

From AI Knowledge to Pedagogical Practice: A Conceptual Framework for AI-Integrated STEM Education among Rural Primary Science Teachers

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Abstract

Artificial Intelligence (AI) is increasingly influencing education, particularly in teaching, learning, assessment and educational decision-making. However, its educational value largely depends on teachers' ability to apply their AI knowledge in pedagogically meaningful ways in the classroom. This conceptual paper proposes a framework for the understanding of transitioning of rural primary science teachers into learning and teaching Science, Technology, Engineering and Mathematics (STEM) with AI. Drawing on the latest literature on AI literacy, teacher readiness for AI, AI-integrated STEM pedagogical practice, professional development and technology integration in rural areas. The paper identifies three interrelated constructs comprising AI knowledge, AI readiness and AI-integrated STEM pedagogical practice. Will-Skill-Tool is the most important theoretical lens used to understand the importance of enabling resources and institutional conditions, teacher knowledge and willingness. The proposed framework situates AI readiness between the knowledge and the pedagogical practice, recognizes a pathway from knowledge to practice and provides room for the development of AI competence in the form of literacy. The concept of 'rural contextual conditions' focuses on factors that can support or hinder implementation such as digital infrastructure, access to AI tools, professional development and school support. The framework includes propositions and implications for teachers, professional development providers, school leaders, policymakers and additional empirical research.

Keywords: Artificial Intelligence, AI Knowledge, AI Readiness, STEM Education, Rural Primary Science Teachers

Introduction

Artificial intelligence (AI) has come a long way from being a specialized technical term to becoming a common part of the educational landscape. AI systems can generate explanations, questions, images, simulations, feedback and summaries and lesson resources in the modern era. Other AI applications can aid in adaptive learning, automated assessment, learning analytics and educational decision making. UNESCO (Miao et al., 2021), Chen et al. (2020) and OECD (2023) therefore recognize that AI is more of a change in digital education than just a classroom application. However, AI's potential in education goes beyond simply

having high-tech systems. It has a high potential for educational value only if teachers are able to make proper decisions on using AI and embed them in teaching and learning. Teachers also need to evaluate the outputs of the AI and apply them judiciously and appropriately in assisting rather than supplanting their professional judgment (Miao & Holmes, 2023; Miao & Cukurova, 2024).

This is particularly relevant in Science, Technology, Engineering and Mathematics (STEM) education, where AI can support inquiry, problem-solving, experimentation and other aspects of Science teaching and learning. In Science education, AI has been shown to support various teaching and learning practices, including personalised learning, intelligent tutoring, assessment, data analysis, content generation, inquiry and problem-solving across Kindergarten to Grade 12 (K–12) settings (Almasri, 2024; Chiu et al., 2023; Lee & Kwon, 2024). Generative AI can also help teachers create inquiry-based lesson plans, create differentiated tasks and create formative assessment materials (Moundridou et al., 2024). But the opportunities come with new challenges for educators too. It is crucial for teachers to grasp the promises and limitations of AI, spot inaccuracies and biases, safeguard privacy and use AI to foster scientific inquiry and age-appropriate learning goals.

Primary Science teachers play a distinctive role in developing key Science concepts and practices during the early years of education. At the primary level, inappropriate use of AI may lead to oversimplification, unchecked claims and overreliance on AI-generated answers. In contrast, well-designed use of AI can foster curiosity, questioning, visualisation, feedback and differentiated inquiry. The importance of age-appropriate, ethical and culturally responsive approaches to AI literacy has also been highlighted for younger learners (Yang, 2022; Yim, 2024). However, integrating AI into the classroom requires more than awareness of AI tools. Teachers need to understand how AI relates to Science content, pedagogy, assessment and responsible classroom use. This highlights the importance of professional knowledge that connects AI concepts and capabilities with Science content, pedagogy, assessment and responsible use (Celik, 2023; Mishra et al., 2023).

These challenges become particularly significant in rural school contexts. Technology integration in rural education is influenced by several contextual factors including connectivity, access to devices, technical support, professional learning opportunities and school leadership alongside broader challenges associated with the digital divide (Mustafa et al., 2024). A study conducted in Malaysia has revealed some disparities between schools in the rural and urban areas in providing conditions for learning such as network connectivity, technical issues and school infrastructure (Yap et al., 2024). The other problem areas that were found in previous rural-school research involved facility-related issues and teacher competence as well as the need for on-going training of ICTs (Hasin & Nasir, 2021). These contextual conditions are significant because while AI-literate teachers can access AI tools, they may have challenges in implementing the tools when they do not have institutional support.

