must be guided by ethical principles, transparency, and human oversight to avoid misinformation and bias.

IR 4.0 is defined by the integration of digital, physical, and biological systems through technologies such as artificial intelligence, robotics, big data, cloud computing, and the Internet of Things (Schwab, 2016). In education, this transformation has led to the emergence of Education 4.0, which emphasises flexibility, digital learning ecosystems, and personalised education. Selwyn (2019) argues that digital transformation in education is not purely technological but also deeply social, involving power structures, institutional readiness, and pedagogical change. IR 4.0 requires educators to develop advanced digital competencies, including technological fluency, data literacy, and the ability to integrate emerging technologies into teaching practice.

Hussin (2018) emphasises that Education 4.0 necessitates a paradigm shift from traditional rote learning approaches towards more interactive, technology-enhanced, and student-centred pedagogies that prioritise active learning and learner engagement. However, despite this vision, many education systems continue to face persistent challenges related to uneven digital infrastructure, limited institutional capacity, and insufficient teacher readiness to fully integrate emerging technologies into pedagogical practice. Within teacher education contexts, Fourth Industrial Revolution (IR 4.0) technologies such as augmented reality (AR), virtual reality (VR), and simulation-based learning have demonstrated strong potential to enhance experiential and immersive learning experiences. These technologies are particularly relevant in History education, as they enable the spatial and temporal reconstruction of historical events, thereby supporting deeper contextual understanding, increased student engagement, and more meaningful interpretation of historical knowledge.

21st-century pedagogy focuses on developing learners' competencies in critical thinking, communication, collaboration, and creativity (Partnership for 21st Century Learning, 2019). It emphasises learner-centred instruction, problem-based learning, and the integration of digital technologies into classroom practice. The framework proposed by P21 (2019) remains one of the most widely used models in educational research and policy. It highlights the importance of preparing learners for a knowledge-based and technology-driven economy.

Hussin (2018) argues that 21st-century teaching requires educators to transition from knowledge transmitters to learning facilitators who design interactive and technology-enhanced learning environments. This shift is essential in History education, where students must develop historical thinking skills such as sourcing, contextualisation, and corroboration. Kasneci et al. (2023) further suggest that AI technologies can support 21st-century pedagogy by enabling personalised learning and enhancing student engagement. However, they also stress the importance of critical evaluation skills to ensure that students do not rely uncritically on AI-generated content. UNESCO (2021) emphasises that digital pedagogy must be guided by ethical frameworks to ensure

equity, inclusion, and responsible use of technology.

Recent literature shows that AI and IR 4.0 technologies function as enabling forces for 21st-century pedagogy. AI provides adaptive learning systems and intelligent feedback mechanisms, while IR 4.0 technologies such as VR, AR, and big data analytics create immersive and data-driven learning environments (Holmes et al., 2022). Together, these technologies support student-centred learning approaches that emphasise engagement, creativity, and critical thinking. However, successful implementation depends heavily on teacher readiness, digital competence, and pedagogical knowledge. Chan and Hu (2023) found that although pre-service teachers are generally open to using AI, their integration remains surface-level due to limited pedagogical training. This suggests that technology alone is insufficient without strong pedagogical grounding. Therefore, the intersection of AI, IR 4.0, and 21st-century pedagogy highlights the need for comprehensive teacher preparation programmes that integrate digital literacy, ethical awareness, and instructional innovation.

METHODOLOGY

This study adopts a quantitative research approach. The research design employed is a non-experimental research design, which examines the relationship between independent and dependent variables without manipulating the independent variables (Piaw, 2011). This design is appropriate for identifying naturally occurring relationships among variables, particularly in educational research where experimental manipulation is not feasible. The study utilises a survey research method, which is widely recognised for its effectiveness in collecting data from large populations within a relatively short period of time. In this study, the survey is conducted using a structured questionnaire as the primary data collection instrument. The questionnaire method is advantageous as it allows respondents to provide answers anonymously and comfortably, thereby reducing social desirability bias compared to interviews. In addition, survey research is cost-effective, time-efficient, and suitable for large-scale data collection.

