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Preparing educators for the AI-enhanced future: Insights from a teacher professional development for K-12 education in Singapore

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Abstract

The integration of Artificial Intelligence (AI) in education has underscored the urgent need to equip educators with essential AI literacy and related competencies. This paper highlights the critical importance of advancing research on the development of teachers' AI literacy, particularly through targeted professional development (PD) programs. The study piloted a PD program involving 19 mid-career teachers in Singapore. Over six sessions, each lasting three hours, participants engaged in an intensive program designed to enhance their ability to integrate AI into educational practices. The program placed a strong emphasis on ethical considerations and the responsible use of AI. Mixed methods were employed. Data collection included pre- and post- intelligent Technological Pedagogical Content Knowledge (TPACK) surveys, teachers' perceptions on AI, in-class group discussions, and written assignments. Data analyses included content analysis and quantitative data analysis. The results showed a significant enhancement in i-TPACK, accompanied by a noteworthy shift in their overall perceptions of AI. The teachers not only acquired a good understanding of ethical frameworks but also demonstrated adept application in envisioning innovative AI in teaching, schools, and assessment. Importantly, they formulated tailored action plans for implementing AI in their respective schools. The study employed a novel analytical matrix based on the Aristotelian tripartite division of knowledge—episteme, techne, and phronesis—to compare action plans between teachers with different perceived i-TPACK levels, focusing on AI's application in teaching, schools and assessment. This study contributes valuable insights into teacher PD concerning AI in education and informs the implementation of AI in teaching practices.

Keywords: Teacher AI literacy, Teacher Professional Development, Intelligent TPACK, AI in Education, Teacher Perceptions, AI ethics consideration



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Introduction

In the era of rapid advancements in Artificial Intelligence (AI) technology, its far-reaching influence on society is evident (Huang, et al., 2023). As AI permeates various aspects of our lives, it becomes imperative for citizens, including students and teachers, to acquire essential skills to navigate a society and their related areas increasingly shaped by AI (Park, et al., 2023; Tyson & Sauers, 2021).

However, despite these clear benefits, many educators face significant challenges in integrating AI into their teaching practice. AI literacy has emerged as a critical skill set in this context. A lack of deep AI literacy often hampers teachers' ability to utilize AI tools effectively and to address the ethical dilemmas that may arise (Lin et al., 2023). Given these challenges, there is a growing demand for teachers to attain high levels of AI literacy. AI literacy enables individuals to evaluate, communicate, and collaborate effectively with AI, fostering ethical and responsible use in online, home, and workplace environments (Kong et al., 2023; Yang et al., 2023; Wang et al., 2023; Kong & Yang, 2025).

Such competency not only supports the effective use of AI in teaching and learning but also ensures that educators can address related ethical concerns (Adams et al., 2023). Supporting teachers in this endeavor is crucial for advancing professional development and for the successful integration of AI into pedagogical design and daily classroom practice.

The intersection of AI and education presents unique opportunities and challenges (Montebello, 2018; Luckin et al., 2022). Seamless integration of AI technologies into instructional practice requires a deep understanding of both the potential and the pitfalls of these tools (Montebello, 2018; Luckin et al., 2022). Studies such as those by Celik (2023b) highlight the necessity of augmenting TPACK with ethical assessment knowledge to effectively harness AI's potential in education. Technology knowledge (TK) positively predicts ethical assessments, while it does not affect Technological Pedagogical Content Knowledge (TPACK). The integration of AI-based tools is highly dependent on Technological and Pedagogical Knowledge (TPK). Ethical assessment proves to be as influential as TPK in shaping Technological Pedagogical Content Knowledge (TPACK).

So far, limited research has been conducted on teacher's i-TPACK which probe their teaching strategies and challenges in integrating AI in education. To address the above, the study intended to explore a case of an AI literacy training program in Singapore. Singapore is known for its microcosm of highly structured educational systems facing rapid technological integration (Looi et al., 2011). Singapore's commitment to high educational standards and its forward-thinking approach to technology integration make it an exemplary context for this research. The nation's "Smart Nation" vision underscores a national drive to harness technology for societal advancement and individual fulfillment. Central to this vision is the advancement of educational technologies, including AI, to

ensure that educators are prepared to equip the next generation for the opportunities and challenges of a digitally driven world (Smart Nation 2.0).

This study aims to explore how an AI literacy training program affects Singaporean teachers' perceptions of AI, their plans for using AI, and their comprehension of ethical considerations in the context of AI use in the classroom. This research not only contributes to the limited studies on K-12 in-service teacher professional development for AI literacy but also aligns with global educational goals and addresses the pressing need for teachers. The following research questions are posed:

- Research Question 1: What are in-service teachers' initial perceptions on AI for education?
- Research Question 2: To what extent does the AI literacy teacher professional development influence teachers' development of i-TPACK?
- Research Question 3: How do different levels of i-TPACK among teachers influence their capacity to effectively integrate AI tools in education?

The rest of the article is structured as follows: Section 2 presents a comprehensive literature review on AI literacy, the intelligent TPACK framework, and the Aristotelian theoretical framework underpinning this study. Section 3 details the research methodology, including participants, study design, and data collection and analysis methods. Section 4 reports the findings regarding teachers' initial perceptions, changes in i-TPACK, and a comparative analysis of their action plans. Finally, Sections 5 and 6 discuss the conclusions, study implications, limitations, and provide recommendations for future research and professional development programs.

Literature review

AI literacy: Definitions and frameworks

Artificial Intelligence (AI) has rapidly evolved over the past few decades, driven by collaborative efforts spanning computer science, mathematics, philosophy, neuroscience, and psychology (Kok et al., 2009; Simmons & Chappell, 1988). This convergence of multidisciplinary contributions has given rise to the inherently interdisciplinary nature of AI. AI has been defined as a tool to comprehend, model, and replicate human intelligence and cognitive processes through the creation of artificial systems (Zawacki-Richter et al., 2019). It is also defined as a field of computer science research aimed at developing computer systems that are capable of performing tasks requiring human intelligence, such as visual and voice recognition, inferencing and decision making from more technical perspectives (Yang, 2021).

Literacy traditionally refers to the ability to read and write (McBride, 2015). However, in a broader sense, literacy has evolved to encompass a range of skills associated with comprehending and interpreting information. In the context of AI literacy, it would involve the ability to comprehend, evaluate, and effectively navigate information related to artificial intelligence (Chiu et al, 2024). Long and Magerko (2020) define AI literacy as “a set of competencies that enables individuals to critically evaluate AI technologies, communicate effectively with AI, and use AI as a tool across various contexts” (p. 2). The AI literacy enables a solid understanding of AI through three priority axes: learning about AI, learning about how AI works, and learning for life with AI (Casal-Otero, et al., 2023; Long & Magerko, 2020). This includes understanding basic concepts, critically assessing AI-generated content, and possessing the skills to use AI tools responsibly. The fusion of AI with literacy skills essential for individuals to navigate, educate, and actively participate in the digital realm facilitated by AI-driven technologies (Southworth et al., 2023; Yi, 2021).