Malaysia's Digital Education Policy and strategic directions emphasise the development of digital competence, adequate infrastructure, access to digital learning resources and equitable participation in digital transformation (Kementerian Pendidikan Malaysia [KPM], 2023a, 2024). Meanwhile, recent studies in Malaysia have begun to explore primary teachers'

knowledge related to teaching with AI. For example, Saharuddin et al. (2025) studied technopedagogical content knowledge (TPCK) possessed by primary school teachers in Semporna, Sabah. At the international scale, Wang et al. (2023) proposed a theoretical framework on AI readiness for primary teachers and Castro et al. (2025) examined rural elementary teachers' attitudes towards using AI. Yet, a coherent body of literature on AI literacy, preparedness, AI classroom practices and technology conditions in rural contexts is missing. In this paper, the question is not whether teachers should be competent in AI but how teachers' knowledge of AI can be transferred to teaching STEM with AI in rural settings.

There are three points in the literature that are still significant. First, AI literacy and AI competence research have established what teachers need to know about AI, its capabilities and limitations, pedagogical uses and ethical implications but there is a lack of research that explains how this knowledge translates into sustained classroom practice (Ng et al., 2021; Chiu et al., 2024). Second, AI-readiness studies have come up with general aspects of teacher readiness but the concept of "readiness" has also included knowledge and ability to some extent. This raises the question of whether the lack of classroom integration is due to the lack of understanding or the lack of confidence, self-efficacy, willingness and preparedness to implement such integration (Wang et al., 2023; Yue et al., 2024). Third, some of the important conditions identified from rural technology-integration studies examine general digital technology or barriers and facilitating conditions to the integration of digital technology without regard to how rural conditions influence the transition from knowledge to readiness to pedagogical use of AI (Hasin & Nasir, 2021; Mustafa et al., 2024; Yap et al., 2024; Castro et al., 2025).

The aforementioned gaps are particularly crucial for rural primary science teachers in Malaysia, as most studies have investigated teacher knowledge of AI, teacher readiness and rural enabling conditions in isolation. A more integrated framework is therefore needed to connect what teachers know and understand about AI with their confidence and readiness to apply this knowledge in practice. The framework should also account for observable AI-integrated STEM pedagogical practices and the rural contextual conditions that may support or hinder their implementation. This type of integration can account for the differences in the teachers' use of AI in the classroom and can determine whether the key constraint is knowledge, readiness or teacher work context.

Accordingly, this paper proposes a conceptual framework to explain the relationships among AI knowledge, AI readiness and AI-integrated STEM pedagogical practice among rural primary Science teachers. It consolidates recent and peer-reviewed publications and pertinent policy papers since 2020 while including older theory about integration of technology when relevant. The framework proposes that AI knowledge contributes to AI readiness which in turn supports AI-integrated STEM pedagogical practice. It also recognises a direct pathway from AI knowledge to pedagogical practice while rural contextual conditions may facilitate or constrain these relationships. The conceptual contribution extends beyond access to or acceptance of AI by focusing on the knowledge-to-readiness-to-practice process within a subject-specific and rural educational context.

Literature Review

Artificial Intelligence Integration in STEM Education

Different definitions of AI integration in STEM education can be viewed as the intentional utilization of AI systems to enhance learning in STEM subjects, STEM practices and instructional decisions. This, rather than just offering students an introduction to the concept of AI. AI can be used in science and STEM classrooms as a learning tool, a feedback tool, an information analysis tool, a modelling and problem-solving tool or a teacher assistance tool for lesson planning and assessment. In the field of education, AI is defined by systems that can offer personalized guidance, support, feedback and decision assistance (Hwang et al., 2020). Ouyang and Jiao (2021) also differentiate between AI directed education, AI supported education and AI empowered education where AI could be used to automate or enhance human-AI learning in various ways.

K-12 research indicates that the use of productive AI is closely tied to engaging pedagogy not passive use. Lee and Kwon's (2024) systematic review found that hands on and project-based approaches are prevalent in K-12 AI education. Learning can focus on AI concepts, applications, problem-solving and ethical reflection. Casal-Otero et al. (2023) also demonstrate the increasing significance of AI literacy in K-12 STEM education. Yue et al (2022) also demonstrate the importance of pedagogical design in the context of meaningful K-12 AI education. Concluding with the science field, Almasri (2024) notes that AI has an impact on the instructional practice and assessment of science teaching but the impact on education will be determined by the way the tools are used in the learning process. The main question for rural primary science teachers is not simply whether AI tools are available. Rather, it is whether teachers can use their capabilities to support inquiry, explanation, evidence-based reasoning, problem-solving and feedback relevant to primary STEM learning.