The study is conducted at the Faculty of Education and Sports Studies (FPPS), Universiti Malaysia Sabah (UMS). The population consists of third-year and fourth-year students enrolled in the History Education programme. These students are selected because they have completed Teaching Practice Phase 1 and Phase 2, which means they have been exposed to authentic classroom teaching and learning environments. Therefore, they are considered capable of providing informed responses regarding pedagogical practices and the integration of technology in teaching.

The sample size is determined using the Krejcie and Morgan (1970) sample size determination table, which is widely accepted in social science research for ensuring adequate statistical representation of the population. Based on this guideline, a total of 71 students are selected as the sample for the quantitative phase of the study. The study employs Simple Random Sampling (probability sampling) to ensure that every respondent in the population has an equal chance of being selected, thereby reducing sampling bias and increasing generalisability of the findings.

For data collection, the research instrument consists of a questionnaire adapted and modified from established instruments developed by previous researchers to suit the context of this study. The instrument is adapted from Domingo, Genon et al. (2023), Sidin et al. (2020), as well Rajikal and Hamzah (2021). The reliability analysis of the instrument, measured using Cronbach's Alpha, indicates a high level of internal consistency for all constructs, with values exceeding 0.80, which is considered highly reliable in social science research. In addition, all retained items exhibit factor loadings above 0.40, indicating satisfactory construct validity.

FINDINGS

a) The level of mastery of Artificial Intelligence (AI), the Fourth Industrial Revolution (IR 4.0), and 21st-century pedagogy among students in the History Education Programme, Faculty of Education and Sports

Sciences, Universiti Malaysia Sabah

Table 1. Mastery of AI, IR 4.0, and 21st-Century Pedagogy among History Education Students

	Frequency	Mean	Standard Deviation
AI	71	4.393	0.287
IR 4.0	71	4.450	0.233
21st-century pedagogy	71	4.497	0.249

Based on Table 1, the mean scores for AI (M = 4.393, SD = 0.287), IR 4.0 (M = 4.450, SD = 0.233), and 21st-century pedagogy (M = 4.497, SD = 0.249) indicate that respondents demonstrate a high level of competence across all three constructs.

b) The impact of Artificial Intelligence and Industrial Revolution 4.0 on 21st-Century Pedagogy among Pre-Service History Education Teachers.

Table 2. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.416[a]	0.173	0.149	0.230

Table 3. ANOVA Analysis

	Model	Sum of Square	df	Mean Square	F	Sig.
1	Regression	0.757	2	0.379	7.130	0.002[b]
	Residual	3.612	68	0.053		
	Total	4.369	70			

Table 2 presents the summary model of the multiple regression analysis. The results indicate that the regression model, which includes AI and IR 4.0 as predictors, significantly explains 17.30% of the variance in 21st-century pedagogy. Table 3 further shows that the model is statistically significant, with F (2, 68) = 7.130, and a significance level of p = 0.002 ($p < 0.05$).

Table 4. Coefficient Analysis

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.041	0.659		3.095	0.003
	AI	0.169	0.096	0.195	1.762	0.083
	IR 4.0	0.385	0.118	0.359	3.254	0.002

The coefficient analysis in Table 4 shows that AI ($\beta = 0.195$, $t = 1.762$) does not act as a significant predictor of 21st-century pedagogy, as its significance value is higher than the predetermined significance level ($p = 0.083$, $p > 0.05$). In contrast, the IR 4.0 is identified as a significant positive predictor of 21st-century pedagogy ($\beta = 0.359$, $t = 3.254$), with a significance value lower than the threshold (p = 0.002, $p < 0.05$). The non-significant influence of AI on 21st-century pedagogy indicates that Artificial Intelligence is not a primary factor affecting pedagogical practices among the respondents. On the other hand, the significant and positive influence of IR 4.0 suggests that 21st-century pedagogy improves when pre-service teachers' IR 4.0 competencies are enhanced.

