EXPLORING THE EMERGING ROLES OF ARTIFICIAL INTELLIGENCE IN TEACHING PRACTICES AND ITS RELATIONSHIPS WITH TEACHERS

by

LEHONG SHI

(Under the Direction of Ikseon Choi & Ai-Chu Elisha Ding)

ABSTRACT

Artificial intelligence (AI), utilizing machine learning techniques to 'learn' from data, as humans learn from experiences, has the promise to perform various cognitive tasks, such as learning, thinking, problem-solving, and decision-making, which usually demands human cognition. In recent decades, the remarkable advancements in AI have led to its pervasive integration across various sectors of society, and has facilitated human-machine interactions encompassing language, action, and behaviors. Within the educational sphere, AI has played emerging roles, driving significant changes in teachers' instructional practices and potentially revolutionizing teaching practices in unprecedented ways. To fully harness the innovative potential of AI in teaching, it becomes imperative to unpack the diverse pedagogical roles that AI can assume and examine the emergent relationship between teachers and AI, however, which remain ambiguously defined and have yet to be comprehensively explored.

Presented as three journal-ready manuscripts, the dissertation delves into the theoretical and practical exploration of the emerging pedagogical roles of AI and the formation of a novel teacher-AI relationship. The first manuscript (Chapter 2) provides a systematic review to elucidate the pedagogical roles and characteristics of AI in enhancing teachers' instructional practices. Implications for teachers' pedagogy and the teacher-AI relationship are discussed. Given the pedagogical potential of AI in teaching practices, the second manuscript (Chapter 3) proposes an integrated conceptual framework, encompassing a three-dimensional teacher-AI pedagogical partnership model and its impacts on teachers. It has implications for collaborative teaching design and future research foci in this emerging area of research.

In the third manuscript (Chapter 4), the qualitative data revealed a mutual interaction between teachers and AI: AI provides substantial support to teachers and teachers actively support work of AI. Two distinct perceived roles of AI were found: a supportive tool and a collaborative partner. Three changes in classroom interactions emerged: individualized instruction, data-driven and targeted approaches, and shifts in teachers' roles. Findings suggest that AI promotes the transformation of technology from being merely a supportive tool to becoming a partner and a novel collaborative relationship. The implications for teachers' changed mindset and professional learning are discussed. Chapter 5 discusses the implications and suggestions for future research.

INDEX WORDS: Artificial Intelligence, Pedagogical Roles, Teachers' Instructional Practice, AI Agency, Collaborative Partner, Teacher-AI Relationship, Pedagogical Partnership

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LEHONG SHI

B.S., Northeast Normal University, China, 2004

M.A., Northeast Normal University, China, 2006

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

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LEHONG SHI

Major Professor: Ikseon Choi
Ai-Chu Elisha Ding

Committee: Janette R. Hill
Marie-Claude Boudreau
Janice Gobert

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
August 2023

DEDICATION

This dissertation is dedicated to my beloved family. To my parents who selflessly showered me with love, thank you for the unconditional support and encouragement for me to value this experience and overcome all challenges. To my two lovely boys, you are the best gift that God handed to me to encourage me to do my best. Last but not least, to my dear husband who inspired me to put in my very best in completing this dissertation, thank you for being my rock and the better half of me, for your love and endless support in daily life and academic study for me to achieve my dream. I LOVE YOU LOVE.

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CHAPTER 1

INTRODUCTION

Throughout the past century, educators have embraced an array of educational technologies to enhance their teaching practices, motivated by the rapid evolution of these technologies. From the chalkboard to the overhead projector, from interactive whiteboards to mobile technologies, traditional technologies have acted as tools or mediators to facilitate teachers' interactions with their students and environments (Jonassen, 1994; Jonassen et al., 1999; Taylor, 1980). However, these technologies have typically been limited in their capacity for autonomy, decision-making, and personalization, and were often used to address human-defined, human-perceived, or human-felt issues, goals, or purposes (Lee et al., 2015).

In the past decade, the development of artificial intelligence (AI) has led to the increasing integration and momentum of AI in teachers' instructional practices. Researchers typically incorporate two dimensions to define AI: (a) human-like thinking, and (b) rational actions (Luckin et al., 2016; Russell, 2010). Basically, AI is a term used to label machines that perform tasks, such as learning, thinking, problem-solving, and decision-making, or that deal with complexity as well as human experts (Spector & Ma, 2019). This marks a significant departure from traditional technologies. In addition, AI can interact and communicate with people in a human-like manner (Nourbakhsh, 2013) through language (i.e., speech, written text), behaviors (e.g., facial expression, head and body movement), and other non-verbal cues (Breazeal, Dautenhahn, & Kanda, 2016; Epley et al., 2007; Van Pinxteren et al., 2019), playing the role of a communicator rather than a communication channel (Guzman & Lewis, 2020). The evolution of intelligent machines has equipped them with the ability to engage in human-machine dialogue, action, and emotional interaction and exchange (Guan et al., 2021), making AI capable of transforming teaching and learning in previously unimaginable ways.

Integrating AI into teachers' instructional practices has shown significant potential to change teachers' behaviors and practices and participate in the pedagogical decision-making process. Many studies have discussed the complementary roles of machine intelligence and teacher intelligence in collaborating to facilitate student learning (Fridin, 2014; Hashimoto et al., 2011; Pai et al., 2021). For example, Chou et al. (2011) suggested two mechanisms for their complementary roles, including the extension of human intelligence to machine intelligence and the reuse of human intelligence by machine intelligence, suggesting a novel classroom pedagogical paradigm. In addition, AI has the potential to monitor student progress in real-time, providing personalized learning experiences that are otherwise challenging to achieve in traditional classrooms. Moreover, by analyzing students' behavioral, cognitive, and emotional information, AI can offer teachers actionable insights into students' learning progress, allowing them to provide personalized and targeted scaffolding (Adair et al., 2020; Gobert et al., 2016, 2018). The significant potential of AI enables it to participate in the pedagogical decision-making process, including automatically generating personalized feedback to students' investigations and responses and recognizing students' emotions to tailor AI responses accordingly (Eklundh & Jonsson, 2017; Karsenti & Fievez, 2018; Gobert et al., 2023a, b).

Given the advancements and potential of AI in education, many researchers have expressed concerns about how to inform teachers of the perfect ways to integrate AI into their teaching practice. Amanda Sharkey (2016) argued that “advanced AI systems, such as humanoid robotics, have progressed to a point where there is a real possibility of taking on social roles in our lives” (p. 2). For instance, in many work settings, automated systems have increasingly replaced employees’ tasks, responsibilities, and decision-making (e.g., Lewis et al., 2019; Strich et al., 2021). Thus, Schuetz and Venkatesh (2020) suggested that AI technology has the significant potential to engage in a new type of human-system-environment interaction, which challenges traditional assumptions about how humans and systems interact. The question is whether this will also happen to teachers and how teachers can and will deal with this, especially when contemporary students interact with AI applications in ways that they usually only do with teachers or peers (Guilherme, 2019). Those arguments in the literature resulted in the dilemma of the pedagogical benefits and its challenges to teachers.

To overcome this dilemma, it is essential to thoroughly explore the pedagogical potentials of AI in teachers’ instructional practices and its corresponding impacts on their practices and experiences. This has garnered researchers’ attention and interest but with contradictory reflections. Some researchers particularly emphasize that machine intelligence empowers teachers with higher responsibilities, privileges, and competencies to facilitate individualized learning and make data-driven instructional adjustments (Strich et al., 2021, Zhai et al., 2020a, 2020b) with hybrid intelligence (Chou, Huang, & Lin, 2011; Kamar, 2016). However, the emergence of an AI threat cannot be overlooked, especially as some scholars have suggested addressing the global teacher shortage with AI (e.g., Edwards & Cheok, 2018; Ivanov, 2016; Sharkey, 2016). The above discussion does not fully address the dilemma of AI integration and its challenges. Therefore, there is a need to theoretically and empirically investigate the pedagogical potential of AI and how it can be integrated by teachers in novel ways to inform innovative pedagogical paradigms. To this end, this dissertation study investigates and discusses (1) the pedagogical potential and characteristics of AI in teaching, (2) the novel relationships between teachers and AI, and (3) teachers' engagement with AI and their instructional experience.

Dissertation Overview

The dissertation consists of five chapters, three of which are individual manuscripts to be submitted for publication. Using a theoretical analysis of the literature, the studies aim to investigate the pedagogical roles and characteristics of AI, as well as its novel relationships with teachers. Additionally, using an exploratory research design, the research explores the ways in which AI interacts with teachers, its emerging roles, and the perceived and observed changes it brings about in classroom interactions.

The first manuscript (Chapter 2), titled *The Pedagogical Roles and Characteristics of Artificial Intelligence in Supporting Teaching Practices: A Systematic Review*, presents a systematic review of the literature on AI in Education (AIED) studies, focusing on AI-supporting teaching practices. The study categorizes five pedagogical roles and three unique characteristics of AI to potentially support and transform teaching practices. The paper concludes with the implications of the emerging pedagogical roles and characteristics of AI in teachers' pedagogy and the relationship between teachers and AI.

The second manuscript (Chapter 3), *The Emergence of AI Agency in Teaching: An Integrated Conceptual Framework of the Teacher-AI Pedagogical Partnership*, aims to develop a conceptual framework for the relationship between teachers and AI. The paper reviews the literature on the integration of AI in teachers' instructional practices and its potential to transform human-AI relationships. Drawing on actor-network theory (Callon, 1984; Latour, 1987), social presence theory (Short et al., 1976), and distributed cognition (Hollan, Hutchins, & Kirsh, 2000; Hutchins, 1995), the paper articulates that AI is emerging as an artificial social agent to co-present with teachers for distributed intelligence in classroom instructional practices. The paper develops an integrated conceptual framework for outlining the teacher-AI pedagogical partnership and demonstrating its impact on teachers. This chapter concludes by suggesting potential implications for teachers' mindset shifts, the effective design of AI-integrated collaborative instruction, and the future research foci in the emerging area of research.

The third manuscript (Chapter 4), *Exploring Teachers' Pedagogical Practices and Experiences of Integrating Artificial Intelligence into Teaching: A Qualitative Case Study*, presents a qualitative case study that aims to understand in-service teachers' engagement with AI and their experiences and perceptions in terms of emerged AI roles and changes in classroom interactions. The study conducts interviews with participating science teachers while observing their AI-integrated classroom practices to explore teachers' use and engagement with AI, as well as their perceptions and experiences that informed the findings. The study discussed the implications that can enhance teachers' integration of AI.

Chapter 5 presents a summary of the key ideas and implications of the three manuscripts. Limitations of the study and recommendations for future research are also discussed.

Significance of the Study

The integration of advanced technology in teaching and learning can be transformative, but only if teachers incorporate innovative pedagogical practices that leverage these technologies.