AI Knowledge among Primary Science Teachers

This paper uses the term AI knowledge to refer to the knowledge that teachers need to comprehend, assess, choose and pedagogically explain technologies of artificial intelligence. It involves understanding the basics of AI literacy, common AI tools and their strengths and limitations. It also includes pedagogical knowledge of AI use and ethical understanding of bias, privacy, transparency, authorship and responsible use. According to Ng et al. (2021), AI literacy encompasses four broad dimensions that involve understanding AI, applying it in practice, evaluating and creating AI and considering its ethical implications. Similarly, Long and Magerko (2020) define AI literacy as a bundle of skills that allows individuals to critically analyze AI technologies, interact and engage with AI and effectively leverage it in various situations.

However, literacy must be linked to the professional use of teachers. The authors of Chiu et al. (2024) distinguish between AI literacy (knowledge) and AI competency (application of knowledge). UNESCO's AI Competency Framework for Teachers also combines the foundations and applications of AI with human-centered values and ethics as well as AI pedagogy and professional learning (Miao & Cukurova, 2024). This distinction is particularly important for primary science teachers. Generative AI responses do not automatically translate into effective pedagogical use. Teachers must determine whether AI can support inquiry, identify misconceptions, generate formative questions and provide scientifically accurate and developmentally appropriate explanations.

The distinction is supported by a body of research on teacher knowledge. Celik (2023) showed that only technological knowledge was not sufficient for meaningful application of AI in education but the teachers' ethical evaluation and the Technological Pedagogical Content Knowledge (TPACK) were also important. This is also echoed by Mishra et al. (2023) who claim that teachers need to bring together a range of technological, pedagogical, content and contextual knowledge to harness the potential of generative AI. A study by Saharuddin et al. (2025) also shows the importance of TPACK in primary teachers' use of AI in Malaysia. AI knowledge is thus treated as a valuable asset for practice rather than as a requirement for practice.

For conceptual clarity, AI knowledge in this framework refers specifically to what teachers know and understand about AI. It encompasses an understanding of AI concepts, the purposes and functions of commonly used AI technologies, their potential to support Science and STEM pedagogy, and ethical considerations such as bias, privacy, transparency, authorship and responsible use. However, AI knowledge does not encompass teachers' confidence, self-efficacy, willingness or preparedness to use AI in the classroom. These factors are instead conceptualised as dimensions of AI readiness.

Teachers' readiness for AI integration.

In this context, AI readiness is the level of confidence, capability, willingness and preparedness of the teacher in using the knowledge of AI in professional practice. It thus focuses on confidence, self-efficacy, willingness, perceived relevance and hands-on readiness instead of reciting what teachers learned about AI. A teacher might have an understanding of the concepts of AI, know the strengths and limitations of AI tools and be aware of the ethical principles for responsible use of AI but still not be prepared to use AI as a classroom tool due to a lack of confidence, willingness or a sense of preparedness. Wang et al. (2023) conceptualized teacher AI readiness broadly through cognition, ability, vision and ethics. The above framework emphasizes the action-oriented part of readiness, placing substantive knowledge of AI and pedagogic use and ethics considerations under the umbrella of knowledge. This division enables AI knowledge to serve as a basis for readiness rather than being a part of it.

Other studies have highlighted the role of teachers' confidence and attitudes in shaping their readiness to use AI. Ayanwale et al. (2022) found that perceived relevance was a significant predictor of readiness to teach AI and that confidence in teaching AI was a strong predictor of behavioural intention. Yue et al. (2024) who analyzed 1,664 K-12 teachers identified the gaps in AI-related content and technological knowledge as well as the teacher's preparedness and attitude toward artificial intelligence and professional development needs. Self-efficacy is central to several definitions of teacher AI competence. Chiu et al. (2025) describe it as teachers' belief in their ability to use AI in the classroom. Delcker et al. (2025) define teacher AI competence as the capacity to develop, apply and assess AI in teaching and learning ethically and responsibly. There are also science specific findings which highlight issues related to trust, utility and the transformation of knowledge in the science classroom (Garofalo & Farenga, 2025).