DISCUSSION

Level of Mastery of AI, IR 4.0, and 21st-Century Pedagogy

The findings demonstrate that pre-service History education teachers exhibit a high level of mastery in AI, IR 4.0, and 21st-century pedagogy. This indicates a strong foundational readiness to engage with digital transformation in education and suggests that respondents possess both conceptual understanding and initial applied competence in integrating emerging technologies into pedagogical contexts. The high level of AI mastery reflects increasing exposure to intelligent digital tools and data-driven educational applications. In History education, AI has the potential to support instructional design through adaptive learning systems, content generation, and personalised feedback mechanisms. Such capabilities align with the evolving role of teachers as facilitators of technology-enhanced learning environments. This finding is consistent with Runge et al. (2025), who highlight that early engagement with AI significantly enhances pre-service teachers' acceptance and pedagogical readiness for technology integration.

Similarly, the high level of IR 4.0 mastery suggests that respondents are aware of the broader digital transformation shaping contemporary education systems. IR 4.0 competencies extend beyond technical skills to include digital fluency, data literacy, and the ability to operate within interconnected technological ecosystems. This finding is consistent with recent scholarship which emphasises that IR 4.0 competencies are essential for preparing educators to integrate technology effectively into pedagogical practice and to adopt more innovative, student-centred instructional approaches (Teo et al., 2021; Zulnaidi et al., 2024). The high level of 21st-century pedagogy mastery reflects strong competence in critical competencies such as communication, collaboration, critical thinking, and creativity. These competencies are particularly important in History education, where students are required to engage in historical inquiry, source evaluation, and evidence-based interpretation. This aligns with the P21 framework, which emphasises the integration of cognitive, interpersonal, and digital skills as core outcomes of contemporary education (Partnership for 21st Century Learning, 2019). From a theoretical perspective, these findings strongly support the TPACK framework, indicating that pre-service teachers demonstrate emerging integration between technological knowledge (AI and IR 4.0) and pedagogical knowledge (21st-century pedagogy). Furthermore, consistent with the TAM, the high levels of mastery suggest positive perceived usefulness and ease of use of digital technologies in educational practice.

Influence of AI and IR 4.0 on 21st-Century Pedagogy

The regression analysis reveals that AI and IR 4.0 collectively exert a statistically significant but weak influence on 21st-century pedagogy, with IR 4.0 emerging as the only significant predictor. AI, in contrast, does not significantly predict 21st-century pedagogy, indicating a limited pedagogical transformation despite increasing exposure to AI technologies. This finding is theoretically significant as it suggests that technological familiarity does not necessarily translate into pedagogical transformation. As argued by Fullan (2013) educational change is a complex process that requires alignment between technology, pedagogy, and institutional design rather than mere access to digital tools. The weak influence of IR 4.0 indicates that its application among pre-service teachers remains largely instrumental, primarily limited to basic digital practices such as online learning platforms and resource retrieval. It has not yet fully evolved into transformative pedagogical practices that foster creativity, collaboration, and critical thinking. More critically, the non-significant effect of AI suggests that AI is still predominantly used as a supportive academic tool rather than a pedagogical driver. This reflects limited pedagogical appropriation of AI for higher-order instructional functions such as adaptive learning, intelligent tutoring, and problem-based learning design (Luckin et al., 2016).

From a TPACK perspective, these findings indicate that although technological knowledge is present, its integration with pedagogical and content knowledge remains underdeveloped. This reinforces Koehler and Mishra's (2009) assertion that meaningful technology integration requires deep and contextualised understanding of how technology reshapes pedagogy rather than surface-level usage. Within the TAM

framework, the findings suggest that AI has not yet achieved strong perceived usefulness among respondents in History education contexts. This is consistent with recent meta-analytic evidence which shows that while technology acceptance is generally high in educational contexts, its impact on pedagogical transformation remains limited unless supported by strong pedagogical and contextual factors (Xue et al., 2026; Marikyan et al., 2023).