AI literacy in education can be broadly categorized into two distinct yet interconnected aspects, namely, functional literacy (Kirsch & Guthrie, 1977) and critical literacy (Janks, 2013). Functional literacy prepares individuals for skills deemed required for the future labour market whilst critical literacy entails skills and knowledge that enable individuals to critically engage in society and question and reinvent themselves and the societies they live in (Janke, 2000). Current AI literacy research is heavily focused on functional AI literacy (Velander et al., 2024) i.e. on acquiring practical knowledge and skills to effectively interact with and utilize AI technologies (Casal-Otero 2023). It places a strong emphasis on hands-on experience and the ability to apply AI tools and techniques to solve real-world problems (Touretzky et al., 2019).

In K-12 education, a rich tapestry of scholarly inquiry of AI literacy has emerged. Researchers such as Druga et al. (2019), Kim et al. (2021), and Mertala et al. (2022) have developed comprehensive AI learning curricula with purposeful activities. These educational efforts emphasize nurturing AI literacy, particularly among young learners, to cultivate a deep understanding of fundamental AI concepts. Casal-Otero et al. (2023) conducted a systematic review, examining 179 articles, which affirms that the seamless integration of AI into core subjects is a potent catalyst for enhancing AI literacy. Tenório et al. (2023) performed a comprehensive analysis of a corpus of 244 articles, concluding that machine learning and AI terminology converge with the overarching construct of AI literacy. They underscored the need for future research to consider the ethical aspects of AI literacy. In teacher education, the emphasis on AI literacy is critical for preparing educators to effectively implement and leverage AI technologies in the classroom (Ding et al., 2024; Kim, 2024).

Technological pedagogical and content knowledge (TPACK) framework for AI education

The integration of technology and teacher education often relies on the utilization of Technological Pedagogical Content Knowledge (TPACK) (Koehler & Mishra, 2009). TPACK equips educators with a comprehensive knowledge of effective integration of technologies into the teaching practices, granting them capability and flexibility in tailoring instructional approaches (Kadioğlu-Akbulut et al., 2023). TPACK capability empowers teachers to engage with a broader range of technologies, ultimately enhancing their ability to curate vital instructional information, incorporate it into teaching, and benefit their students in technology supported learning environments. Specifically, the TPACK paradigm inspires educators to employ technologies constructively within their instructional spaces, emphasizing the effective integration of technology rather than mere surface-level application (Clark et al., 2015; Hammond et al., 2009).

Within the realm of TPACK, an extension known as Intelligent Technological Pedagogical Content Knowledge (i-TPACK) is gaining prominence. i-TPACK involves the incorporation of artificial intelligence and advanced technologies into the existing TPACK framework. It is crucial to assess how existing frameworks, initially designed for traditional AI applications, can be adapted to suit the unique capabilities and limitations of advanced AI models (i.e. ChatGPT3). Ethical considerations surrounding AI, including issues of bias, privacy, and transparency, must be comprehensively integrated within these frameworks (Celik, 2023a; Steinbauer et al., 2021; Nam & Bai, 2023). Examining how current integration frameworks reflect ethical concerns provides valuable insights into potential constraints and opportunities for incorporating AI in an ethically responsible manner.

Theoretical framework for AI education for teachers' professional development

AI literacy is increasingly seen as an essential element in education. However, empirical studies on how practicing teachers perceive, develop, and implement AI literacy skills are still scant (Fernández-Batanero et al., 2022; Kohnke et al., 2025). Despite the growing interest in this field, the literature often lacks a unified approach to embedding AI literacy within teacher education programs (Sperling et al., 2024). To bridge this gap, several frameworks have emerged. UNESCO has introduced an AI Competency Framework aimed at a global audience of teachers, designed to equip educators with the skills needed to incorporate AI into their teaching from a human-centered perspective (Miao & Cukurova, 2024). Additionally, the European Union's DigComp 2.2 framework now includes AI literacy as a vital component of digital competence, helping citizens interact with AI technologies responsibly (Vuorikari et al., 2022). Singaporean government introduced a

framework for K-12 educators and students (Ministry of Education Singapore, 2023a, 2023b).

Despite these efforts, the development of AI literacy for teachers in different areas varies significantly, with notable differences in understanding and application across educational settings. This study adopted Aristotelian tripartite division of knowledge: episteme (theoretical-scientific knowledge), techne (practical-productive knowledge), and phronesis (political-ethical knowledge or practical wisdom) (Sperling et al., 2024). This framework encapsulates the comprehensive set of skills and knowledge that teachers need to effectively integrate AI technologies into their teaching practices in Singapore.

First, episteme refers to universal, context-independent knowledge that is often theoretical and scientific (Sperling et al., 2024). In the context of AI education for teachers, episteme encompasses the foundational theories of artificial intelligence, including its historical development, key concepts, and the underlying principles of machine learning algorithms. Understanding episteme allows teachers to grasp the “what” and “why” of AI technologies, providing them with the scientific knowledge necessary to understand how AI works at a fundamental level. Studies have incorporated technological knowledge into teacher professional development (Theodorio, 2024).

Second, ‘techne’ involves the practical application of knowledge, focusing on the skills and abilities to create or produce something. For AI education in teacher professional development, techne in this paper refers to the ability to apply AI tools and techniques in educational settings, including using AI for classroom management, personalized learning, assessment, and school administration (Casal-Otero, 2023; Kong et al., 2024; Touretzky et al., 2019).

Third, ‘phronesis’ involves ethical and practical wisdom. Regarding the AI education, phronesis is crucial for teachers as it involves understanding the ethical implications of AI technologies in education, including privacy, bias, and the broader societal impacts.

Research methods

Participants

The study involved a purposive sample of nineteen teachers. They were selected based on their middle management roles within their respective schools in Singapore. These participants included both primary and secondary school teachers, aged between 30 and 40 years, each with a minimum of five years of teaching experience. The gender distribution consisted of 11 female and eight male teachers. The professional development course was conducted at the National Institute of Education, Singapore. During this period,

participants were relieved from their regular teaching responsibilities to fully engage in the course. The course was guided by the Aristotelian tripartite division of knowledge (theoretical-scientific knowledge, practical-productive knowledge, and political-ethical knowledge or practical wisdom), aiming to enhance participants' understanding of AI technologies, expose them to various AI-powered educational tools, and develop strategies for integrating AI into their teaching practices in an ethical way.

Research design

Context

The study was conducted within the framework of a specialized course named Leadership in AI for Education. This 18-hour course unfolded over six sessions, featuring three-hour sessions per week from January 27 to March 3, 2023. The primary objective of the course was to enhance teachers' leadership capabilities in selectively adopting and effectively implementing AI and educational technology tools. The course was designed to aid educators in making well-informed decisions about educational tools, guiding their practical application, and ensuring AI tools and systems are integrated into classrooms in an ethical manner that addresses student needs, safeguards privacy, and considers other pertinent issues. As a key component of the educational strategy, ChatGPT was introduced to the participants.