Professional development is thus a pivotal element to readiness. Nazaretsky et al. (2022) exemplifies how the trust and readiness of teachers in the use of AI-based educational

technology can be reinforced through professional learning. Recent systematic reviews further affirm that professional development programmes need to align the technical and pedagogical dimensions, classroom strategies, ethical considerations and opportunities to put knowledge into practice (Dogan et al., 2025; Tan et al., 2025). AI readiness should also be considered within the realities of rural teaching contexts. Teachers' confidence and preparedness may be affected by limited training opportunities, restricted access to AI tools and limited opportunities to experiment with AI in the classroom.

AI-Integrated STEM Pedagogical Practice

AI-integrated STEM pedagogical practice is the observable practice of teachers using AI to support STEM planning, teaching, learning activities, assessment and feedback for the furtherance of a STEM learning goal. It features AI-driven lesson planning, inquiry-driven learning, problem-solving, personalised feedback, formative assessment and explicit instruction on the responsible use of AI. This construct is oriented towards pedagogy and not on the frequency of using a tool. A teacher who occasionally uses AI to create worksheets may not necessarily be integrating AI meaningfully into teaching. Meaningful integration involves using AI to support Science content, inquiry processes, student thinking, assessment of learning and teacher judgement.

The above distinction is reflected in generative AI as it is a subset of artificial intelligence. Moundridou et al. (2024) demonstrate the ways in which GenAI can be used to assist in different stages of inquiry-based lesson design in content creation, learning activities, assessment and feedback. In primary science, AI can generate alternative explanations at different reading levels and develop sequences of inquiry questions. It can also create problem-solving scenarios, formative quizzes and representations that teachers can evaluate for scientific accuracy. AI can also support differentiated learning. However, teachers remain responsible for validating its outputs and safeguarding student information. They must also determine when direct experience, observation, discussion or experimentation is more appropriate than AI use (Miao & Holmes, 2023).

Therefore, teacher agency becomes the main focus. Zhai (2025) claims that generative AI is changing the role of teachers through perception, acceptance, knowledge and practice. The most helpful place to stand between educationally valuable is neither to be uncritical nor to be altogether against it but to be an informed orchestrator. This reflects scientific learning which is characterised by evidence, explanation, uncertainty and reasoning. In this regard, the quality of the pedagogy and of scientific learning that is enabled should be the basis for evaluating the use of AI in practice rather than the novelty of the technology itself.

Rural Context of AI Integration

Rural educational environments create contextual conditions that can impact the adoption of AI knowledge and preparedness in the classroom. While the digital divide is not just about devices, Mustafa et al. (2024) highlighted several barriers to technology integration in rural schools on both macro, school and teacher-level. There are interdependencies among connectivity, infrastructure, access to appropriate resources, technical assistance, teacher development and institutional capacity that can make the implementation of technology routine or fragile.

Malaysian studies give evidences based on the context. Yap et al. (2024) discussed the facilitating conditions for rural and urban secondary-school teachers and identified network connection, technical issues and school infrastructures as factors of the digital divide. Similar conditions were reported in rural Malaysian schools by Hasin and Nasir (2021). They found constraints related to facilities and expertise despite positive attitudes toward technology use. These results are in line with the focus of Malaysia's Digital Education Policy which centers on competence, infrastructure, digital content and equity (KPM, 2023a). They also suggest that the integration of AI into rural education is not a problem of one teacher when the context in which they teach is not conducive to it.

The new evidence that is emerging specific to AI is particularly noteworthy. Castro et al. (2025) conducted a study of 45 rural elementary teachers and found that access to resources and professional development are key challenges and opportunities for the integration of AI. Nevertheless, teachers saw benefits in personalised learning, reduced workload and multigrade teaching. Rural context, therefore needs to be both limiting and enabling. Strong school leadership, practical professional learning, shared resources, technical support and low-bandwidth or offline strategies can provide enabling conditions while inconsistent access and support can hinder the readiness-to-practice transition.

Theoretical Foundation

The Will-Skill-Tool Model

The Will-Skill-Tool (WST) model is the basic theoretical framework in the proposed research framework as it describes the integration of technology with the interaction of internal and external elements. In this model, will reflects teachers' attitudes, beliefs, confidence and willingness to use technology while skill represents their technological competence and tool refers to the technology and resources available for implementation. Specific to the field of science and mathematics education, Sasota et al. (2021) found that will, skill and tool were important factors in technology integration and each component had varying importance across the different subject areas. Other studies conducted with the model also suggest that classroom use is related to technology competence, beliefs and access (Petko, 2012).