Teachers play a vital role in shaping the adoption and effective implementation of new technologies in classrooms. Without teachers' creative use of these tools, it is difficult to realize the full pedagogical potential of advanced technologies. To facilitate the effective integration of AI in classrooms, it is crucial to investigate the pedagogical practices of teachers who use AI technology. This dissertation study focuses specifically on the pedagogical practices of teachers who use AI technology, aiming to provide both theoretical contributions and empirical evidence of the impact of AI on teacher-AI interactions and relationships. The study advances theories by differentiating AI from traditional technologies in terms of its relationship with teachers. The findings of this research could inform policymakers on best practices for curriculum innovation and the introduction of AI technology, taking into account teachers' pedagogical practices. In addition, the study could enhance teachers' understanding of AI innovation, leading to better pedagogical practices in AI-enhanced environments. Furthermore, the challenges and obstacles that emerged in teachers' pedagogical practices could inform instructional designers and researchers about appropriate professional development and training opportunities in both technological and pedagogical aspects.

References

Ahmad, M. I., Mubin, O., & Orlando, J. (2016). Understanding behaviors and roles for social and adaptive robots in education: Teacher's perspective. *HAI 2016 – Proceedings of the 4th International Conference on Human Agent Interaction*, 297–304.

Callon, M. (1984). Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay. *The Sociological Review*, 32(1-suppl), 196–233.

Chen, L., Chen, P., & Lin, Z. (2020). Artificial Intelligence in Education: A Review. *IEEE Access, 8*, 75264–75278. https://doi.org/10.1109/ACCESS.2020.2988510

Chou, C. Y., Huang, B. H., & Lin, C. J. (2011). Complementary machine intelligence and human intelligence in virtual teaching assistant for tutoring program tracing. *Computers & Education*, *57*(4), 2303-2312.

Felix, C. V. (2020). The role of the teacher and AI in education. In *International perspectives on the role of technology in humanizing higher education*. Emerald Publishing Limited.

Gobert, J. D., Sao Pedro, M., Raziuddin, J., & Baker, R. S. (2013). From log files to assessment metrics: Measuring students' science inquiry skills using educational data mining. *Journal of the Learning Sciences*, *22*(4), 521-563.

Gobert, J. D., Sao Pedro, M.A., Betts, C.G. (2023a). An AI-Based Teacher Dashboard to Support Students' Inquiry: Design Principles, Features, and Technological Specifications. In N. Lederman, D. Zeidler, & J. Lederman (Eds.), Handbook of Research on Science Education, (Vol. 3, pp. 1011-1044). Routledge. https://doi.org/10.4324/9780367855758

Gobert, J.D., Sao Pedro, M.A., Li, H., & Lott, C. (2023b). Intelligent Tutoring systems: a history and an example of an ITS for science. In R.Tierney, F. Rizvi, K. Ercikan, & G. Smith, (Eds.), *International Encyclopaedia of Education* (Vol. 4, pp. 460-470), Elsevier.

Guilherme, A. (2019). AI and education: the importance of teacher and student relations. *AI and Society*, *34*(1), 47–54.

Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *7*(2), 174-196.

Hutchins, E. (1995). *Cognition in the Wild*. MIT press.

Huang, S.-L., & Shiu, J.-H. (2012). A user-centric adaptive learning system for e-learning 2.0. *Journal of Educational Technology & Society*, *15*(3), 214–225.

Jonassen, D. H. (1994). Technology as Cognitive Tools: Learners as Designers. *ITForum Pape*, *1*(1), 67–80. https://it.coe.uga.edu/itforum/paper1/paper1.html

Jonassen, D. H., Peck, K. L., & Wilson, B. G. (1999). *Learning with technology: A constructivist perspective*. Upper Saddle River, NJ: Merrill.

Kamar, E. (2016, July). Directions in Hybrid Intelligence: Complementing AI Systems with Human Intelligence. In *IJCAI*(pp. 4070-4073).

Latour, B. (1987). *Science in action*. Cambridge MA: Harvard university press.

Lee, A. S., Thomas, M., & Baskerville, R. L. (2015). Going back to basics in design science: From the information technology artifact to the information systems artifact. *Information Systems Journal*, *25*(1), 5–21. https://doi.org/10.1111/isj.12054.

Moussavi, R., Gobert, J., & Sao Pedro, M. (2016). The effect of scaffolding on the immediate transfer of students' data interpretation skills within science topics. In, *Proceedings of the 12th International Conference of the Learning Science*s. Singapore (pp. 1002-1006).

Rai, A., Constantinides, P., & Sarker, S. (2019). Next Generation Digital Platforms: Toward Human-AI Hybrids. *Management Information Systems Quarterly*, *43*(1), iii–ix.

Russell, S. J. (2010). *Artificial intelligence a modern approach*. Pearson Education, Inc.

Serholt, S., Barendregt, W., Leite, I., Hastie, H., Jones, A., Paiva, A., ... & Castellano, G. (2014, August). Teachers' views on the use of empathic robotic tutors in the classroom. In *The*

23rd IEEE International Symposium on Robot and Human Interactive Communication (pp. 955-960). IEEE.

Schuetz, S. W., & Venkatesh, V. (2020). The Rise of Human Machines: How Cognitive Computing Systems Challenge Assumptions of User-System Interaction. *Journal of the AIS*, *21*(2), 460–482. https://ssrn.com/abstract=3680306

Sharkey, A. J. (2016). Should we welcome robot teachers? *Ethics and Information Technology*, *18*(4), 283-297.

Short, J., Williams, E., & Christie, B. (1976). *The social psychology of telecommunications* (Vol. 19, No. 4, pp. 451-484). London: Wiley.

Strich, F., Mayer, A. S., & Fiedler, M. (2021). What do I do in a world of artificial intelligence? Investigating the impact of substitutive decision-making AI systems on employees' professional role identity. *Journal of the Association for Information Systems*, *22*(2), 9.

Taylor, R. P. (1980). The computer in the school: Tutor, tool, tutee. In *Contemporary Issues in Technology and Teacher Education* (Vol. 3, Issue 2).

Zhai, X., Yin, Y., Pellegrino, J. W., Haudek, K. C., & Shi, L. (2020a). Applying machine learning in science assessment: a systematic review. In *Studies in Science Education* (Vol. 56, Issue 1, pp. 111–151). Routledge.

CHAPTER 2

THE PEDAGOGICAL ROLES AND CHARACTERISTICS OF ARTIFICIAL INTELLIGENCE IN SUPPORTING TEACHING PRACTICE: A SYSTEMATIC REVIEW [1]

[1] Shi, L. and Choi, I. To be submitted to X., Zhai & J., Krajcik, (Eds). *Uses of Artificial Intelligence in STEM Education*. Oxford University Press

Abstract

A growing scholarly interest emerged in the exploration of Artificial Intelligence (AI) within the realm of teaching practices. In order to enhance our understanding of how AI has been utilized in this context, we conducted a comprehensive systematic review encompassing 44 studies in the field of AI in education. The review was guided by a proposed three-dimensional analytical framework, which encompassed functionality, pedagogy, and uniqueness, thereby informing the data analysis and subsequent findings. Through the analysis of eligible studies, we classified five distinct pedagogical roles of AI in contributing to the enhancement and transformation of teaching practices, including (1) participating in instruction, (2) monitoring student progress, (3) innovating assessment practices, (4) providing teacher pedagogical recommendations, and (5) driving teachers' effective pedagogical decision-making and action-taking. Furthermore, we extracted the unique characteristics of AI that significantly contribute to its efficacy in supporting teaching, including its interactivity with humans, automaticity, and autonomy. By shedding light on the current research foci and identifying gaps in the literature, our systematic review provides valuable insights and sets the stage for potential future directions aimed at further exploring the multifaceted roles of AI in teachers' pedagogical practices.

Keywords: Artificial intelligence; Pedagogical role; AI characteristics; Teacher's pedagogical practice

Introduction

Recent advancements in artificial intelligence (AI), utilizing machine learning (ML) and deep learning, have garnered significant attention across various sectors, including the domain of education. AI has the promise to perform human-like cognitive tasks, such as learning, problem-solving, handling complexity, and making rational decisions (Guilherme, 2019; Russell, 2010; Spector & Ma, 2019). Within the educational context, embedded in intelligent applications such as intelligent tutoring systems (ITS) (Gerard et al., 2019; Gobert et al., 2016, Gobert et al., 2023a, b), teaching assistants (Goel & Polepeddi, 2018), and ML-based automatic scoring systems (Zhai et al., 2020a; Gobert et al., 2013, 2023a, b), AI presents significant potential to support teachers' instructional decision-making and transform their instructional practices. Extensive research has illustrated the promising role of AI in enhancing teachers' design of learning activities and providing personalized scaffolding through AI-generated feedback and recommendations (Edwards & Cheok, 2018; Yun et al., 2013). AI has also shown potential in alleviating teachers' concerns regarding the breadth of domain-specific knowledge they must possess (Wenger, 1987; Roll & Wylie, 2016) and in assessing students' constructed responses to provide timely and informative feedback (Zhai et al., 2020a, b, Zhai et al., 2021, Gobert et al., 2019). Moreover, recent studies have advocated the complementary of machine intelligence and human intelligence to facilitate teachers' immediate instructional decision-making and actions within dynamic educational context (Chounta et al., 2022; Paiva & Bittencourt, 2020). Recognizing the significant potential of AI in enhancing teachers' pedagogical practices, numerous researchers, organizations, and stakeholders have emphasized the importance of teachers swiftly adopting AI into their instructional approaches. Some scholars are enthusiastic about the use of AI applications, such as educational social robots, to address the prevailing teacher shortage (Edwards & Cheok, 2018; Morita et al., 2018; Mubin et al., 2013; Serholt et al., 2017) with the notion of robot teachers gaining favor (Sharkey, 2016).

Despite acknowledging the potential and promise of AI to support and revolutionize traditional teaching practices, the role of AI remains a vital inquiry that necessitates careful reflection and thorough investigation. Harstinski et al. (2019) posed a crucial question regarding the driving forces of the potential of AI in teaching: AI advancements, teachers' innovative AI integrations, or other factors. Many have emphasized the significance of technological advancements, suggesting that teachers' previous responsibilities and roles have been shaped and potentially diminished due to the advent of AI in education (Player-Koro et al., 2018; Williamson, 2016). Some review studies have endeavored to examine the potential of AI in educational contexts from various perspectives. For instance, AI functionalities in education have been categorized into several domains, such as profiling and prediction, assessment and evaluation, adaptive systems and personalization, and intelligent tutoring systems (Chen et al., 2020a; Hwang et al., 2020; Zawacki-Richter et al., 2019). Baker and Smith (2019) classified AI tools based on the direction of their use, distinguishing between learner-directing, instructor-directing, and system-directing tools. Additionally, Ouyang and Jiao (2021) categorized three types of AI and learner relationships within the learner-directing AI tools. Furthermore, Xu and Ouyang (2021) identified three roles that AI can play in the teaching and learning process, including serving as a new subject, a direct mediator, or a supplementary assistant. Notably, no review study was found to explicitly investigate the impact of AI on teachers' pedagogical practices from the perspective of teachers themselves. However, such a pedagogical perspective is essential in the design and promotion of AI technology within teachers' classroom practices.