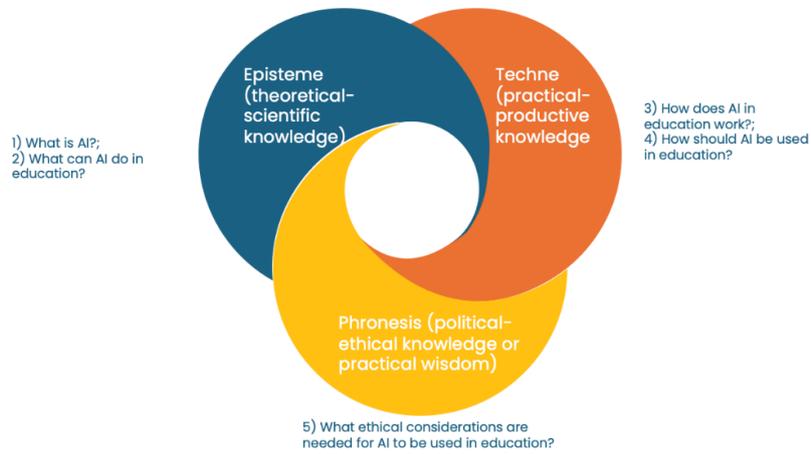
The course design was rooted in the conceptual framework for AI literacy outlined by Long and Magerko (2020), encompassing five overarching themes: 1) What is AI? 2) What can AI do? 3) How does AI work? 4) How should AI be used? and 5) How do people perceive AI? This framework was further enhanced by adhering to the Aristotelian tripartite division of knowledge: episteme (theoretical-scientific knowledge), techne (practical-productive knowledge), and phronesis (political-ethical knowledge or practical wisdom) (Sperling et al., 2024).

The curriculum was structured around these dimensions as follows (refer to Figure 1):

- Under episteme (theoretical-scientific knowledge), the focus was on: 1) What is AI? 2) What can AI do in education?
- Under techne (practical-productive knowledge), the course covered: 3) How does AI in education work?; 4) How should AI be used in education?
- Under phronesis (political-ethical knowledge or practical wisdom), emphasis was placed on: 5) Ethical considerations necessary for the responsible use of AI in education.

Fig. 1

The Aristotelian Tripartite Division of Knowledge-Guided AI Literacy Education for Teachers (Adapted from Sperling et al., 2024).



The design of the teacher professional development (TPD) programme

The TPD are mainly structured by five phases. The phases are designed to progressively build the participants' understanding, skills, and practical application of AI tools in education, with an emphasis on ethical considerations and strategic implementation. Table 1 shows an outline of the phases and their corresponding activities:

Table 1

Phases and Activities of Teacher Professional Development

Phase	Activities
<p>Episteme (Theoretical-Scientific Knowledge)</p> <p>Phase 1: Establishing Fundamental AI Understanding</p>	<ul style="list-style-type: none"> Instructor-led discussions on core AI concepts: 1) What is AI? 2) How does an AI program work? 3) How does a neural network work? 4) How does machine learning work? Hands-on exercises using tools like Teachable Machines to create and share classification models.
<p>Phase 2: Exploring the Evolution of AI in Education</p>	<ul style="list-style-type: none"> Lectures on the historical development and application of AI in education over the past five decades. Practical activities with ChatGPT, reflecting on the educational opportunities it offers.
<p>Techne (Practical-Productive Knowledge)</p> <p>Phase 3: Application and Implementation Activities</p>	<ul style="list-style-type: none"> Case Study Analysis: Participants analyze real-world examples of AI implementation in various educational contexts.

	<ul style="list-style-type: none"> Analyze some ITS products. Development of AI-Enhanced Lesson Plans: Participants design lesson plans that incorporate AI tools tailored to their specific subject areas and grade levels.
Phronesis (Political-Ethical Knowledge or Practical Wisdom) Phase 4: Exploring Ethics in AI & Human-AI Collaboration	<ul style="list-style-type: none"> Guided discussions on AI ethics and collaboration between humans and AI, including the introduction of ethical frameworks. Discussion on AI literacy and ethical considerations in different contexts. Participants engage in discussions that contextualize AI ethics within Singapore.
Phase 5: Leading Innovation in AI Practice	<ul style="list-style-type: none"> Guided Application of the ETHICAL AI Readiness Framework. Group Work on AI Strategy Development: In group settings, educators brainstorm and discuss specific AI implementation strategies for their schools. They explore questions such as “What ethical issues might arise from using AI in our education system?” and “How can these issues be resolved?” Integration of Pedagogic Expertise: Participants leverage their pedagogical knowledge and classroom experiences to design AI plans that effectively bridge educational needs with AI capabilities.

The TPD incorporates a series of interactive lectures, which cover foundational and advanced concepts of AI integration in education. Alongside the lectures, the program also facilitates structured group discussions, allowing participants to engage deeply with specific topics.

Data collection

The study adopted mixed-methods research. Both quantitative and qualitative data are analysed, including 1) teachers’ perceptions of AI, 2) i-TPACK questionnaires, 3) in-class group discussions, and 4) individual 1000-word written assignment.

Teachers’ perceptions of AI

At the beginning of the course, the teachers were asked to respond to seven questions to assess their initial perceptions and understanding of AI in education (Pappa et al., 2023) (refer to Appendix A). The questions were adapted from Lindner and Berges (2020), aimed at evaluating the teachers' baseline knowledge and attitudes toward AI in education. Topics discussed included sources of AI knowledge, emotional reactions to AI, definitions of AI,

understanding of machine learning, encounters with AI in daily life, expectations for future AI developments, and other AI-related thoughts.

Pre-and post-surveys of i-TPACK

The study employed pre- and post-questionnaire to measure shifts in the teachers' Intelligent-TPACK skills and their awareness of ethical considerations regarding AI in education, as proposed by Celik (2023a). The questionnaire has 27 items using 7-point Likert type covering technological knowledge (i-TK, 5 items), technological pedagogical knowledge (i-TPK, 7 items), technological content knowledge (i-TCK, 4 items), technological pedagogical and content knowledge (i-TPACK, 7 items) and ethical awareness of AI in education (ethics, 4 items) (Appendix B).

Group discussions

The structured group discussions were facilitated throughout the course. Participants were divided into five groups. Topics discussed included potential AI automations in teaching, ethical frameworks for AI in education, hands-on experiences with AI tools like ChatGPT, and the application of the 7-step AI readiness framework (Luckin et al., 2022). During the group discussions, the following questions were raised:

- 1) How can AI literacy be integrated into the curriculum, and what competencies are needed for teachers to become AI literate?
- 2) Is there a vision for universal AI literacy among teachers, and how can this vision be realized?
- 3) Should the approach be to choose AI and then train teachers or vice versa, and how should professional development for AI literacy be structured?
- 4) How can teacher competence in AI be qualified and quantified, and what is the trade-off between competence and work-life balance?

The participants could choose a topic and present on the class. The presentations were recorded and analysed.

Individual 1000-word written assignment

In the final week of the course, each teacher was tasked with creating a 1000-word assignment focused on developing an AI-enabled action plan tailored to the specific needs of their school. This assignment required a comprehensive exploration of ethical considerations, alignment of AI tools with pedagogical objectives, and the practical application of AI in their educational environment.