The WST model is particularly suitable for this concept paper for three reasons. First, it distinguishes competence from willingness, thereby clarifying the distinction between AI knowledge and AI readiness. While a teacher might comprehend the concepts of AI, they might not be confident enough, ethically certain or even feel it is relevant to their profession. Second, the model acknowledges the role of access and environmental support as elements of technology integration not as background variables. This is very crucial in a rural setting where infrastructure and resources could be critical. Third, the development of WST is specifically oriented towards technology integration by teachers and has been used in science and mathematics learning environments which is more relevant than a general consumer-acceptance model (Sasota et al., 2021).

The present framework adapts rather than mechanically reproduces WST. AI knowledge corresponds primarily to the skill dimension and is defined here as teachers' understanding of AI concepts, tools and limitations, pedagogical applications and ethical principles. The will dimension is represented by AI readiness which focuses on confidence, self-efficacy, willingness, perceived relevance and practical preparedness to apply that knowledge (Wang

et al., 2023). The dimension of rural contexts includes not only hardware and connectivity but also access to AI services, professional development, technical assistance and school support. The result is an integrated pedagogical practice for STEM using AI. The adaptation is aligned with the perspective that integration of AI is a competence, motivational, pedagogical and contextual process. Table 1 presents the alignment between the Will-Skill-Tool model and the constructs used in the proposed framework.

Table 1

Alignment of the Will-Skill-Tool Model with the Proposed Framework

WST element	Meaning in technology integration	Adaptation in the proposed framework
Will	Attitudes, beliefs, confidence and willingness to use technology	AI readiness, including confidence, self-efficacy, willingness, perceived relevance and practical preparedness to apply AI knowledge
Skill	Technology competence and capacity to use technology for teaching	AI knowledge, including understanding of AI concepts, tools and limitations, pedagogical applications and ethical principles
Tool	Access to technology, infrastructure and enabling resources	Rural contextual conditions as moderators of implementation: connectivity, devices, AI access, professional development, technical assistance and school support
Integration outcome	Use of technology in classroom teaching and learning	AI-integrated STEM pedagogical practice

Application to Rural Primary Science Education

Applied to rural primary science education, WST helps explain why isolated interventions may have limited effect. Learning without confidence building and discussion of teachers' concerns may not lead to classroom use. Positive attitudes may result in superficial or unsafe adoption if they are not backed by adequate pedagogical knowledge. Underuse also can result from the provision of devices or connectivity without professional learning. Successful integration therefore depends on the alignment between teachers' knowledge, their readiness to apply it, and the conditions within their schools that enable implementation. In the proposed framework, rural context is not treated as an additional direct cause of pedagogical practice. Instead, it moderates the knowledge-to-practice and readiness-to-practice relationships by making implementation more or less feasible.

Proposed Conceptual Framework

The proposed framework discusses the integration of AI as a nonlinear process that moves incrementally from professional knowledge to classroom practice. AI knowledge is positioned as a fundamental component, as teachers need an understanding of AI technologies to make informed pedagogical and ethical decisions. AI readiness is intended as a bridge as knowledge needs to be transformed into confidence, willingness, practical readiness and professional judgement for sustained use. The result is AI-integrated STEM pedagogical practice that is manifested in the purposeful use of AI in science and STEM instruction. This process takes place within a rural context where teachers work under varying conditions related to infrastructure, technology access, professional training, technical support and school leadership. In the model, rural contextual conditions are therefore specified as moderators of

the pathways leading to pedagogical practice rather than as a separate direct predictor of practice.

The framework also provides for a direct contribution of AI knowledge to the practice of education. Some teachers might be able to quickly transfer new knowledge into experimentation within the classroom especially if tools are readily available or the teacher already has a good digital-pedagogical competence. But the readiness pathway is still relevant as the repeated, responsible and confident integration will probably be more than just a technical affair. The relations are therefore separated conceptually in the propositions below in order to be tested in future empirical studies. Figure 1 presents the proposed conceptual framework linking AI knowledge, AI readiness, AI-integrated STEM pedagogical practice and rural contextual conditions.