It is of special interest in this study to systematically review the literature on AI in education studies to investigate how AI can support and transform teachers' pedagogical practices in science classrooms and beyond through analyzing the pedagogical roles and characteristics of AI. The findings of this study are expected to contribute to a deeper understanding of how AI has been incorporated into classrooms to enhance teachers' instruction. Moreover, the study aims to provide a comprehensive reference for researchers and educators, enabling them to make informed decisions when integrating AI into teaching. To achieve these objectives, the following research questions guide the study:

(1) What are the grade levels, subject domains, and contexts in which AI has been integrated into teaching?

(2) What are the technological functionalities of AI that support and enhance teaching?

(3) What are the pedagogical roles of AI in supporting and improving teaching?

(4) What unique characteristics are exhibited by AI in teachers' instructional practices?

Analytical Framework

The existing body of literature emphasizes that the effectiveness of technology integration in education can be measured by the degree to which technology becomes an integral part of pedagogy practice (De Koster et al., 2017; Harris, 2005; Howard et al., 2015). Accordingly, the successful implementation of technology in instructional settings depends on its alignment with teachers' pedagogical objectives and purposes (e.g., Okojie et al., 2006). Studies have demonstrated that teachers perceive technology as valuable when it offers significant pedagogical potential in supporting various aspects of their teaching practices, including classroom management, grading, and decision-making (Howard et al., 2015; McKnight et al., 2016). Moreover, it is essential to recognize that each technology possesses distinct characteristics that influence its impact on pedagogy. It is crucial to consider the unique attributes of specific technologies in relation to pedagogical practices (Zhai & Jackson, 2021).

Our investigation identified three primary considerations for effectively integrating AI to support and enhance teaching practices: (1) the selection and implementation of AI technologies; (2) the pedagogical roles of AI and their associated benefits for teaching; and (3) the unique characteristics exhibited by AI in supporting teaching. In response to these concerns, we proposed a three-dimensional analytical framework encompassing three components: *functionality, pedagogy,* and *uniqueness* (see Figure 2.1). The *functionality* dimension of the analytical framework functionally determines the specific AI technology employed in teaching. Since AI has the potential to facilitate and promote instructional decision-making and pedagogical innovation, it is crucial to comprehend its pedagogical roles to ensure its *pedagogy* affordance and benefits. The *uniqueness* dimension highlights the distinctive features of AI technology in teaching, setting it apart from traditional technologies.

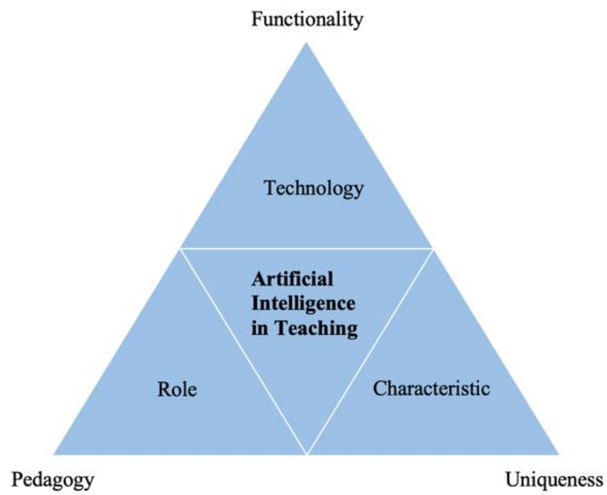

Figure 2.1. The proposed triangular analytical framework

Functionality

In the discourse of technology integration in education, it is crucial to understand the technological features inherent in the discussed technology (ChanLin et al., 2006; Inan, & Lowther, 2010) and this principle applies to AI as well. In the case of AI implementation in teaching, we emphasize a foundational comprehension of the technological features of AI across three key aspects. Firstly, a thorough identification of the specific AI systems and applications utilized in educational settings is imperative, given the diverse range of AI technologies available in the field of education. Secondly, within a given AI system or application, a close examination of its design features becomes necessary. For example, the inclusion of a teacher dashboard within an AI system allows educators to effectively engage and interact with AI technology. Investigating such design features provides valuable insights into how AI can be effectively integrated into the instructional process. Also, we examine the accessibility of AI systems for teachers, particularly regarding their involvement in the design process of AI integration within the curriculum.

Pedagogy

A fundamental assumption underlying the integration of technology in education is its potential to yield pedagogical benefits for users, including teachers and students (Zhai, et al., 2020a). Building upon this assumption, we highlight the importance of examining AI from the perspective of teachers' pedagogical practices. In order to investigate the specific pedagogical potential of AI for teachers, we delve into its potential roles in teaching and explore how these roles can support and innovate teachers' pedagogical practices. Understanding the pedagogical roles of AI in teaching is crucial as it enables a clear differentiation between AI and traditional technologies in terms of their support for teachers.

Uniqueness

AI has been recognized as a revolutionary and disruptive innovation (Bughin et al., 2018), compared with conventional technologies. To delve deeper into its influence on teaching practices, it is crucial to discern the distinctiveness of AI technology, setting it apart from traditional technologies. It is worth emphasizing that AI possesses multiple distinctive features that have diverse implications in the field of education. However, this particular study focuses on uncovering AI's uniqueness solely from the perspective of teachers' pedagogy and may not provide a comprehensive overview of all characteristics of AI within the educational context. Therefore, further research and exploration are warranted to fully elucidate the breadth of AI's characteristics and their implications in the realm of education.

The proposed framework presents a concise argument for comprehending the potential of AI in teaching, encompassing its technological functionalities, pedagogical roles, and unique characteristics. This framework serves as a roadmap for the process of literature selection, coding, analysis, and findings reported in this study. Guided by this framework, we conducted a systematic search and analysis of the literature pertaining to AI in educational studies, aiming to address the research questions at hand. The first question focuses on investigating the contextual factors surrounding AI integration in teaching, while the subsequent three questions correspond to the three dimensions of the framework, respectively.

Method

Eligibility criteria

To address the research questions in accordance with the analytical framework, a set of inclusive and exclusive rules were established to guide the search for relevant studies (see Table 2.1), employing a comprehensive literature review methodology (Onwuegbuzie & Frels, 2016).

Table 2.1. The inclusion and exclusion criteria for literature search

	Criteria	Rational
	Study focus	Studies that integrated AI technology to support or improve teaching or mentioned how AI supports teachers in classrooms even though the focus of the study is on student learning.
	Study type	Studies that provide empirical evidence (e.g., qualitative, quantitative, or mixed-method studies) to explain the pedagogical benefits of AI in teaching.
Inclusion	Study purpose	Studies explained the integration of AI in pedagogy and teacher performance, although student learning might be another important purpose for many studies.
	Participants	The primary focus of research is integrating AI in k-12 classrooms or in postsecondary contexts.
	Time range	Studies conducted in the past decade (i.e., 2010-2022) since we focus mostly on the recent studies of AI in education.

	Study quality	Written in the English language and peer-reviewed journal articles.
Exclusion	Study focus	Studies that only focus on student learning, without any information on how AI benefits teachers' pedagogy.
	Study type	Studies that discussed AI technology in education, however, focus on AI system description and evaluation, rather than implementation in practice.
	Study purpose	Studies that were theoretical or conceptual papers without empirical data to report how teachers integrate AI in teaching.

Literature selection

To facilitate a comprehensive literature selection process and ensure the inclusion of high-quality studies, an extensive search was conducted across multiple academic databases, including EBSCOhost, ERIC, ProQuest, Web of Science, ScienceDirect, and Google Scholar. Two sets of keywords were utilized to retrieve relevant articles: (1) AI-related keywords, encompassing terms such as Artificial intelligence, machine learning, deep learning, virtual assistant, intelligent tutoring system, and social robots and (2) teaching-related keywords, such as teaching, instruction, scaffolding, facilitation, feedback, and automatic scoring. The initial search generated 1327 studies.

To ensure the integrity and relevance of the study, a rigorous screening process was undertaken. Initially, duplicate studies (n=235) were removed. Subsequently, the titles and abstracts of the remaining studies were carefully reviewed to exclude articles that focused on the design and testing of AI systems rather than the implementation of AI in teaching (n=451). Furthermore, studies (n=339) lacking empirical evidence of AI utilization in teaching were also excluded. To maintain a consistent level of quality, additional exclusions were made for conference papers, book chapters, dissertations (n=262), and studies without accessible full-text versions. Also, a snowball search strategy was used to identify relevant studies, resulting in four additional articles. Ultimately, 44 studies met the eligibility criteria and were subjected to thorough full-text analysis in the current study.

Coding of AI features in teaching

The analysis of the eligible studies followed a qualitative inductive content analysis approach, drawing on the work of Elo and Kyngäs (2008) and Mayring (2014). Prior to the coding process, a coding protocol was developed, aligning with the proposed analytical framework. The coding protocol encompassed four key sections: *descriptive information*, *functionality*, *pedagogy*, and *uniqueness*. *Descriptive information* coding involves capturing details such as the author(s), years of publication, article title, grade level, subject domain, and integration settings of each study. The *functionality* was coded to identify the type of AI utilized, the presence of a teacher dashboard, and the extent of teacher involvement in the design and development process. The *pedagogy* was coded based on the roles of AI in supporting teaching in distinct aspects. Finally, the *uniqueness* of AI was extracted by identifying its unique attributes across different pedagogical roles of AI in supporting teaching.

Following the development of the coding protocol, two coders were involved in the coding process. One-fifth of the eligible studies were coded by both coders to establish interrater reliability. Cohen’s kappa coefficient was computed to assess the level of agreement, yielding a value of 0.895, indicating substantial agreement (Nehm & Haertig, 2012). Any discrepancies were thoroughly discussed and resolved, leading to iterative revisions of the coding protocol.

Subsequently, the first coder proceeded to independently code the remaining studies, adhering to the finalized coding protocol. Figure 2.2 presents the literature search and coding process.