In this study, the individual assignment was typically expected to encompass the following elements of AI literacy:

- Demonstrated or inferred knowledge of AI: What insights are evident from the assignment regarding the understanding of AI?
- Application of AI: How is AI strategically applied to address a specific problem or requirement within the school?
- Ethical concerns: What ethical considerations are explicitly addressed and highlighted in the assignment?
- Overall AI literacy: What level of AI literacy is demonstrated holistically in the assignment?

Data analysis

The data analysis methods were designed to deepen the understanding of teachers' i-TPACK and their ethical awareness regarding AI in education. Thematic analysis and a paired-sample t-test were conducted using NVivo 14 and SPSS 25.0 to assess the qualitative and quantitative data, respectively.

To address the first question, thematic analysis was employed to analyse teachers' perceptions of AI, including understanding their comprehension of AI, the origins of their AI knowledge, their encounters with AI in their everyday activities, and their attitudes towards AI. The teachers' sources of AI knowledge were classified into two distinct categories: incidental knowledge and intentional knowledge of AI (Velandar et al., 2023). Incidental knowledge pertained to information acquired inadvertently, whereas intentional knowledge referred to consciously sought-out AI-related information. The study examined teachers' familiarity with various types of AI and their corresponding functions in daily life, termed as experience knowledge of AI. The data analysis was facilitated using NVivo 14, a powerful qualitative data analysis software, enabling a comprehensive exploration of the themes and patterns emerging from teachers' responses.

To address the second research questions, the descriptive statistics, including standard deviation, mean, skewness, and kurtosis, were employed to assess the normality of the data distribution. A paired-sample t-test was conducted to examine the changes of teachers' i-TPACK after the TPD. Regarding the reliability and validity of this questionnaire, the results showed that the Cronbach's alpha values for the dimensions are ranged from 0.947 to 0.968, suggesting a high level of internal consistency among the items in each of these dimensions (Bonett & Wright, 2015). The Kaiser-Meyer-Olkin (KMO) test was conducted to assess the sampling adequacy for factor analysis, and the results confirmed the

appropriateness of the data for this analytical method. The KMO values ranged from 0.750 to 0.887 across the different dimensions of the survey, indicating a good to excellent suitability for factor analysis. Specifically, the KMO values were as follows: Intelligent Technological Knowledge (i-TK) scored 0.872, Intelligent Technological Pedagogical Knowledge (i-TPK) scored 0.887, Intelligent Technological Content Knowledge (i-TCK) scored 0.831, Intelligent Technological Pedagogical and Content Knowledge (i-TPACK) scored 0.872, and Ethics scored 0.750.

In addition, group discussions were analysed to triangulate the findings. Two researchers coded the data. The researchers independently code the data and then compare their findings to identify any discrepancies or common themes. This dual-coding approach ensures that the interpretation of discussion content is accurate and consistent, providing a reliable basis for the conclusions drawn from the program.

To address the third question, the individual assignments were thoroughly analysed using content analysis to evaluate the depth of teachers' understanding of AI, the application of ethical frameworks, and the specificity of the action plans proposed. Four samples were analysed. Table 2 shows the matrix used to analyse the teachers' action plans is structured around the Aristotelian tripartite division of knowledge, which includes episteme (theoretical-scientific knowledge), techne (practical-productive knowledge), and phronesis (political-ethical knowledge or practical wisdom) as its horizontal dimension. The vertical dimension of the matrix addresses different aspects of AI, specifically AI for teaching, AI for schools, and AI for assessment. This coding matrix facilitates a detailed examination of how educators integrate AI into various educational contexts based on their theoretical understanding, practical application skills, and ethical considerations. Four samples were highlighted in this study.

Table 2

The Coding Matrix for Analysing AI Actions

Knowledge Type	AI for Teaching	AI for Schools	AI for Assessment
Episteme	<ul style="list-style-type: none"> Understanding the theoretical foundations and scientific principles underlying AI technologies to enhance teaching. 	<ul style="list-style-type: none"> Comprehensive grasp of systemic implications of integrating AI, including policy and theoretical impact on schools. 	<ul style="list-style-type: none"> Focus on the scientific basis and theoretical underpinnings of AI in developing and refining assessment tools.
Techne	<ul style="list-style-type: none"> Practical application of AI tools in teaching processes, like educational software and resources. 	<ul style="list-style-type: none"> Skills required to deploy and manage AI technologies across school systems to support 	<ul style="list-style-type: none"> Practical skills needed for implementing AI-driven assessment systems, including

Phronesis	<ul style="list-style-type: none"> Ethical use of AI in the classroom, focusing on fairness, equity, and responsible integration. 	educational objectives. <ul style="list-style-type: none"> Wise and ethical management of AI integration, addressing data privacy, security, and ethical implications. 	configuration and maintenance. <ul style="list-style-type: none"> Ensuring ethical use of AI in assessment practices, focusing on fairness, transparency, and sustainability.
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Results

Teachers' initial perceptions of AI

Teachers understanding of AI

Regarding Research Question 1, the study found that in-service teachers held diverse initial perceptions of AI for education. The research findings indicated a spectrum of AI knowledge levels among teachers. Among the surveyed teachers, 15 demonstrated incidental knowledge of AI, suggesting they had a basic awareness or exposure to AI concepts, possibly through casual exposure or incidental learning. A smaller subset of two teachers possessed a combination of incidental and intentional knowledge about AI, indicating they had some prior awareness but also actively sought a deeper understanding of AI. Notably, only three teachers exhibited intentional knowledge of AI, signifying that these teachers actively pursued and acquired a more profound understanding of AI, possibly through formal training or deliberate self-education efforts.

Teacher knowledge of AI in daily life

In response to what they understood as their definition of AI, there is fair homogeneity in their perceptions of what AI is. Here are some of their responses:

- *"Intelligence that is manufactured and performed by machines" (T3)*
- *"Working of robots and automation to replace human brains" (T5)*
- *"Machines can learn and improve over time and experiences and become better at what they do" (T4)*
- *"A computer programme that gets better the more it is used" (T9)*
- *"When a robot/computer uses the information programmed into it to solve problems. AI systems are designed to be able to learn from new experiences, adapt to new situations and make decisions based on the available information" (T11)*
- *"My definition of AI is an intelligence that mimics human intelligence with the propensity to be more intelligent than humans" (T2)*

Inquiring about teachers' interactions with AI in their daily lives offers valuable insights into the extent of AI integration into their routines. The responses to this inquiry exhibit diversity, influenced by individual backgrounds, interests, and levels of exposure to AI. Our survey of teachers unveiled a noteworthy presence of AI applications in their day-to-day experiences. Prominently, chatbots emerged as the most frequently cited AI application, with numerous respondents mentioning their encounters with AI-powered chatbots, including ChatGPT, website or app chatbots typically located at the lower left corner of webpages. Virtual personal assistants such as Siri and Google Assistant featured prominently in teachers' AI experiences. Many teachers reported using these digital helpers regularly. Recommender systems employed by online platforms, exemplified by Netflix's content recommendation algorithms, were another noteworthy AI application acknowledged by teachers. Teachers noted the role of AI in social media platforms like Facebook and Instagram, where AI-driven content curation and user engagement features are prevalent. In a slightly less frequent but still notable context, some teachers shared their experiences with AI technologies like image recognition and speech recognition. These technologies contribute to various aspects of their daily routines.