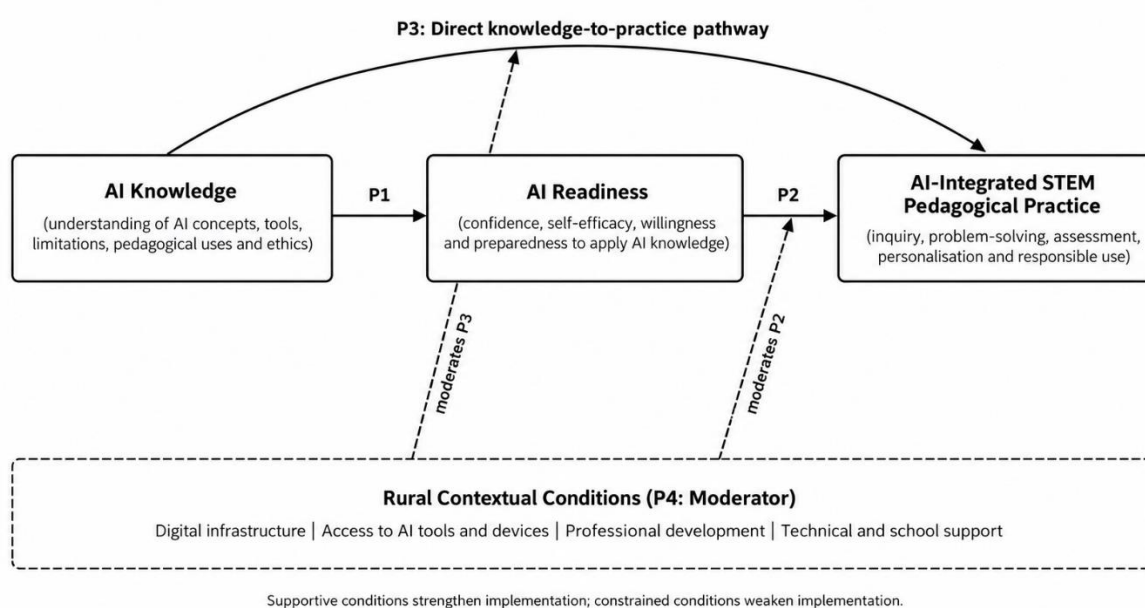


Figure 1 Proposed conceptual framework for AI-integrated STEM education among rural primary science teachers.

AI Knowledge and AI Readiness

AI knowledge is expected to improve readiness by reducing uncertainty and giving teachers the cognitive and practical resources to assess educational value. Ng et al. (2021) and Chiu et al. (2024) highlight the importance of understanding, using, evaluating and considering the ethical aspects of AI literacy and competency. At the teacher level, Yue et al. (2024) show that gaps in AI technology and content knowledge are strongly related to teachers' AI readiness. Similarly, Wang et al. (2023) incorporate cognition and ability into their empirical model of AI readiness. Knowledge is not the same as readiness but can be a foundation for developing confidence, informed attitudes and ethical judgments.

Proposition 1 (P1): AI knowledge positively influences rural primary science teachers' readiness to integrate AI into STEM education.

AI Readiness and Pedagogical Practice

Readiness is likely to affect teachers' practice as it is associated with perceiving AI as relevant, feeling capable of using AI and managing risks. Readiness is expected to affect teachers' practice and is linked to perceived AI relevance, teachers' sense of capability in using AI and managing associated risks. Ayanwale et al. (2022) show that confidence and perceived relevance influence intention and readiness while Wang et al. (2023) identified AI-enhanced innovation readiness dimensions. Professional development can further boost trust and readiness to use AI-based educational technologies (Nazaretsky et al., 2022). This relationship may be especially important in rural schools where teachers may need to be highly creative in using available tools.

Proposition 2 (P2): AI readiness positively influences rural primary science teachers' AI-integrated STEM pedagogical practices.

AI Knowledge and Pedagogical Practice

The findings also suggest a direct link between knowledge and practice. AI knowledge is linked to selecting tools and creating effective prompts, recognizing inaccurate outputs, aligning AI with curriculum content and making appropriate decisions on ethical issues. Celik (2023) provides evidence that technological pedagogical knowledge and ethical assessment are important for integrating AI and Moundridou et al. (2024) show how knowledge of GenAI affordances can be translated into inquiry-oriented planning and assessment. The direct pathway recognizes that preparedness is not the only way professional knowledge affects classroom behavior.

Proposition 3 (P3): AI knowledge contributes positively to AI-integrated STEM pedagogical practice among rural primary science teachers.