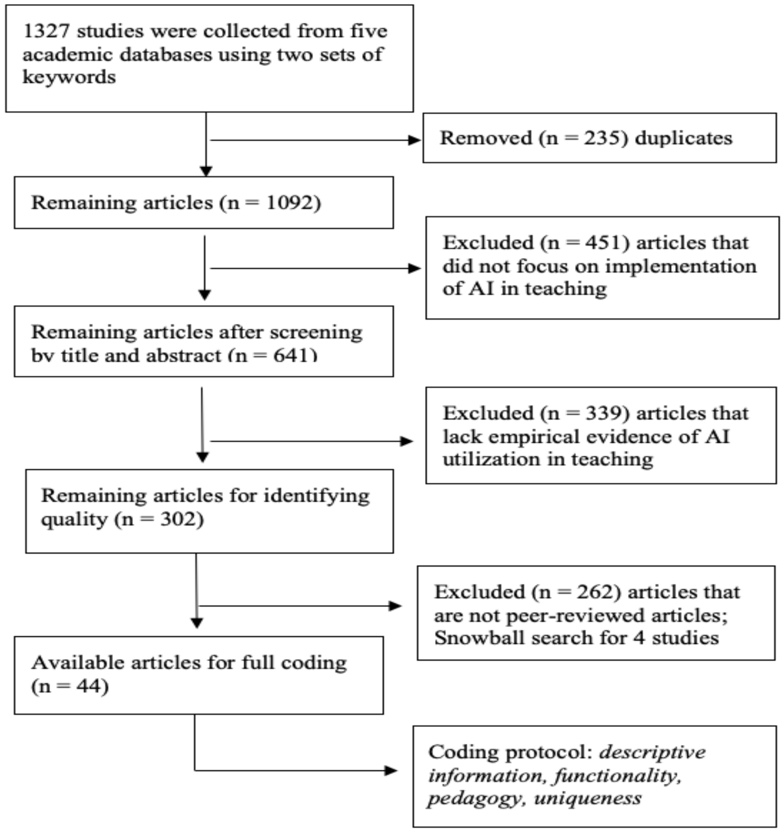

Figure 2.2. The flowchart of the literature selection and coding process

Results

The educational context of reviewed studies

Educational levels: Studies included in the analysis were across various educational levels. As indicated in Table 2.2, postsecondary and elementary schools emerged as the most extensively studied educational levels, constituting approximately one-third of the reviewed studies (38.64%

and 25% respectively). Middle schools accounted for the next considerable proportion of research attention (20.45%), followed by high schools (15.9%).

Subject matter domains: Our investigation also focused on identifying the subject matter domains in which AI was employed to enhance teaching practices. As depicted in Table 2.2, the analysis revealed that Science, in general sense, received the highest frequency of research attention (38.64%). Mathematics was the second most explored subject domain (15.91%), followed by computer science (13.64%). A smaller proportion of studies (6.81%) examined the integration of AI into language teaching activities conducted by teachers. It is worth noting that a considerable body of research investigated how AI facilitates language learning for students without explicitly mentioning the involvement of teachers (Haristiani, 2019; Woo et al., 2021). Overall, most researchers primarily focused on leveraging AI to support teachers' pedagogical practice in the field of science (54.54%), with three articles specifically addressing biology (6.81%) and four articles discussing physics (9.09%).

To gain a comprehensive understanding of the utilization of AI across various educational levels and subject domains, we conducted an analysis to examine the distribution of subject areas within four educational levels across the studies included in our review. The findings indicated that the distribution of subject domains in middle school studies exhibited similarities to those in high school studies, as illustrated in Figure 2.3. Notably, the implementation of AI to support teachers' language teaching activities was exclusively identified within the K-elementary school-level studies. Conversely, no studies were identified that explored the integration of AI into teachers' pedagogy for computer science across elementary to high school levels. Also, general science emerged as the most extensively studied subject domain at the K-elementary and middle school levels.

Educational setting: As shown in Table 2.2, a substantial majority of the studies (74.47%) were conducted within the confines of a formal educational context, specifically within classroom settings. The remaining studies investigated the integration of AI in teaching within informal settings, including online learning platforms and after-school programs. The prevalence of studies conducted in formal educational settings is in line with the recognition of AI's potential to support diverse pedagogical practices in which teachers assume a crucial role.

Table 2.2. Educational contexts and technological features of reviewed studies.

Variables	Categories	Numbers of study	Percentage
Educational level	K-elementary	11	25%
	Middle school	9	20.45%
	High school	7	15.9%
	Postsecondary	17	38.64%
Subject matter	General science	17	38.64%
	Biology	3	6.81%
	Physics	4	9.09%
	Computer science	6	13.64%
	Math	7	15.91%
	Language	3	6.81%
	No specified	4	9.09%
Educational setting	Formal	35	74.47%
	Informal	12	25.53%
AI technology types	Social robots	9	20.45%
	Intelligent tutoring system	14	31.82%
	Pedagogical agents	5	11.36%
	AI-enabled specific tools	8	18.18%
	Machine learning models	8	18.18%
Teacher-involved design	Yes	10	22.72%
	No	34	77.29%
Teacher interface	Yes	15	34.09%
	No	29	65.91%

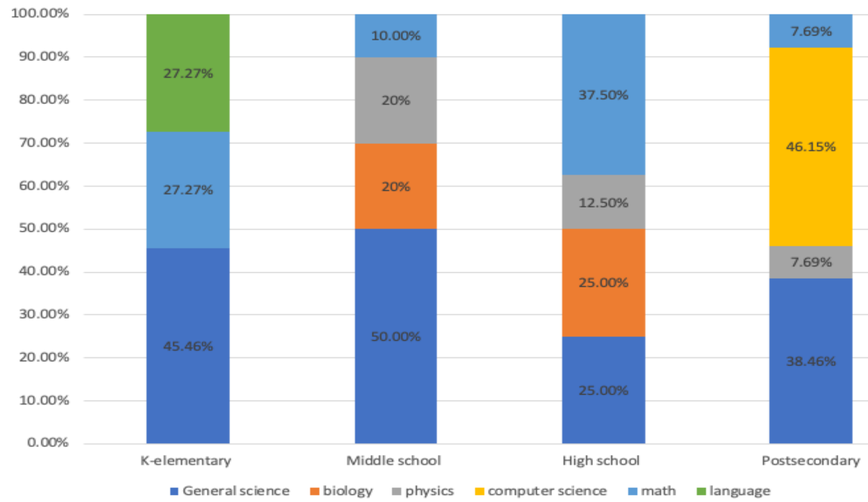

Figure 2.3. Relationship between educational levels and subject domains of the reviewed AI in teaching studies.

AI functionality in teaching

To answer RQ2, the analysis identified three key technological functionalities that warrant consideration: the specific types of AI technologies utilized, the degree of teacher involvement in designing AI-integrated instructions, and the interface provided for teachers to interact with AI.

We categorized the integration of AI technologies into teachers' pedagogical practices across different subject domains and educational levels into five distinct types, as presented in Table 2.2. Humanoid social robots were employed in nine studies to assist teachers in facilitating students' learning in language, science, and safety activities (e.g., Fridin, 2014; Hashimoto et al., 2011; Morita et al., 2018). Intelligent tutoring systems, discussed in 14 studies, can monitor and analyze students' progress (i.e., Arroyo, et al., 2014; Dickler, 2019; Karen et al., 2021) and provide teachers with reports and feedback (i.e., Adair et al., 2020). Virtual pedagogical agents or teaching assistants, the third type, were investigated in five studies, supporting teachers in various instructional activities within and outside the classroom (i.e., Chin, et al., 2010; Goel & Polepeddi, 2018; Huang et al., 2011). Notably, Jill Watson (Goel & Polepeddi, 2018), an AI virtual teaching assistant, was developed to assist teachers in an online course by communicating with students, responding to inquiries, grading assignments, and providing prompt feedback, enabling teachers to focus more on core instructional activities. Various AI-enabled specific tools, such as teacher-responding tools (Bywater et al., 2019), AI learning analytics tools (Van Leeuwen et al., 2015), AI automated tools (Smith et al., 2019), and teacher-partner tools (Paiva & Bittencourt, 2020), were explored in terms of their functions and features to assist teachers' diverse pedagogical practices. Lastly, machine learning algorithmic models were reported in eight studies in aiding teachers to predict at-risk students or dropout rates (Hung et al., 2017; Moreno-Marcos et al., 2020), monitor students' classroom engagement (Hussain et al., 2018), learn from experts' decision-making process (Cukurova, Kent, & Luckin, 2019), and score constructed responses (Käser et al., 2017; Smith et al., 2019).

To investigate how teachers interact with various AI systems and tools from a technological aspect, we conducted a specific analysis of teacher interfaces and teacher involvement in the design process. As depicted in Table 2.2, out of the 44 reviewed studies, approximately one-fifth (22.72%) discussed the mechanisms through which teachers collaborated with researchers in designing AI-integrated curriculum/activities or AI tools/systems (i.e., Gerard & Lin, 2016; Morita et al., 2018). For instance, teachers collaborated with researchers to develop five robotic modes that aligned with different learning goals based on their curriculum and teaching objectives (Chang et al., 2010). Furthermore, we examined whether the AI systems were equipped with a teacher interface to facilitate better communication between teachers, students, and AI, particularly in terms of displaying student data to teachers. Only one-third (34.09%) of the 44 studies emphasized the features of the teacher interface (e.g., teacher dashboard) and how it presented student data to teachers (i.e., Arroyo et al., 2014; Bywater et al., 2019; Dickler et al., 2021; Hashimoto et al., 2011; Hussain et al., 2018).

Figure 2.4 illustrates the distribution of two important technological functionalities: teacher-involved systems or curriculum/activity design and teacher dashboards across the five AI technology types examined in the reviewed studies. Among the 10 studies that mentioned teacher-involved systems or curriculum/activity design, five were related to intelligent/adaptive learning systems. The teacher interface feature was observed in intelligent/adaptive learning systems (7 studies) and social robots (5 studies).

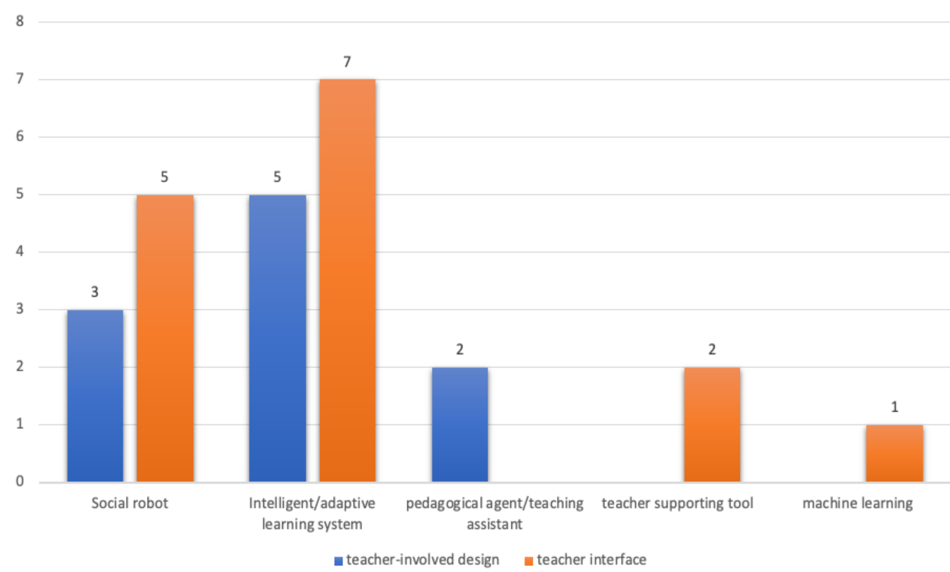

Figure 2.4. The distribution of teacher-involved design and teacher interface across the five types of AI technologies in reviewed studies.