Teacher feelings towards AI

The outcomes unveiled a rich tapestry of emotions and attitudes among teachers regarding AI. Teachers' feelings associated with AI revealed a range of emotions, including excitement, curiosity, anxiety, apprehension, trepidation, intrigue, fascination, uncertainty, and mixed feelings.

Responses to the question "When thinking of artificial intelligence, what feelings do you associate with it?" range from: "no human touch", "uncertainty", "excited, anxious", "excited, curious", "excitement and trepidation", "curiosity and fascination, but at the same time concerned about how personal data are being used to customize experiences for us." Thus, some teachers expressed enthusiastic anticipation about AI's potential to revolutionize education and tackle intricate challenges, seeing it as a promising force for positive change. Conversely, others conveyed feelings of anxiety or uncertainty, stemming from concerns about potential risks and adverse consequences associated with this technology. A subset of teachers exhibited curiosity and fascination with AI, driven by the allure of its capabilities and the possibilities it presents.

At the same time, some individuals approached AI with scepticism or indifference, not necessarily sharing the same level of enthusiasm or curiosity. Ethical considerations and concerns about the accuracy and reliability of AI systems also surfaced in the responses.

Intelligent TK (i-TK)		5.000	1.067		6.000	0.718	3.57**
	i-TK 1	5.400	1.265	6.100	0.568		
	i-TK 2	4.900	1.197	6.000	0.943		
	i-TK 3	4.700	1.418	6.200	0.632		
	i-TK 4	4.300	1.703	5.900	0.738		
	i-TK5	5.000	0.943	5.800	1.135		
Intelligent TPK (i-TPK)		4.171	1.425		5.971	0.485	4.28**
	i-TPK1	4.500	1.650	6.100	0.568		
	i-TPK 2	4.300	1.636	6.100	0.568		
	i-TPK 3	3.800	1.619	6.000	0.943		
	i-TPK 4	4.000	1.563	2.700	0.823		
	i-TPK 5	4.200	1.687	6.000	0.471		
	i-TPK 6	4.400	1.350	6.000	0.471		
	i-TPK 7	4.000	1.414	5.900	0.568		
Intelligent TCK(i- TCK)		3.925	1.486		5.925	0.646	3.94**
	i-TCK1	4.000	1.491	6.200	0.632		
	i-TCK 2	4.000	1.563	5.800	0.919		
	i-TCK 3	4.000	1.333	6.100	0.568		
	i-TCK 4	3.700	1.767	5.600	0.843		
Intelligent TPACK (i-TPACK)		3.729	1.179		5.700	0.454	5.51***
	i-TPACK1	3.600	1.506	5.700	0.483		

	i-TPACK 2	3.700	1.160	5.700	0.675		
	i-TPACK 3	3.900	1.101	5.500	0.527		
	i-TPACK 4	3.300	1.494	5.800	1.033		
	i-TPACK 5	3.700	1.337	5.800	0.789		
	i-TPACK 6	3.900	1.287	5.700	0.832		
	i-TPACK 7	4.000	1.333	5.700	0.483		
Ethics		3.600	0.810			5.975	0.558 7.60***
	Ethics 1	3.600	1.075	6.000	0.816		
	Ethics 2	2.900	0.994	6.000	0.667		
	Ethics 3	3.800	1.229	5.800	0.632		
	Ethics 4	4.100	1.197	6.100	0.568		

Over the course of six sessions, teachers engaged in rich discussions regarding the integration of Artificial Intelligence (AI) in education, exploring various facets from theoretical underpinnings to practical applications and ethical considerations. These discussions are summarized in Table 4, which categorizes each group's insights into three distinct knowledge types: Episteme (theoretical-scientific knowledge), Techne (practical-productive knowledge), and Phronesis (political-ethical knowledge or practical wisdom).

Table 4

The Summary of Five Group's Discussions

Groups	Understandings of AI			
	Episteme (Theoretical-Scientific Knowledge)	Techne (Practical- Productive Knowledge)	Phronesis (Political- Ethical Knowledge or Practical Wisdom)	

1	<ul style="list-style-type: none"> • Embracing AI literacy with a focus on policies, leadership, and professional development. • Initial excitement tempered by AI limitations. 	<ul style="list-style-type: none"> • Academic performance analysis • Personalized learning programs • Exam setting 	<ul style="list-style-type: none"> • Concerns about AI grading accuracy and fairness • Potential redundancy of teachers • Autonomy issues with mandatory AI use
2	<ul style="list-style-type: none"> • Addressing emotional responses to AI, emphasizing cooperative approaches and the sequencing of training. • Viewing AI as a potential social equalizer. 	<ul style="list-style-type: none"> • Basic grading and feedback • Chatbots for student queries • Writing feedback and testimonials 	<ul style="list-style-type: none"> • Bias and discrimination risks in AI behaviour management • Importance of ‘human-in-the-loop’ for sensitive decisions • Emphasized the role of policies, curriculum, leadership, and professional development.
3	<ul style="list-style-type: none"> • Overcoming preconceptions and fears, focusing on ethics. Considers AI as a socio-economic equalizer. 	<ul style="list-style-type: none"> • Rudimentary task automation • Data analysis for predictive insights • Managing information resources 	<ul style="list-style-type: none"> • Risk of dehumanization by reducing students to numbers • Potential bias affecting teacher perceptions

4	<ul style="list-style-type: none"> • Leveraging AI capabilities to enhance teaching and learning, emphasizing the importance of AI literacy among educators. 	<ul style="list-style-type: none"> • Routine academic tasks (marking, tracking) • Analysing student interests and abilities • Virtual assistance for class discussions 	<ul style="list-style-type: none"> • AI transparency and fairness concerns • Accountability in AI-driven decisions • Ensuring AI aligns with school values
5	<ul style="list-style-type: none"> • Viewing AI as a supportive tool when understood 	<ul style="list-style-type: none"> • Marking straightforward assessments • Data processing and analysis • Chatbots for parent parents' queries. • Exploring the idea of AI literacy in the curriculum. 	<ul style="list-style-type: none"> • Justice and explicability in AI assessments • Potential for AI to ignore complex human factors • Ensuring AI does not unfairly impact students

The following excerpt includes responses from several teachers:

Teacher A:

“The national posture towards AI is forward-looking and is in alignment the global trend. This will put us in good stead as we embrace the power of technology in our education system. At the school level, we must be cognizant of the pros and cons when harnessing AI. There are ethical issues that we need to be mindful of, and AI is there to support us and not replace us – especially in decision making process.”

Teacher B:

“The use of AI in assessment has the potential to revolutionise teaching and learning in Singapore schools. By automating certain tasks, AI can free up time for teachers to focus more on 1 to 1 interaction with students. Additionally, AI can help to find learning gaps and supply targeted interventions to support students. However, it is important to approach the

use of AI in assessments with caution, taking into consideration issues such as privacy, bias, and the potential for creating inequalities. Ultimately, by making use of the power of AI in responsible and ethical ways, schools can create a more fair and effective education environment for all students.”