Role of Rural Contextual Conditions

In this context, rural contextual conditions are conceptualised as moderating variables of implementation rather than as an extra independent predictor of the implementation of an AI-supported STEM pedagogical approach. The conditions they are talking about are connectivity, access to adequate AI tools and devices, professional development, technical assistance and school leadership. These are thought to be likely to alter the strength of relationships that contribute to practice. When rural conditions are supportive, teachers are more likely to translate their AI knowledge and readiness into classroom practice. In contrast, less supportive conditions, such as limited connectivity, restricted access to AI tools and inadequate support may result in lower levels of implementation even among teachers with similar levels of AI knowledge and readiness. This is in line with studies conducted across the rural context on technology-integration research which have demonstrated that infrastructure and enabling conditions can either facilitate or hinder the use of technology by teachers (Mustafa et al., 2024; Hasin & Nasir, 2021; Yap et al., 2024). Castro et al. (2025) also cite access to resources and professional development opportunities as key factors in the successful implementation of AI in low-resource settings.

Proposition 4 (P4): Rural contextual conditions moderate the relationship between AI knowledge and AI-integrated STEM pedagogical practice and the relationship between AI readiness and AI-integrated STEM pedagogical practice. Supportive rural conditions

strengthen the translation of knowledge and readiness into practice whereas constrained conditions weaken these relationships.

Discussion and Implications

The proposed framework places a focus on the interdependency of AI knowledge and AI readiness, and the entangled relationship between the latter and the contextual conditions in rural environments and their effects on AI-integrated STEM pedagogical practice. The conceptual contribution and the practical implications are discussed below. Rural contextual conditions are considered as a moderator influencing the strength of the relationship between knowledge and readiness to the pedagogical practice specifically.

Conceptual Contribution

One of the main concepts of the framework is to differentiate the concepts of knowing, being ready and practicing. In the discourse on educational AI, teacher competence is often equated with awareness of AI tools which is assumed to lead to classroom use. However, the reviewed literature indicates that teachers' knowledge of AI does not necessarily translate into its integration into classroom practice. AI literacy includes understanding, using and evaluating AI with ethical considerations (Ng et al., 2021). However, AI readiness in the framework involves confidence, self-efficacy and readiness to utilize the current AI knowledge (Wang et al., 2023). The pedagogical practice is an extra step in which teachers reconceive activities, assessment, inquiry and feedback. The separation of these constructs makes it possible to identify breakdowns in the knowledge-to-practice process and to inform the provision of support.

The framework also plays a supporting role in positioning the integration of AI into the rural school context. It is in contrast to the deficit view that low use is the absence of the capacity or the resistance of teachers. Despite teachers' motivation, external conditions can enable or hinder integration as the WST perspective and rural research show. Finally, it is specific to the content of primary science and STEM curriculum and not standard for judging the learning value of AI use is the same for all content areas.

While the original Will-Skill-Tool model identifies will, skill and tool as key conditions related to technology integration, the proposed model adds the concept of Will-Skill-Tool as a process. The first conceptual pathway that it introduces is AI knowledge, AI readiness, pedagogical practice pathway. The concept of readiness is differentiated from the concept of knowledge; the AI knowledge is the knowledge that is necessary to inform pedagogical and ethical decisions, while the AI readiness is confidence, self-efficacy, willingness and preparedness to take actions based on the acquired knowledge. This pathway illustrates how knowledge could be transformed into classroom practice when ready and provides a foundation for future research to explore the indirect knowledge-to-practice pathway.

The second extension is the direct pathway of AI knowledge directly to pedagogical practice. This acknowledges that teachers might use their knowledge in lesson planning, research, assessment and evaluation of AI outputs or in other classroom decisions even when there is still limited readiness. The third extension is related to the tool part of WST. While the framework considers infrastructure and resources as a separate direct cause of practice, the rural contextual conditions are listed as moderators of the implementation. Connectivity,

access to AI tools and devices, professional development, technical assistance and school support can either enhance or diminish the magnitude of the AI knowledge and readiness to become classroom practice. The framework extends beyond a simple re-labelling of the WST components by providing a pathway-based explanation of how teacher knowledge, teacher readiness and rural contextual conditions interact to shape AI-integrated STEM pedagogical practice. The framework thus extends beyond merely re-labeling WST components by clarifying how teacher knowledge, readiness and rural conditions collectively influence the pedagogical practices of integrating AI into STEM.

Implications for Primary Science Teachers

The framework proposes that the use of AI in primary science is not limited to using the tools to improve the learning process but should go beyond that. AI teachers should understand AI's capabilities and limitations, assess the scientific accuracy of AI-generated text, identify potential bias or fabrication, safeguard pupils' privacy and determine whether an AI activity truly enhances science teaching and learning. AI is a tool to aid and augment observation, practical investigation, discussion and evidence-based reasoning. Teachers should also share with their students at an age-appropriate level an awareness of the value of verifying AI-generated content and the responsibility of the user of the AI. These expectations are in line with UNESCO's attention to human and ethical AI competency of teachers (Miao & Cukurova, 2024).