The pedagogical roles of AI to support teachers' instructional practices

Despite the diverse range of AI technologies employed in the reviewed studies, the literature indicated five primary pedagogical roles of AI from the teacher's perspective for answering RQ3. These roles encompassed (1) *participating in instructional activities*, (2) *monitoring student progress*, (3) *innovating teachers' classroom assessment practice*, (4) *providing teacher pedagogical recommendations*, and (5) *driving teachers' effective pedagogical decision-making and action-taking*. Table 2.3 provides an overview of each pedagogical role of AI along with its associated features, supported by reference examples.

AI participates in instructional activities

The findings from the reviewed studies indicate that AI, when employed to assist teachers in their instructional activities, fulfills three distinct roles: (a) serving as an independent *tutor/instructor*, as evidenced in 14 studies (e.g., Arroyo et al., 2014; Buttussi & Chittaro, 2020); (b) functioning as a *teaching assistant*, as demonstrated in 16 studies (e.g., Dicker, 2019; Goel & Polepeddi, 2018; Hashimoto et al., 2011); and (c) acting as a *teaching aid*, as observed in 10 studies (e.g., Hung et al., 2017; Van Leeuwen et al., 2015).

Independent tutor/instructor. Numerous AI systems demonstrate their potential to function as knowledgeable tutors or instructors, facilitating students' knowledge and skill acquisition by offering immediate instruction, guidance, tutorials, supervision, and hints. This capability presents the possibility of replacing the need for a human teacher in certain contexts.

Intelligent tutoring systems exemplify this potential, aiming to replicate the effective practices of one-on-one human tutoring to enhance student learning outcomes (Baker, 2016). Several intelligent tutoring systems (e.g., Gobert et al., 2013; Graesser, Li, & Forsyth, 2014) incorporate pedagogical strategies employed by human experts (Kara & Sevim, 2013). In some instances, AI virtual tutor avatars, such as Rex in the Inquiry ITS (Gobert et al., 2018), have been introduced to substitute human teachers. These intelligent machine tutors/instructors possess the capability to analyze individual students' progress and engagement, creating comprehensive learner profiles and thereby alleviating the burden on teachers to possess extensive knowledge and pedagogical expertise while monitoring student advancement.

Sophisticated educational robots have also been implemented as robot tutors (Yun et al., 2013) to substitute human teachers partially or temporarily in classroom settings. These robot teachers adopt roles as authoritative figures or explicit sources of knowledge through storytelling, conversation-based interactions, and human-like behaviors (Buttussi & Chittaro, 2020; Fridin 2014; Hashimoto et al., 2011). For instance, Saya, a humanoid robot with a female appearance, has been deployed as a teacher in classrooms (Hashimoto et al., 2011). In Saya's "lecture mode," she provides explanations about class content, while in the "interactive mode," she engages in interactive behaviors such as paying attention to students, looking around the classroom, and conversing with students using head and eye movements. Furthermore, Saya can express human-like facial expressions, including surprise, fear, anger, and happiness, to interact with humans. Social robots functioning as tutors or mentors can adapt their actions based on students' learning styles, personalities, and emotional states, thereby offering personalized assistance in student learning (Westlund et al., 2016).

Teaching assistant. The findings from the reviewed studies indicate that AI can serve as a teaching assistant, providing support and aiding teachers in various instructional activities, including timely identification of students' needs, answering questions, and reminding students of deadlines (Gerard et al., 2019; Goel et al., 2018; Morita et al., 2018). Two types of AI teaching assistants were identified: virtual teaching assistants (VTA) such as chatbots (Goel et al., 2018), and physically embodied teaching assistants like humanoid social robots (Chang, et al., 2010). A notable example of a VTA is Jill Watson (Goel et al., 2018), a conversational chatbot designed to assist teachers in an online course by responding to student queries, grading assignments, and providing feedback through text or dialogue-based communication.

Teaching aids. Through our review, we have identified AI technologies that can serve as a valuable teaching aid, acting as platforms or tools to enhance teachers' instructional activities. Firstly, AI can function as a teaching platform by providing teachers with materials and resources to facilitate dynamic instructional activities. For instance, Yu (2017) developed a feedback system that enables teachers to collect student responses and engage in communication with them through a dual-channel mechanism. Secondly, AI can serve as an intelligent tool to support teachers in various pedagogical activities (Van Leeuwen et al., 2014; Smith et al., 2019). These tools offer specific functionalities that assist teachers in their instructional tasks. For instance, Smith et al. (2019) developed a multimodal computational model capable of automatically analyzing student writing and drawings in elementary science learning, providing valuable insights to teachers. Another example is the teacher-responding tool (Bywater et al., 2019), which utilizes natural language processing techniques to offer feedback recommendations to teachers.

AI supports teachers in monitoring student progress

Many studies have highlighted the growing role of AI in supporting teachers to track student performance and provide timely and valuable reports. To explore how AI fulfills this role, we conducted an analysis of eligible studies, focusing on the domains of student performance that were tracked (28 studies) (e.g., cognitive, engagement, and emotional) the performance states that were monitored (19 studies) (e.g., progression, difficulties and at-risk).

Performance domains. The reviewed studies revealed that AI has the potential to assist teachers in monitoring and predicting students' cognitive and metacognitive performance, analyzing their learning engagement, and detecting their emotional states (Hung et al., 2017; Hussain et al., 2018; Käser et al., 2017; Moreno-Marcos et al., 2020; Yağci & Çevik, 2019). Various intelligent tutoring systems continuously monitor and analyze students' behaviors and cognition to evaluate their mastery of concepts, skills, and activities within the content domain (e.g., Arroyo et al., 2014; Dickler 2019; Gerard & Lin, 2016; Gobert et al., 2014). For instance, Käser et al. (2017) employed dynamic Bayesian networks for student modeling performance, enabling instructors to adapt their instructional strategies to meet individual student needs. Hussain et al. (2018) developed an automated disengagement tracking tool that forecasts students' engagement in an online course, assisting instructors in modifying their instruction to enhance student engagement. Moreover, affect-sensitive ITS can identify and responsively address learners' affective states, including confusion, frustration, boredom, and engagement, enabling teachers to become aware of students' emotional states and adjust their instruction accordingly (e.g., Arroyo et al., 2014; Liaw et al., 2020). By providing real-time insights into students' behavior interactions, cognitive performance, and emotional states, AI empowers teachers to accurately track student performance and make informed instructional adjustments.

Performance states. AI can monitor student performance by identifying their progress and difficulties, and generating actionable reports to support teachers' decision-making and actions. Shin, Chen, Lu, and Bulut (2022) conducted a study on an AI-enabled prediction system for formative assessment practices in elementary school math classrooms. This system automatically monitors and detects students' progress in various learning states by analyzing their performance scores, providing valuable information for teachers to make informed decisions about future assessments and providing appropriate scaffolding for specific students.

AI systems also can detect when a student is struggling or deviating from the expected trajectory (Gobert et al., 2015). This ability provides teachers with predictive analytics on student difficulties and early warnings to identify at-risk students (Arnold & Pistilli, 2012; Jayaprakash et al., 2014). Teacher alerts (Dickler, 2019; Gobert et al., 2014) and time-series clustering approaches (Hung et al., 2017) have been utilized to notify teachers when students face challenges or to detect at-risk students in learning, enabling early intervention to support student success. Additionally, Course Signals is an example of a system that predicts student success in real-time, determines the reasons behind students being at risk, and provides this information to instructors (Arnold & Pistilli, 2012). Armed with valuable information from AI, teachers can approach students to gain a deeper understanding of their off-track performance and provide the necessary assistance.

AI innovates teachers' classroom assessment practice

Our analysis revealed that the utilization of ML-based automatic scoring systems and tools has the potential to bring innovation and transformation to teachers' conventional classroom assessment practices in terms of assessment constructs and score availability.

Assessment construct. The assessment of student performance holds significant importance in many intelligent tutoring systems as they employ students' behavioral activities and written artifacts to evaluate their performance. These systems collect data on students' behavior and their interactions with the system, enabling teachers to track their progress throughout the learning process. An example of such a system is the inquiry ITS, which employs educational machine algorithms to assess students' cognitive performance and their practice at each stage of scientific investigations (Adair et al., 2020; Dickler, 2019; Gobert et al., 2018).

Many studies have investigated various assessment constructs used in teachers' classroom assessments, such as written explanation and argumentation (e.g., Adair et al., 2020; Huang et al., 2011; Smith et al., 2019), essays (e.g., Gerard & Lin, 2016; Gerard et al., 2019), simulations (e.g., Käser et al., 2017), and games (e.g., Karen et al., 2021). The adoption of performance-based assessments and constructed responses is particularly transformative for teachers' traditional assessment practices, which often rely on multiple-choice items. These assessments aid teachers in eliciting students' higher order thinking and evaluating their ability to apply knowledge in problem-solving (Zhai et al., 2020a).

Score availability. The use of performance-based assessments and constructed responses by teachers is often hindered by the difficulties associated with timely and effective scoring and feedback. However, ML-based assessments can overcome these challenges by automatically scoring students' constructed responses using advanced ML algorithms trained on human-labeled response results. Studies investigating various assessment constructs have reported the utilization of ML algorithms and their scoring accuracy (e.g., Gerard & Lin, 2016; Gerard et al., 2019; Huang et al., 2011; Käser et al., 2017; Smith et al., 2019). ML automatic scoring can significantly reduce teachers' workload in terms of scoring time and cost, enabling them to employ more performance-based assessments that utilize constructed responses.

Furthermore, the provision of timely feedback on constructed response assessments is crucial for students and teachers to make appropriate decisions. Our review revealed that the ML automatic scoring enables the machine not only to provide scores but also to offer personalized feedback for students to promptly revise their responses (e.g., Gerard et al., 2019; Huang et al., 2011; Smith et al., 2019). Additionally, many ML-based assessments provide teachers with feedback and reports on students' performance, (Adair et al., 2020; Dickler et al., 2021; Shin et al., 2022) as well as immediate guidance on incorporating machine feedback into their pedagogy to deliver personalized feedback to students (Bywater et al., 2019; Gerard & Lin, 2016; Gerard et al., 2019; Gobert et al., 2018).

AI provides teachers pedagogical recommendations

The literature analysis revealed that certain AI systems can provide pedagogical guidance and recommendations to support teachers in making informed decisions and taking appropriate actions. While most AI systems primarily provide reports on student performance and difficulties, leaving teachers to determine how to support their students, this can pose a challenge, especially for novice teachers. A subset of AI systems can offer pedagogical recommendations and suggestions to guide teachers' practices (6 studies), which was categorized into prescriptive and descriptive recommendations.

One example of prescriptive AI recommendations is the Course Signals system introduced by Arnold and Pistilli (2012), which provides instructors with specific actions to take based on AI's analysis of student behavior, such as sending an email to a student to discuss their course activities when they are inactive or falling behind peers. Also, the system offers suggested text for the email to help instructors talk with the student.