In summary, the discussions across the different groups indicated that teachers in this course possess a solid understanding of AI and its capabilities to automate specific educational tasks. They acknowledged the value of AI in tasks like analysing student performance data, delivering personalized learning experiences, and grading multiple-choice questions and simple essays. Nonetheless, the teachers were also aware of the limitations of AI, recognizing that it cannot replace human involvement in areas requiring socio-emotional support, creativity, critical thinking, and physical skills. This awareness underscores their understanding of the unique contributions and irreplaceable roles that human teachers play in the classroom.

Furthermore, the teachers demonstrated a nuanced perspective on the role of AI in education. They appreciated AI's potential to streamline certain tasks and enhance personalized learning. However, they equally emphasized the importance of the human touch in teaching. For instance, Group 4 acknowledged that while AI could assist in analysing students' abilities and interests to optimize learning methods, the ultimate responsibility of facilitating group learning and providing holistic feedback about students rests with the teachers, who see students as complete human beings rather than mere data points.

Comparative analysis of teacher individual assignments on AI integration in education based on i-TPACK levels

The study highlights action plans from four teachers—Nick, Tony, Woody, and Betty—who have varying degrees of i-TPACK, with Woody and Betty scoring above and Nick and Tony below the class average. Table 5 shows the four teachers' mean of i-TPACK. Their assignments are analyzed to reveal how each teacher contextualizes AI in the realms of teaching and assessment, reflecting their individual competencies and understanding of AI's potential and ethical implications in education.

Table 5

Four Participants' Perceived i-TPACK

Teachers i-TPACK	Woody	Nick	Betty	Tony	Class average
Intelligent TK (M)	6.00	5.00	6.00	5.00	6.00
Intelligent TPK (M)	5.86	5.00	6.00	4.57	5.97
Intelligent TCK (M)	6.00	5.00	6.00	5.00	5.93
Intelligent TPACK (M)	6.00	4.71	5.71	4.71	5.70
Ethics (M)	6.00	5.00	6.00	4.50	5.98

Tables 6 and 7 present the coding results of individual assignments from teachers recognized for their high perceived i-TPACK. Woody and Betty, who are categorized as having high i-TPACK, exhibit a profound integration of epistemic, technical, and ethical dimensions in their assignments. Woody's approach includes educating peers on AI capabilities and exploring global applications, developing AI tools for enhancing lesson delivery and feedback, and adhering to FAST principles for ethical AI development. Similarly, Betty demonstrates a comprehensive understanding of AI's theoretical aspects and policy implications in education, skillful application of AI tools for adaptive learning, and a strong commitment to ethical issues, ensuring fairness and preventing data discrimination.

Table 6

High Perceived i-TPACK Teacher's Individual Assignments (Case: Woody)

Knowledge Type	AI for Teaching	AI for Schools	AI for Assessment
Episteme	<ul style="list-style-type: none"> Educate teachers on AI capabilities in Mathematics. Research global AI teaching applications. 	<ul style="list-style-type: none"> Discuss AI's data protection in education. 	<ul style="list-style-type: none"> Analyze student performance and provide customized feedback using AI.

Techne	<ul style="list-style-type: none"> Develop AI tools to assist in lesson delivery and feedback mechanisms. AI provides feedback on teaching methods and identifies misconceptions. 	<ul style="list-style-type: none"> Implement AI technologies to monitor and enhance classroom dynamics. 	<ul style="list-style-type: none"> AI tools mark assignments and generate performance reports.
Phronesis	<ul style="list-style-type: none"> Discuss FAST principles for ethical AI development: fairness, accountability, sustainability, transparency. 	<ul style="list-style-type: none"> Ensure fairness, accountability, sustainability, and transparency in AI use in schools. 	<ul style="list-style-type: none"> Ensure AI assessments are unbiased and respectful of student privacy.

Table 7
High Perceived i-TPACK Teacher’s Individual Assignments (Case: Betty)

Knowledge Type	AI for Teaching	AI for Schools	AI for Assessment
Episteme	<ul style="list-style-type: none"> Understanding the theoretical aspects of AI applications in education. 	<ul style="list-style-type: none"> Understanding the technical infrastructure in schools. Comprehensive knowledge of AI impacts and policies in the educational sector. 	<ul style="list-style-type: none"> Insight into the functions of AI apps (e.g., Gradescope, Crowdmark, Smart Sparrow, Knewton, Examyty).
Techne	<ul style="list-style-type: none"> Practical skills in using AI tools for teaching, such as 	<ul style="list-style-type: none"> Technical proficiency in deploying and 	<ul style="list-style-type: none"> Technical skills in setting up and managing AI-

Phronesis	<p>adaptive learning platforms.</p> <ul style="list-style-type: none"> • The “meta-autonomy” principle should be applied, emphasizing that teachers make a conscious effort to make the final marking decision. 	<p>maintaining AI systems across a school.</p> <ul style="list-style-type: none"> • Schools will need to put more emphasis on pedagogical principles in the development of AI assessment apps. 	<p>driven assessment systems: Automated marking, adaptive testing, automated test</p>
	<ul style="list-style-type: none"> • Making wise and ethical decisions about how AI is used in the classroom to enhance learning. • AI should "enable equal access to the benefits and contribute to global justice." The data fed into the AI app must be scrutinized by the ICT team to ensure no student group is discriminated against. 	<ul style="list-style-type: none"> • Practical wisdom in overseeing the integration of AI within school operations and curriculum to prevent data breaches and unauthorized access. 	<ul style="list-style-type: none"> • Ethical judgment in the application of AI for fair and effective assessments. • Set up clear lines of teacher accountability for marking decisions made by AI and how the individual marks are translated into final grades. • Continuous monitoring of the app for any ethical issues, such as data leaks, and adjustments must be made to prevent this.

In contrast, Nick and Tony, with lower i-TPACK scores, present a more foundational understanding and application of AI (Table 8, Table 9). Nick's assignment shows an awareness of AI functionalities like face recognition and adaptive testing but lacks a strategic vision for broader educational integration. His technical applications focus on immediate content delivery and administrative efficiencies, with ethical considerations that touch on data protection but are less detailed. Tony's work reflects an understanding of personalized learning enhancements through AI and administrative efficiencies but similarly lacks depth in strategic integration and detailed ethical planning, despite mentioning the 7-step ETHICAL framework (citation).

Table 8

Low Perceived i-TPACK Teacher's Individual Assignments (Case: Nick)

Knowledge Type	AI for Teaching	AI for Schools	AI for Assessment
Episteme	<ul style="list-style-type: none"> Understanding the examples of facial recognition door system, attendance taking functions using AIMS, 	<ul style="list-style-type: none"> AI-driven analysis of school-wide data for trends and patterns. 	<ul style="list-style-type: none"> AI-enhanced adaptive testing and grading systems to better evaluate student's knowledge.
Techne	<ul style="list-style-type: none"> Implementation of AI tools to help with instructional content creation and delivery. 	<ul style="list-style-type: none"> Automation of administrative tasks like attendance and scheduling. 	<ul style="list-style-type: none"> AI tools for real-time feedback and assessment adjustments during exams.
Phronesis	<ul style="list-style-type: none"> Ethical considerations in personalized education, ensuring student data protection and unbiased AI. 	<ul style="list-style-type: none"> Decisions on data privacy, storage, and access, ensuring transparency and security. Outline 7-step ETHICAL 	<ul style="list-style-type: none"> NA

framework to systematically plan, implement.