Implications for Teacher Professional Development

Professional development should be continuous, hands on and STEM-related. A single session of a popular AI application to learners will not create lasting changes to teaching and learning. Professional development should be structured progressively, beginning with AI literacy and advancing towards the design of AI-supported lessons, inquiry-based learning, assessment and ethical scenarios, followed by classroom implementation and reflection on evidence of student learning. Teachers also need opportunities to check and correct as well as to prompt and check safely. The importance of incorporating technology knowledge with pedagogy and real teaching tasks in teacher learning is highlighted in reviews of AI professional learning (Dogan et al., 2025; Tan et al., 2025). Rural programs also need to include low bandwidth use, shared device based models and offline preparation and local resources to reflect the school not an idealized school infrastructure.

Implications for Schools and Educational Leaders

The conditions that school leaders create in the 'tool' of knowledge and readiness to become practice. Stable connectivity, appropriate devices, access to approved AI services, data privacy and responsible-use guidelines, technical support, experimentation time and structures for peer learning are highlighted priorities. Professional learning communities can help reduce teacher isolation by providing opportunities to share AI prompts, lesson ideas, identified challenges and practical solutions. Another risk that leadership should steer clear of is identifying innovation solely by the number of AI tools adopted. One risk leadership should not take is equating innovation with the number of AI tools used. More meaningful indicators include improvements in the quality of explanation, inquiry, feedback, differentiation and assessment resulting from AI use while maintaining appropriate teacher oversight.

Implications for Educational Policy

The framework provides a policy level foundation for equity-based approach to AI in education. AI in education national goals should be complemented by targeted interventions to schools that have lower levels of infrastructure, access and professional development. Competence, infrastructure, digital content and equitable participation are also already valued in the Digital Education Policy (KPM, 2023a) and digital transformation is already embedded in the broader educational development in the Ministry's strategic plan (KPM, 2024). The next policy question is how to ensure that the use of AI doesn't further deepen the existing rural-urban gap. AI pedagogy and ethics along with governance mechanisms for approved tools and student privacy and monitoring to evaluate access and meaningful education should be part of teacher competency standards.

Directions for Future Research

The proposed framework requires empirical validation within actual rural educational settings. Future research could be designed to create and test the assessment tools for AI knowledge, AI readiness, and AI-integrated STEM practice and rural context for primary science teachers. The knowledge-to-practice and AI readiness-to-practice relationships should be tested in quantitative studies with P1-P3 as the proposed knowledge while the moderation of AI should be examined specifically as P4 and is expected to either strengthen or weaken the aforementioned relationships for rural contextual conditions. The indirect pathway from AI knowledge through AI readiness to pedagogical practice can also be explored to determine the extent to which AI knowledge translates into classroom practice. Qualitative interviews, observations in the classroom and teacher-led design studies might be helpful to understand how teachers adapt to local conditions while using AI and how teachers' professional judgment develops throughout their experience with AI. Comparative studies of rural and urban school contexts could help distinguish factors that are specific to rural settings from broader systemic factors affecting AI implementation. In addition, longitudinal studies are needed because both AI tools and teacher competencies are rapidly evolving and readiness at one time may not reflect practice as tools and policies are updated and expectations change.

Conclusion

While AI has significant promise for supporting STEM education, the critical question is how teachers can integrate AI knowledge into responsible and effective teaching. For rural primary Science teachers, this shift requires more than access to new technologies. Teachers need AI literacy, readiness to use AI, professional judgement and a supportive school environment that enables meaningful integration into classroom practice. The framework connects AI knowledge with readiness and AI-integrated STEM pedagogical practice. It also recognises a direct pathway from AI knowledge to pedagogical practice. Rural infrastructure, access to resources, professional development and school support are considered contextual factors that may strengthen or weaken the translation of AI knowledge and readiness into classroom practice. The Will-Skill-Tool approach is grounded in the perspective that AI knowledge can produce varying classroom outcomes among teachers and schools and it offers a parsimonious explanation. Its value now lies in empirical testing with rural primary science teachers especially in Malaysia to ensure future professional development and policy focus on the specific areas where the knowledge-to-practice process succeeds or falters.

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