Several studies have reported the use of descriptive and dynamic AI recommendations for pedagogical strategies that teachers can choose from and integrate into their teaching practices. An example is the Teacher Inquiry Practice Support (TIPS) (Adair, Dickler, & Gobert, 2020), which offers teachers four categories of support: orienting, conceptual, procedural, and instrumental. By incorporating one or more AI recommendations with their own pedagogical knowledge and strategies, teachers can provide personalized and timely scaffolding to students.

AI drives teachers' effective pedagogical decision-making and action-taking

Based on the reviewed studies, AI is increasingly playing a role in the decision-making process within the classroom by providing data-driven insights to guide teachers in making effective pedagogical decisions and taking appropriate action.

AI's ability to process vast amounts of complex data and information quickly (Kent, 2022) offers valuable insights into students' learning processes, allowing teachers to make data-driven instructional adjustments based on ongoing learning dynamics. For instance, through the analysis of multimodal data from students' interactions with intelligent tutoring systems (Dickler et al., 2021; Fridin, 2014; Van Leeuwen et al., 2014), AI can generate personalized learning profiles that capture student behaviors and cognitive performance. These profiles enable teachers to provide appropriate support and facilitation at both the individual and group levels (Gobert et al., 2018).

AI can support teachers' decision-making across various student activities. For example, the Teacher's Partner, an AI-powered tool designed to collaborate with human intelligence (Paiva & Bittencourt, 2020), automatically retrieves and processes students' online learning data to generate visualizations of their learning patterns and trends. This information informs instructors about pedagogical situations and issues occurring during the online learning process, empowering them to make pedagogical decisions and offer personalized assistance. In the case of Reasoning Mind, teachers use real-time AI-provided reports to identify students struggling with specific concepts and engage in proactive remediation (Miller et al., 2015). Additionally, AI-enabled learning analytics supports teachers in facilitating student collaboration. The Virtual Collaborative Research Institute system provides real-time information on student participation in collaborative chat, allowing teachers to take immediate action to improve the quality of collaborative discussions, particularly targeting individuals or groups facing difficulties (Van Leeuwen et al., 2014, 2015).

The combination of machine intelligence and human intelligence can enhance teachers' support for learning. Gerard and Linn (2016) found that the combination of automated guidance and teacher guidance was more effective for learning topics such as Photosynthesis and Cells compared to individual automated guidance alone. Gerard et al. (2019) further explored how teachers customized automated guidance in their classrooms in a timely manner. Similarly, the teacher alert system (Adair et al., 2020; Gobert et al., 2018) provides teachers with information about students' difficulties and pedagogical support, enabling teachers to provide targeted scaffolding when needed. The findings indicate that AI can support responsive teaching by actively participating in the classroom's decision-making process.

Table 2.3. The pedagogical roles of AI and reference examples

Pedagogical roles	Attributes	Sub-categories	Reference examples
AI participates in instructional activities	AI facilitates and substitutes teachers	Independent tutor/instructor	Arroyo et al. (2014); Buttussi & Chittaro, (2020); Pai et al. (2021)

	to instruct student learning activities	Teaching assistant	Chang, et al. (2010); Dicker (2019, 2021); Goel and Polepeddi (2018); Hashimoto et al. (2011)
		Teaching aid	Bywater, et al. (2019); Hung et al. (2017); Leeuwen et al. (2015)
AI supports teachers in monitoring student progress	AI automatically tracks students' performance at various domains and gives teachers timely reports and feedback.	Performance domains	Leeuwen et al. (2015); Hussain et al. (2018); Liaw et al. (2020); Yu (2017)
		Performance status	Adair et al. (2020); Dickler (2019); Dickler et al. (2021); Karen et al. (2021); Hung et al. (2017)
AI innovates teachers' classroom assessment practice	AI helps teachers to conduct performance-based assessment by employing complex constructs, automatic scoring, and timely feedback.	Assessment construct	Adair et al. (2020); Huang et al. (2011); Käser et al. (2017); Karen et al. (2021); Smith et al. (2019)
		Score availability	Bywater et al. (2019); Gerard and Lin (2016); Gerard et al. (2019); Huang et al. (2011)
AI provides teachers pedagogical recommendations	AI can recommend teachers the appropriate content, pedagogy, and technical strategies for teachers' pedagogical practices.	prescriptive recommendations	Arnold and Pistilli (2012)
		descriptive recommendations	Adair et al. (2020); Hussain et al. (2018)
AI drives teachers' effective pedagogical decision-making and action-taking	AI insights can support teachers to make timely instructional adjustments and provide personalized learning experiences.	-	Gerard and Lin (2016); Gobert et al. (2018); Miller et al. (2015); Van Leeuwen et al. (2014)

The profile of AI uniqueness

To answer the RQ4, we identified three distinct characteristics of AI in the reviewed studies: *AI-teacher interactivity*, *automaticity*, and *autonomous* which collectively contribute to the profile of AI uniqueness in teaching.

AI-teacher interactivity. Following the social behavior norms to interact with human teachers, a wide range of AI systems and applications in the eligible studies displayed the uniqueness of *AI-teacher interactivity*. AI and teachers interact and communicate in a natural and interpersonal manner (Chen et al., 2020b) using various approaches, including written messages, dialogue, and actions and behaviors in the cognition, social, and emotional domains (Buttussi & Chittaro, 2020; Chen et al., 2020b; Fridin, 2014). Natural language processing (NLP) models and systems were utilized to process and comprehend complex human written and spoken languages, enabling information exchange between teachers and AI. For example, teacher reports (Adair et al., 2020; Dickler, 2019) present human-actionable text and graphs on student performance to facilitate interaction with teachers. Social robots like KindSAR (Fridin, 2014) engage in textual and verbal communication with teachers during their assistance in instructional activities. Intelligent tutoring systems, such as AutoTutor, employ conversational interaction through simulated human tutorial dialogue designs (Graesser et al., 2014).

Furthermore, our analysis revealed that certain AI systems can detect and interpret human body movements and behavior, including eye movements, hand gestures, and facial expressions, to communicate with and respond to users, including teachers. Humanoid robots like Nao (Ros et al., 2016), Saya (Hashimoto et al., 2011), and Pepper (Morita et al., 2018) utilize various body cues, such as head movements, blinking eyes, and spatial orientation, to engage in communication and interaction with teachers and their students.

It is important to note that while significant research has focused on investigating how AI can detect and monitor users' emotional states, such as students in educational settings, from an emotional interaction perspective, no studies explored and discussed the emotional dimension of teacher and AI interaction. Nevertheless, some studies have examined the emotional impact of AI on teachers, including aspects like trust and perceived AI competence (Indira, Hermanto, & Pramono, 2020; Serholt et al., 2017; Sharkey, 2016). Additionally, the current AI-teacher interactivity primarily entails one-way interaction, with AI suggesting information, strategies, and guidance to teachers for enhanced pedagogy (e.g., Chen et al., 2020a; Ros et al., 2016; Buttussi & Chittaro, 2020).

AI automaticity. AI *automaticity* is defined by its functionalities in tracking students' performance and challenges, analyzing their behavioral, cognitive, and emotional states, and providing teachers with timely feedback and guidance. This characteristic aligns with the concept of assessment automaticity in ML-based science assessment, as concluded by Zhai et al. (2020a). It is important to note that in this study, the definition of AI automaticity encompasses various AI applications performing automaticity across a wide range of teaching activities, rather than being limited to ML-based science assessment alone.

AI automaticity reflects the capability of AI to automatically process substantial amounts of data and information to detect and understand the occurrences within teaching and learning environments. This feature enables AI to generate automatic messages to teachers, such as machine feedback, teacher reports, and teacher recommendations. The automatic processing of

AI benefits teachers by providing them with more valuable and timely information while minimizing the need for human intervention and reducing their workload. AI automaticity can be observed in various pedagogical tasks, including lesson preparation, student performance assessment, and instructional adjustments.

AI automaticity facilitates the recommendation of teaching materials and resources (Adair et al., 2020; Gobert et al., 2023a, b), the identification of student performance and problems (Dickler, 2019; Jayaprakash et al., 2014), and the provision of AI-based suggestions (Arnold & Pistilli, 2012) to support teachers in their lesson preparation. For instance, AI systems, such as intelligent tutoring systems, can automatically score students' interactions with the system and their progress to generate student performance reports (e.g., Arroyo et al., 2014; Dickler, 2019; Gerard & Linn, 2016; Gobert et al., 2014), enabling teachers to gain insights into student performance states. Based on these automatic resources, teachers can better prepare their lessons and implement interventions and scaffolding strategies more effectively.

In ML-enabled assessments, AI can automatically score students' constructed responses, such as written essays, drawings, and simulations, to provide teachers with automated scores and feedback (Gerard et al., 2016, 2019; Käser et al., 2017; Zhai et al., 2020a, b). AI also offers teachers feedback and guidance (Mehmood et al., 2017; Moharreri et al., 2014; Nehm, Ha, & Mayfield., 2012), alerts (Adair et al., 2020; Dickler, 2019), and recommendations (Heylen et al., 2004; Matthews et al., 2012) to promote instructional decision-making and action-taking.

AI autonomy. Various AI systems distinguish themselves from traditional educational technologies by demonstrating the ability to autonomously perform creative and complex tasks with minimal or no human intervention (Kara & Sevim 2013; Lundie, 2016), highlighting the uniqueness of *AI autonomy*. AI autonomy refers to the level of agency that an AI system possesses in selecting from different options and implementing its selections independently (Gunderson & Gunderson, 2004). This autonomous agency implies that machine intelligence can "learn" from data and its environment to make decisions and take actions like how humans learn from their experiences (Zhai et al., 2020a).

According to the literature, AI autonomy manifests in various forms when AI fulfills the various pedagogical roles identified. Most intelligent tutoring systems that independently adapt to individual student's learning needs and pace can provide teachers with performance reports, feedback, and recommendations. When AI takes on the role of a teaching assistant or pedagogical agent, such as Jill Watson (Goel et al., 2018), it can autonomously make decisions regarding answering student questions, grading assignments, providing feedback, and interacting with students. During this process, AI has the agency to determine when and how to support students and teachers without consulting teachers. Some AI-enabled assessment systems and tools can grade student work and provide actionable feedback and recommendations based on independent machine judgment, without the need for teacher consultation.

It is important to highlight that, in the reviewed studies, AI autonomy in teaching is still limited, as many classroom activities require significant oversight and input from teachers. Nonetheless, AI autonomy enables AI to enhance teaching by performing independent work in grading, analysis, and decision-making, thus reducing the workload for teachers in certain aspects of their pedagogical responsibilities.

Discussion

Over the past decade, there has been a growing interest in exploring the potential impact of AI technology on teaching and learning in various educational contexts. Many researchers have focused on questions related to the role of teachers and factors that drive changes in their roles, such as teacher-AI complementarity and cooperation in classroom orchestration (Holstein et al., 2019; Kang et al., 2023) and the possibility of AI replacing teachers (Edwards & Cheok, 2018). However, we argue that it is crucial to first understand what AI is capable of and how it can contribute to teachers' pedagogical practices from a pedagogical perspective. Therefore, in this study, we systematically reviewed 44 relevant studies based on the proposed framework to shed light on the current state of AI integration in teaching, the pedagogical roles of AI, and its distinctive characteristics in supporting and impacting various pedagogical activities of teachers.