Table 9

Low Perceived i-TPACK Teacher’s Individual Assignments (Case: Tony)

Knowledge Type	AI for Teaching	AI for Schools	AI for Assessment
Episteme	<ul style="list-style-type: none"> AI creates personalized learning experiences. 	<ul style="list-style-type: none"> AI revolutionizes school operations. 	<ul style="list-style-type: none"> Understanding of AI-driven assessments, rule-based AI like tutoring system
Techne	<ul style="list-style-type: none"> AI identifies learning gaps and provides tutoring. 	<ul style="list-style-type: none"> AI eases administrative burdens, reallocating resources. 	<ul style="list-style-type: none"> AI integrates technology to provide specific feedback.
Phronesis	<ul style="list-style-type: none"> Balance AI use and human interaction. 	<ul style="list-style-type: none"> Manage AI implementation responsibly. 7-step ETHICAL framework for AI project planning, implementation, impact analysis, and refinement. 	<ul style="list-style-type: none"> Ensure fairness, accountability, sustainability, and transparency in AI systems.
	<ul style="list-style-type: none"> AI creates personalized learning experiences. 	<ul style="list-style-type: none"> AI revolutionizes school operations. 	<ul style="list-style-type: none"> Understanding of AI-driven assessments, rule-based AI like tutoring system

A cross-case synthesis revealed a typology of teacher responses to AI integration in education (Table 10). Transformative Integrators, like Woody and Betty, demonstrated

high perceived i-TPACK, balancing theoretical understanding, practical application, and ethical wisdom. They demonstrate a sophisticated approach to integrating AI tools that enhance educational outcomes while rigorously addressing ethical concerns. On the other hand, teachers with lower i-TPACK scores, like Nick and Tony, exhibit a more limited scope in their understanding and application of AI. While they recognize certain AI applications, their assignments lack the comprehensive strategic vision and detailed ethical foresight seen in their higher-scoring counterparts.

Instrumental Implementers, such as Nick, showed competence in utilising AI tools and systems but were less reflective in their ethical application. Pragmatic Explorers, exemplified by Tony, recognized the potential of AI in improving teaching and operations but exhibited a surface-level understanding of ethical and theoretical implications.

Table 10

Cross-Case Synthesis Typology of Teachers' Individual Assignments

Typology	Characteristics	Representative Cases	Key Observations
Transformative Integrators	High i-TPACK. Deep epistemic, technical, and ethical grasp. Holistic vision for AI use across contexts.	Woody, Betty	<ul style="list-style-type: none"> • Able to articulate AI pedagogy, ethics (e.g., FAST, meta-autonomy), infrastructure, and systemic accountability. • Demonstrates autonomy and reflective judgment (phronesis).
Instrumental Implementers	Functional techne and episteme. Moderate ethical consideration. Focused on implementation over philosophy.	Nick	<ul style="list-style-type: none"> • Emphasises tools and applications (e.g., facial recognition, AIMS). • Ethics addressed but more procedural than reflective (e.g., ETHICAL framework mentioned but not deeply applied).
Pragmatic Explorers	Emerging i-TPACK. Clear interest in AI	Tony	<ul style="list-style-type: none"> • Emphasises personalisation and

benefits, but limited integration across all dimensions.	operational benefits of AI. Ethical understanding present but not deeply problematised. Often uses general terms (e.g., “AI revolutionises...”)
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Conclusion and discussion

The research findings highlight the crucial role of AI literacy training in equipping teachers for the effective integration of AI into their teaching practices. This initial training program not only enhances their understanding of AI but also fosters a heightened awareness of ethical considerations and instructional strategies. These outcomes ultimately contribute to the improvement of students’ learning experiences and play a pivotal role in shaping the future education. The study strongly advocates for targeted educational initiatives aimed at closing the knowledge gap among teachers, empowering them with essential skills to successfully incorporate AI into their teaching methods.

Through this professional development program, teachers not only enhance their comprehension of AI concepts but also gain a deeper understanding of ethical frameworks within the context of AI use in the classroom. The findings addressing Research Questions 1 revealed that while some teachers only had incidental knowledge of AI, a minority pursued a deeper, intentional understanding. This variation in knowledge underscores a critical need for comprehensive professional development programs tailored to enhance AI literacy across all levels of understanding. Teachers’ initial definitions and daily interactions with AI demonstrated a general awareness of its capabilities and applications, which sets a promising foundation for further educational interventions.

Addressing Research Question 2, the TPD significantly influenced teachers’ i-TPACK development. After the TPD, teachers’ i-TPACK significantly enhanced across all dimensions, with ethics showing the greatest improvement. This indicates that not only did the TPD effectively enhance teachers’ technical and pedagogical skills, but it also critically elevated their ethical awareness concerning AI applications in education. The training program’s success in fostering comprehensive AI competencies highlights its value and necessity in today’s tech-driven educational landscape. This demonstrates the effectiveness of AI literacy training in equipping teachers with the knowledge and awareness necessary to navigate the complex ethical considerations surrounding AI in education. The

development of AI ethics and pedagogical considerations, as emphasized in the study, plays a crucial role in fostering responsible AI use and ensuring that students are prepared for a world where AI technologies are prevalent (Yau, et al., 2023; Choi et al., 2022).

In response to Research Question 3, concerning the influence of i-TPACK levels on AI integration, the comparative analysis of individual teacher assignments revealed that teachers with higher i-TPACK scores were more adept at integrating AI into their teaching strategies, showing sophisticated approaches to both the application of AI tools and the ethical considerations involved. In contrast, those with lower i-TPACK scores were less comprehensive in their understanding and application, often overlooking strategic and ethical dimensions. This correlation underscores the importance of developing high i-TPACK levels to ensure effective and responsible AI integration in educational practices.

Responses from participants in the course indicate that teachers have a good understanding of AI's potential to automate specific teaching tasks. They recognize AI's value in tasks such as analyzing student data, personalizing learning, and grading assessments. However, they also acknowledge AI's limitations, particularly in areas involving socio-emotional support, creativity, critical thinking, and physical skills, which were also discussed in the related studies (Seo, et al., 2021).

The research findings emphasize that while some teachers have been exposed to AI concepts incidentally, only a limited number have deliberately sought in-depth knowledge in this field. This discrepancy in AI knowledge levels among teachers highlights the critical need for targeted educational initiatives and professional development opportunities, as suggested in related studies (Nazaretsky, et al., 2022; Sun, et al., 2023). These initiatives can bridge the knowledge gap and equip educators with the essential skills to effectively integrate AI into their teaching practices.

Furthermore, the findings reveal that teachers' attitudes toward AI are multifaceted, reflecting both the potential benefits and the associated risks and uncertainties (Lin, et al., 2022). This complexity highlights the necessity for continued research and discussion regarding AI's role in education and its potential impact on students, teachers, and society as a whole.