From the perspective of 21st-century learning frameworks, the findings suggest that technology integration has not yet fully translated into the development of key 21st-century competencies among pre-service teachers. Instead, technology use remains largely oriented toward content delivery rather than competency development, thereby limiting its potential to foster creativity, critical thinking, and problem-solving skills that are central to contemporary learning paradigms. This aligns with Redecker (2017), who emphasises that digital competence frameworks must move beyond operational use of technology towards more transformative pedagogical applications that enhance learner agency and higher-order thinking skills. Similarly, Selwyn (2019) argues that digital technology integration in education often remains at a functional level when it is not supported by broader pedagogical and institutional change, particularly in teacher education contexts. However, these findings contrast with studies reporting more substantial pedagogical benefits of artificial intelligence in STEM-related contexts, suggesting that disciplinary differences, pedagogical traditions, and subject-specific epistemologies may significantly influence the extent to which technology integration translates into meaningful educational transformation.

IMPLICATIONS AND CONTRIBUTIONS

Overall, the study reveals a paradoxical relationship: while pre-service teachers demonstrate high levels of technological and pedagogical knowledge, the actual influence of AI and IR 4.0 on pedagogical practice remains limited. This suggests that the transition from technological competence to pedagogical transformation is not automatic but requires structured pedagogical mediation. The findings reinforce the importance of integrating TAM, TPACK, and the 21st-century framework in teacher education. TAM explains technology acceptance behaviour, TPACK highlights the need for integrated knowledge structures, and the 21st-century framework emphasises competency development. Together, these frameworks suggest that effective pedagogical transformation depends not only on technological exposure but also on perception, integration capacity, and instructional design quality. Consequently, teacher education programmes must move beyond basic digital literacy training and focus on the pedagogical orchestration of emerging technologies, particularly AI, to ensure meaningful transformation in 21st-century teaching practices. Without ongoing training, mentoring, and authentic opportunities for technology integration, pre-service teachers are likely to remain at the level of functional use rather than progressing towards transformative pedagogical application. Therefore, teacher education curricula should embed AI literacy, reflective practice, and design-based learning experiences to develop technologically competent, pedagogically adaptive, and innovation-oriented educators. Furthermore, collaboration between universities, schools, and policymakers is essential to ensure coherent implementation of AI-integrated teacher education frameworks, creating sustainable ecosystems that support continuous professional growth and innovation in teaching practice.

Suggestions

Future research is recommended to adopt a mixed-methods research design by integrating quantitative and qualitative approaches. In addition to questionnaire surveys, focus group discussions or semi-structured interviews could be conducted to gain deeper insights into why pre-service teachers perceive artificial intelligence (AI) as beneficial for academic purposes but are less likely to integrate it into their pedagogical practices. Such an approach would provide a more comprehensive understanding of the factors underlying the gap between AI acceptance and its actual implementation in teaching. Furthermore, future research should expand the sampling framework by including multiple teacher education institutions across Malaysia**.** A larger and more diverse sample drawn from different universities and teacher-training institutions would enhance the generalizability of the findings, improve the robustness of the regression model, and increase the national applicability of the study's conclusions.

CONCLUSION

This study examined the level of mastery and the influence of AI and IR 4.0 on 21st-century pedagogy among pre-service History education teachers at Universiti Malaysia Sabah. The findings show that respondents have a high level of mastery in AI, IR 4.0, and 21st-century pedagogy, indicating strong readiness for technology-enhanced teaching. However, the regression results reveal that while IR 4.0 has a significant but weak influence on 21st-century pedagogy, AI does not significantly predict pedagogical practice. This suggests that technological knowledge has not yet been fully translated into meaningful pedagogical transformation. Overall, the study highlights a gap between technological competence and pedagogical application**,** emphasising the need for stronger integration of AI and IR 4.0 within teacher education programmes to enhance 21st-century teaching practices.

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