Our findings reveal that advanced AI technology has significantly transformed and shifted many of the traditional behaviors and activities of teachers. For example, AI can track students' progress, score constructed responses, and provide personalized scaffolding and feedback. Understanding the capabilities of AI in the context of teaching provides a complementary perspective for researchers, practitioners, and other stakeholders to further explore and discuss the evolving roles of teachers in the era of AI. In this section, we discussed the major findings and contributions of our study to the existing literature, highlighting the knowledge gained from understanding the pedagogical contributions of AI.

AI promotes teachers' personalized instruction and scaffolding to students

The intricacies associated with students' cognitive, metacognitive, and emotional states present a significant challenge for teachers in delivering personalized instruction and facilitating timely learning experiences (Gobert et al., 2018). Meeting the individualized needs of each student in an equal and inclusive manner can be exceptionally demanding for teachers.

Our study has revealed that AI technology can effectively assist teachers in addressing these challenges through various means. When AI is employed as a tutor or teaching assistant, it can substitute teachers and provide students with adaptive and personalized learning resources, materials, and feedback, as demonstrated by numerous intelligent tutoring systems (e.g., Gobert et al., 2013; Graesser, Li, & Forsyth, 2014). Furthermore, to deliver personalized instruction and scaffolding, teachers require real-time information on each student's progress and challenges. While conventional technologies, such as video or audio recordings, can capture students' learning behavior and activities during the learning process, analyzing this data to gain insights into students' progress and adjusting instruction accordingly can be time-consuming and complex for teachers. However, our findings indicate that AI can support teachers in tracking student performance. Many intelligent tutoring systems can automatically track and diagnose students' progress and difficulties, manage their behavior, and predict their performance (Arroyo et al., 2014; Howard et al., 2016). These systems can also provide teachers with real-time reports on individual students' progress (e.g., Gobert et al., 2013; Grivokostopoulou et al., 2017) and offer teacher support (e.g., Adair et al., 2020). The data-driven insights provided by AI can facilitate teachers in delivering personalized instruction and scaffolding to students timely (Dickler, 2021).

Furthermore, teachers encounter challenges in identifying and appropriately responding to students' emotional states, in addition to their cognitive and metacognitive performance. Traditional classroom settings often make it difficult for teachers to have a comprehensive understanding of each student's emotional state, which is crucial for effective communication and interaction. Our review findings indicate that affective AI systems, leveraging facial and speech recognition technologies, can detect students' emotional states (Heylen et al., 2004). This technology provides teachers with automatic information on students' emotional states, enabling them to make informed decisions and adjust their instruction accordingly. Consequently, the utilization of affective AI systems can enhance teachers' ability to support their students' emotional needs more effectively and efficiently.

Teachers can assess student performance innovatively and timely

Conventional technologies have had a significant impact on classroom assessment by enabling computer-based assessment items and digital representation. However, most traditional computer-based assessments primarily rely on multiple-choice items, which may not fully capture students' complex cognitive abilities and higher-order thinking. Performance-based assessments and constructed responses have been considered as advantageous alternatives to address these assessment limitations. However, teachers often face challenges in implementing these methods, particularly due to the time-consuming nature of scoring and the lack of timely feedback. Our review highlights the potential of AI to revolutionize teachers' classroom assessment practices, particularly in terms of assessment construct and score availability.

Through our review, we have identified a range of intelligent tutoring systems that can function as assessment tools to evaluate students' progress and their interactions with the systems (Adair et al., 2020; Dickler, 2019; Gobert et al., 2018; Gobert et al., 2023a, b). These intelligent tutoring systems are designed to provide in-process assessments, offering teachers detailed reports on students' progress at various stages of the learning process. Moreover, these assessment results can be presented in multiple modalities, providing teachers with a deeper understanding of students' performance, and informing instructional decision-making in the classroom. By integrating instruction and assessment, we propose that AI-enabled systems with assessment functions can offer teachers a more effective and comprehensive form of assessment (Siler & Vanlehn, 2003)

Our analysis further suggests that AI-based assessment can transform traditional classroom assessment by facilitating the use of performance-based assessments and delivering timely and personalized feedback. Previous research has indicated that educators often hesitate to use authentic tasks, such as written arguments, simulations, and games, for performance-based assessments due to challenges and costs associated with scoring them in a timely manner (Zhai et al., 2020a, b). Additionally, providing timely and individualized feedback to students can be challenging, particularly in large-scale courses. However, the studies we reviewed highlight how AI can support innovative assessment practices (Zhai, 2021) by promoting the use of authentic assessment tasks and ensuring timely scoring and feedback availability. Various authentic assessment constructs, including written explanations and arguments (Adair et al., 2020; Huang et al., 2011), essays (Gerard & Lin, 2016; Gerard et al., 2019), simulations (Käser et al., 2017), and games (Karen et al., 2021), can be implemented, leveraging the potential of AI and ML. AI-based assessment can accurately score constructed responses with a level of precision comparable to human scoring (Zhai, Shi, & Nehm, 2021), while also providing detailed and personalized feedback and reports on students' performance. By providing teachers with comprehensive information about students' performance, AI-based innovative assessment can assist them in making informed instructional decisions.

The functions and roles of AI in tracking students' behavior and interactions with the system, as well as scoring their constructed responses, highlight the automaticity of AI, a prominent attribute that denotes its ability to efficiently process vast amounts of data and information. The reviewed studies in this regard indicate that AI automaticity can not only support teachers in assessing students' progress but also facilitate their lesson planning and instructional adaptations.

AI participates in classroom communication and interaction

The achievement of instructional objectives has traditionally relied on effective communication and interaction between teachers, students, and the available teaching resources in learning environments. While conventional technologies have been used as tools or platforms to facilitate classroom communication, our study suggests that AI is progressively emerging as a communicative agent (Reeves, 2016) in classroom communication and interaction (Guzman & Lewis, 2020), as it assumes various roles that demonstrate its characteristic of AI-human interactivity. In terms of the communication mode between teachers and AI, Edwards and Edwards (2017) argue that "the machine is increasingly being designed to teach and learn through interaction and to be responsive to natural teaching and learning methods employed by their human partners" (p. 487). As a result, several contemporary communication variables, such as immediacy, interaction, and social and emotional attraction (Edwards & Cheok, 2018), have garnered significant attention in research on human-intelligent machine communication.

Our current investigation reveals that various AI technologies (e.g., virtual teaching agents, ITS, and social robots) can engage in automatic communication and interaction with teachers through oral or written discourse (Reeves, 2016) in the domains of behavior, cognition, and social-emotional aspects (Buttussi & Chittaro, 2020; Chen et al., 2020a; Fridin, 2014). We define this interaction as the characteristic of AI-teacher interactivity, which is evident in several identified AI pedagogical roles. For instance, when AI functions as a teaching assistant to support instructional activities, it requires frequent communication with teachers to update its performance in tasks such as grading assignments and responding to questions (Goel et al., 2018). Similarly, when AI assists teachers in monitoring student progress, it must interact with them to convey information about students' advancements and challenges through various natural means, such as text and dialogue (Gobert et al., 2018; Gerard & Linn, 2016). Our review indicates that AI is being developed to engage in message exchange with teachers in classroom communication, marking a departure from traditional technology primarily used for communication between teachers and students (Guzman & Lewis, 2020).

AI becomes a significant player in classrooms

Numerous researchers have raised the argument that the advancement of AI technology holds the potential for assuming significant social roles within educational contexts, including the possibility of replacing teachers (e.g., Edwards & Cheok, 2018; Morita et al., 2018; Mubin et al., 2013; Serholt et al., 2017; Sharkey, 2016). However, these arguments have given rise to critical ethical concerns, such as AI trust and teacher apprehension (Lindner & Romeike, 2019; Serholt et al., 2017; Sharkey, 2016; van Ewijk et al., 2020). To ensure successful integration of AI in teaching, Mubin et al. (2013) proposed that the roles of teachers and AI should be clearly defined. In this regard, our review contributes to the literature by elucidating the potential pedagogical benefits of AI in teaching and how it can support, rather than replace, teachers.

Within this study, we have identified five distinct pedagogical roles of AI that can be leveraged to support teachers across various stages of the teaching process, including lesson planning and instruction, classroom management, performance assessment, student support, and instructional adjustment. Our findings suggest that AI can enable teachers to accomplish previously unattainable tasks. Through continuous monitoring of students' progress and provision of real-time reports and alerts regarding their academic and emotional well-being, AI can facilitate personalized and timely instructional support from teachers (Holstein et al., 2019; Qin et al., 2020). Furthermore, AI-based assessment tools and their automaticity can empower teachers to employ authentic assessment tasks and deliver prompt scoring and personalized feedback, thereby revolutionizing traditional classroom assessment practices. Our study underscores the emerging significance of AI in the classroom, where it serves as a platform or collaborator for teachers, rather than a replacement.

Nevertheless, our review has revealed that studies describing fully autonomous AI instructors evoke apprehension. Instead, several studies have advocated for a hybrid approach that combines teachers' expertise and human qualities with the capabilities of AI to enhance student support (Kent, 2022; Manyika et al., 2017). By augmenting teacher intelligence with machine intelligence, teachers can provide personalized guidance, support, and pedagogy that adapt to the ever-changing dynamics of educational environments.

While our review has shed light on the potential of AI in supporting teachers in education, significant gaps remain in the current literature. Although several studies have explored the potential of AI in formal settings and subjects such as science, language arts, and computer science, further research is warranted to investigate the use of AI in informal settings, including remote teaching and field trips, as well as in other subject domains, such as social studies. While numerous studies have focused on the interactions between learners and AI, only a small percentage has examined how AI can support teachers. Moreover, to foster effective collaboration between teachers and AI, it is imperative to involve teachers in the design process and provide them with interfaces that enable seamless interaction with AI. However, the existing literature on these matters is limited, necessitating further research in these areas.

Conclusion and Limitation

Utilizing the proposed analytical framework encompassing functionality, pedagogy, and uniqueness, our study aims to investigate the application of AI in enhancing teachers' pedagogical practices. By building upon the technological foundations of AI, we have identified five distinct pedagogical roles of AI and three unique features. Our study findings highlight that by comprehending and harnessing the various roles and features of specific AI systems or tools, teachers can effectively collaborate with AI to augment student learning. Through our systematic review, we present comprehensive evidence from the literature to initiate ongoing discussions and explorations concerning the benefits and transformations brought about by AI in the context of teaching.

Notwithstanding the identification of pedagogical roles and characteristics of AI in teaching, our study is subject to certain limitations. Firstly, although we conducted a comprehensive search of studies across educational levels and subject domains to obtain a broad understanding of the topic, it is important to recognize that AI applications and systems may vary in their implementation across different subject domains, potentially presenting distinct roles in supporting teachers. Further research is needed to explore the specific roles of AI within subject domains by integrating the features of AI with the features of the domain. Secondly, for the purpose of this study, we excluded research that solely focused on how students utilize AI without considering the activities of teachers in AI-integrated educational environments. While such studies may provide relevant insights or evidence for classifying AI's pedagogical roles in teaching, they were not included in this study to ensure the quality of the synthesis.