This transformation in educators' perceptions aligns with research studies, such as those conducted by (Velander et al., 2023) and Lindner & Berges (2020), underscoring the importance of understanding teachers' perceptions and preconceptions of AI to inform teacher education practices (Park, et al., 2023). The evolved perspective enables educators to approach AI integration with a more informed and balanced mindset, comprehending both the opportunities and challenges presented by AI in education.

Furthermore, this shift in perception has a significant impact on teachers' engagement levels and the challenges they encounter in integrating AI into their teaching practices. As teachers develop a nuanced understanding of AI's capabilities and limitations, they are better equipped to navigate the complexities associated with incorporating AI into their teaching methods (Zhang, et al., 2023). This informed perspective fosters a more proactive and effective engagement with AI tools, allowing teachers to leverage the technology to its full potential while addressing any challenges that may arise during the integration process.

Implications and study limitations

In presenting the findings arising from this AI literacy training course for teachers in Singapore with the key design feature of a combination of functional (Touretzky, 2019) and critical literacies in progressive manner (Leander & Burris, 2020; Merchant, 2021), this study carries significant implications for various education stakeholders.

First, the findings stress the importance of comprehensive professional development initiatives addressing not only technical AI knowledge but also ethical, pedagogical, and social aspects of AI under the new framework i-TPACK. Through AI literacy, educators can harness AI technologies to enrich student learning experiences, fostering critical thinking, creativity, and problem-solving skills. AI literacy with a focus on ethical aspects of AI, is highlighted here.

With functional AI literacy, teachers can effectively incorporate AI technologies into their teaching practices. This includes understanding AI tools and applications that can enhance instruction, such as adaptive learning systems, intelligent tutoring systems, and educational data analysis. With critical AI literacy, teachers can critically evaluate and reflect on AI technologies and their impact on teaching and learning. Teachers need to understand potential biases in AI algorithms, ensure fairness and inclusivity, protect student privacy, and promote responsible use of AI technologies. An emphasis on ethical aspects of AI helps teachers make informed decisions about the use of AI tools, ensuring that students' well-being and rights are respected. Critical AI literacy empowers teachers to question assumptions, challenge AI-driven recommendations, and promote thoughtful engagement with AI in the classroom.

Second, the study highlights that teachers' attitudes toward AI are multifaceted, reflecting both potential benefits and associated risks and uncertainties. For example, teachers demonstrated a good understanding of AI's potential to automate specific teaching tasks, such as analyzing student data and personalizing learning. However, they also acknowledged AI's limitations, particularly in areas involving socio-emotional support,

creativity, critical thinking, and physical skills. This complexity highlights the need for ongoing research and discussion about AI's evolving role in education and underscores the importance of preparing teachers to navigate both the opportunities and challenges presented by AI.

Despite the insights provided, the study has limitations, including a small sample size restricted to 19 mid-career teachers in Singapore, raising concerns about the generalizability of the findings. Additionally, the six-week duration of the program may not suffice to fully instill and sustain the complex skills required for effective AI integration in education. While the study assessed perceived i-TPACK levels and theoretical knowledge, the actual efficacy of AI integrations in classroom settings was not empirically verified. Future research should therefore consider extended professional development programs and longitudinal studies to evaluate the long-term impact of AI literacy among teachers. Such studies should also explore the direct effects of AI-integrated teaching practices on student outcomes and engage in-depth investigations into the ethical and social implications of AI in education, focusing on issues like equity and access. Finally, although this study required participants to discuss ethical considerations in their written action plans, the assessment of ethical understanding was based solely on self-reported and written evidence. As such, a key limitation of our evaluation is its reliance on what teachers say or write, rather than what they do in real-world contexts. Future research should address this gap by including direct observations of teachers' classroom practices, scenario-based assessments, or follow-up interviews. These methods would provide richer and more authentic insights into how teachers apply ethical principles when integrating AI into their teaching.”

Acknowledging these limitations, the insights from this study nonetheless provide a crucial foundation for future initiatives. Based on our findings and identified areas for further exploration, a number of actionable strategies are recommended to enhance teacher professional development programs in AI literacy. Firstly, it is recommended to incorporate continuous assessment and adaptive learning strategies within the TPD programs, which allow for ongoing monitoring of progress and the ability to make necessary adjustments in real-time, ensuring that the training remains relevant and effective. Secondly, fostering a community of practice among educators is crucial. Such a community would facilitate the sharing of experiences and strategies related to AI integration, enhancing collective knowledge and supporting peer learning.

Appendix A: Open-ended questions of teachers' perceptions of AI

- 1) Where do your current knowledge of AI come from?
- 2) When thinking of artificial intelligence, what feelings do you associate with it? Why do you feel this way?
- 3) What is your definition of AI?
- 4) How do you think machine learning works?
- 5) What applications of AI have you encountered so far in your daily life?
- 6) What do you think will be possible with AI in the future?
- 7) Which other aspects of AI not mentioned above come to your mind?

Appendix B: Intelligent – TPACK Scale (Celik, 2023b)

(The options in a 7-point Likert type ranged from “1: strongly disagree” to “7: strongly agree”)

Intelligent TK

1. I know how to interact with AI-based tools in daily life.
2. know how to execute some tasks with AI-based tools.
3. I know how to initialize a task for AI-based technologies by text or speech.
4. I have sufficient knowledge to use AI-based tools.
5. I am familiar with AI-based tools and their technical capacities.

Intelligent TPK

6. I can understand the pedagogical contribution of AI-based tools to my teaching field.
7. I can evaluate the usefulness of feedback from AI-based tools for teaching and learning.
8. I can select AI-based tools for students to learn.
9. I know how to use AI-based tools to monitor students' learning.
10. I can interpret messages from AI-based tools to give real-time feedback.
11. I can understand alerting (or notification) from AI-based tools to scaffold students' learning.
12. I have the knowledge to select AI-based tools to sustain students' motivation.

Intelligent TCK

13. I can use AI-based tools to search for educational material in my teaching field.
14. I am aware of different AI-based tools which are used by professionals in my teaching field.
15. I can use AI-based tools to better understand the contents of my teaching field.
16. I know how to utilize my field-specific AI-based tools (e.g., intelligent tutor for Math).

Intelligent TPACK

17. In teaching my field, I know how to use different AI-based tools for adaptive feedback.

18. In teaching my field, I know how to use different AI-based tools for personalized learning.

19. In teaching my field, I know how to use different AI-based tools for real-time feedback.

20. I can teach a subject using AI-based tools with diverse teaching strategies.

21. I can teach lessons that appropriately combine my teaching content, AI-based tools, and teaching strategies.

22. I can take a leadership role among my colleagues in the integration of AI-based tools into our teaching field.

23. I can select various AI-based tools to monitor students' learning in my teaching process.

Ethics

24. I can assess to what extent AI-based tools consider individual differences (e.g., race and gender) of all students in my teaching.

25. I can evaluate to what extent AI-based tools behave fair to all students in my teaching.

26. I can understand the justification of any decision made by an AI-based tool.

27. I can understand who the accounted developers are in the design and decision of AI-based tools.

Abbreviations

APSCE: Asia-Pacific Society for Computers in Education; RPTTEL: Research and Practice in Technology Enhanced Learning.

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Data availability statement

The data are not publicly available due to them containing information that could compromise research participant privacy/consent.

Author's contributions

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