References

Adair, A., Dickler, R., Gobert, J. (2020). Supporting teachers supporting students: Iterative development of TIPS in a teacher dashboard. In M., Gresalfi,I. S. Horn, (Eds.), The interdisciplinarity of the learning sciences, 14th international conference of the learning sciences (ICLS) 2020 (pp. 1769-1770). International Society of the Learning Sciences.

Al Darayseh, A. S. (2023). Acceptance of artificial intelligence in teaching science: Science teachers' perspective. *Computers and Education: Artificial Intelligence*, 100132.

Aiken, R. M., & Epstein, R. G. (2000). Ethical guidelines for AI in education: Starting a conversation. *International Journal of Artificial Intelligence in Edu*, *11*(2), 163-176.

Akgun, S., & Greenhow, C. (2021). Artificial intelligence in education: Addressing ethical challenges in K-12 settings. *AI and Ethics*, 1-10.

Arnold, K. E., Pistilli, M. D. (2012) Course Signals at Purdue: Using learning analytics to increase student success. Proceedings of the 2nd International Conference on Learning Analytics and Knowledge. New York, NY: ACM, pp. 267–270.

Arroyo, I., Woolf, B. P., Burelson, W., Muldner, K., Rai, D., & Tai, M. (2014). A multimedia adaptive tutoring system for mathematics that addresses cognition, metacognition and affect. *International Journal of Artificial Intelligence in Education*, *24*(4), 387–426.

Baker, R. S. (2016). Stupid tutoring systems, intelligent humans. International Journal of Artificial Intelligence in Education, 26(2), 600–614. http://dx.doi.org/10.1007/s40593-016-0105-0

Baker, T., & Smith, L. (2019). Educ-AI-tion Rebooted? Exploring the future of artificial intelligence in schools and colleges. Nesta Foundation.

Banzon, A., Walker-McKnight, L., & Taub, M. (2022). AI and Teacher Education: Surveying Pre-Service Teachers' Acceptance and Future Use of Artificial Intelligence. In *Society for Information Technology & Teacher Education International Conference* (pp. 1571-1575). Association for the Advancement of Computing in Education (AACE).

Buttussi, F., & Chittaro, L. (2020). Humor and Fear Appeals in Animated Pedagogical Agents: An Evaluation in Aviation Safety Education. *IEEE Transactions on Learning Technologies*, *13*(1), 63–76. https://doi.org/10.1109/TLT.2019.2902401

ChanLin, L. J., Hong, J. C., Horng, J. S., Chang, S. H., & Chu, H. C. (2006). Factors influencing technology integration in teaching: A Taiwanese perspective. *Innovations in Education and Teaching International*, *43*(1), 57-68.

Chen, H., Park, H. W., & Breazeal, C. (2020b). Teaching and learning with children: Impact of reciprocal peer learning with a social robot on children's learning and emotive engagement. *Computers and Education*, *150*.

Chen, L., Chen, P., & Lin, Z. (2020a). Artificial Intelligence in Education: A Review. *IEEE Access*, *8*, 75264–75278. https://doi.org/10.1109/ACCESS.2020.2988510

Chin, D. B., Dohmen, I. M., & Schwartz, D. L. (2013). Young children can learn scientific reasoning with teachable agents. *IEEE Transactions on Learning Technologies*, *6*(3), 248–257. https://doi.org/10.1109/TLT.2013.24

Choi, S., Jang, Y., & Kim, H. (2022). Influence of pedagogical beliefs and perceived trust on teachers' acceptance of educational artificial intelligence tools. *International Journal of Human–Computer Interaction*, *39*(4), 910-922.

Chounta, I. A., Bardone, E., Raudsep, A., & Pedaste, M. (2022). Exploring teachers' perceptions of Artificial Intelligence as a tool to support their practice in Estonian K-12 education. *International Journal of Artificial Intelligence in Education*, *32*(3), 725-755.

Cukurova, M., Kent, C., & Luckin, R. (2019). Artificial intelligence and multimodal data in the service of human decision-making: A case study in debate tutoring. British Journal of Educational Technology, 50(6), 3032–3046.

De Koster, S., Volman, M., & Kuiper, E. (2017). Concept-guided development of technology in traditional and innovative schools: Quantitative and qualitative differences in technology integration. *Educational Technology Research and Development*, *65*, 1325-1344.

Dickler, R. (2019). *An intelligent tutoring system and teacher dashboard to support students on mathematics in science inquiry* (Doctoral dissertation, Rutgers The State University of New Jersey, School of Graduate Studies).

Dickler, R., Gobert, J., & Sao Pedro, M. (2021). Using Innovative Methods to Explore the Potential of an Alerting Dashboard for Science Inquiry. Journal of Learning Analytics, 8(2), 105-122

Dreyfus, H. L., & Dreyfus, S. E. (1988). Mind over machine: the power of human intuition and expertise in the era of the computer. New York: The Free Press.

Edwards, B. I., & Cheok, A. D. (2018). Why not robot teachers: artificial intelligence for addressing teacher shortage. Applied Artificial Intelligence, 32(4), 345–360.

Edwards, A., & Edwards, C. (2017). The machines are coming: Future directions in instructional communication research. *Communication Education*, *66*(4), 487–488.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107–115. https://doi.org/10.1111/j.1365-2648.2007.04569.x

Fridin, M. (2014). Storytelling by a kindergarten social assistive robot: A tool for constructive learning in preschool education. *Computers and Education*, *70*, 53–64. https://doi.org/10.1016/j.compedu.2013.07.043

Gerard, L. F., & Linn, M. C. (2016). Using automated scores of student essays to support teacher guidance in classroom inquiry. *Journal of Science Teacher Education*, 27(1), 111–129.

Gerard, L., Kidron, A., & Linn, M. C. (2019). Guiding collaborative revision of science explanations. *International Journal of Computer-Supported Collaborative Learning*, 14, 1–34.

Gobert, J. (2019) Inq-Blotter: Designing Supports for Teachers' Real Time Instruction (NSF-IIS-1902647). Awarded by the. National Science Foundation.

Gobert, J. D., Moussavi, R., Li, H., Sao Pedro, M., & Dickler, R. (2018). Scaffolding students' on-line data interpretation during inquiry with Inq-ITS. In M. E. Auer, A. K. M. Azad, A. Edwards, & T. de Jong (Eds.), *Cyber-physical laboratories in engineering and science education* (pp. 191-218). Cham, Switzerland: Springer

Gobert, J., & Sao Pedro, M. (2016). Inq-Blotter: A real-time alerting tool to transform teachers' assessment of science inquiry practices (NSF-IIS-1629045). Awarded from the National Science Foundation.

Gobert, J. D., Sao Pedro, M., Raziuddin, J., & Baker, R. S. (2013). From log files to assessment metrics: Measuring students' science inquiry skills using educational data mining. *Journal of the Learning Sciences*, *22*(4), 521-563.

Gobert, J. D., Sao Pedro, M.A., Betts, C.G. (2023a). An AI-Based Teacher Dashboard to Support Students' Inquiry: Design Principles, Features, and Technological Specifications. In N. Lederman, D. Zeidler, & J. Lederman (Eds.), Handbook of Research on Science Education, (Vol. 3, pp. 1011-1044). Routledge. https://doi.org/10.4324/9780367855758

Gobert, J.D., Sao Pedro, M.A., Li, H., & Lott, C. (2023b). Intelligent Tutoring systems: a history and an example of an ITS for science. In R.Tierney, F. Rizvi, K. Ercikan, & G. Smith, (Eds.), *International Encyclopaedia of Education* (Vol. 4, pp. 460-470), Elsevier.

Goel, A. K., & Polepeddi, L. (2018). Jill Watson: A virtual teaching assistant for online education. In *Learning engineering for online education* (pp. 120-143). Routledge.

Graesser, A. C., Li, H., & Forsyth, C. (2014). Learning by communicating in natural language with conversational agents. *Current Directions in Psychological Science*, *23*, 374-380

Guilherme, A. (2019). AI and education: the importance of teacher and student relations. *AI and Society*, *34*(1), 47–54. https://doi.org/10.1007/s00146-017-0693-8

Gunderson, J. P., & Gunderson, L. F. (2004). Intelligence ≠ Autonomy ≠ Capability. *Performance Metrics for Intelligent Systems, PERMIS*.

Guzman, A. L., & Lewis, S. C. (2020). Artificial intelligence and communication: A Human–Machine Communication research agenda. *New Media and Society*, *22*(1), 70–86.

Haristiani, N. (2019, November). Artificial Intelligence (AI) chatbot as language learning medium: An inquiry. In *Journal of Physics: Conference Series* (Vol. 1387, No. 1, p. 012020). IOP Publishing.

Harris, J. (2005). Our agenda for technology integration: It's time to choose. *Contemporary Issues in Technology and Teacher Education*,*5*(2), 116–122.

Hashimoto, T., Kato, N., & Kobayashi, H. (2011). Development of educational system with the android robot SAYA and evaluation. *International Journal of Advanced Robotic Systems*, *8*(3), 28.

Heylen, D., Vissers, M., Op Den Akker, R., & Nijholt, A. (2004). *Affective Feedback in a Tutoring System for Procedural Tasks*.

Holstein, K., McLaren, B. M., & Aleven, V. (2019). Co-designing a real-time classroom orchestration tool to support teacher–AI complementarity. *Journal of Learning Analytics, 6*(2), 27–52.

Howard, S. K., Chan, A., Mozejko, A., & Caputi, P. (2015). Technology practices: Confirmatory factor analysis and exploration of teachers' technology integration in subject areas. *Computers & Education,90*, 24–35.

Howard, C., Jordan, P., di Eugenio, B., & Katz, S. (2017). Shifting the Load: a Peer Dialogue Agent that Encourages its Human Collaborator to Contribute More to Problem Solving. *International Journal of Artificial Intelligence in Education*, *27*(1), 101–129.

Huang, S.-L., & Shiu, J.-H. (2012). A user-centric adaptive learning system for e-learning 2.0. *Journal of Educational Technology & Society, 15*(3), 214–225.

Hung, J. L., Wang, M. C., Wang, S., Abdelrasoul, M., Li, Y., & He, W. (2017). Identifying at-risk students for early interventions - A time-series clustering approach. *IEEE Transactions on Emerging Topics in Computing*, *5*(1), 45–55.

Hussain, M., Zhu, W., Zhang, W., & Abidi, S. M. R. (2018). Student engagement predictions in an e-Learning system and their impact on student course assessment scores. *Computational Intelligence and Neuroscience*, *2018*, 6,347,186.

Hwang, G.-J., Xie, H., Wah, B. W., & Gašević, D. (2020). Vision, challenges, roles and research issues of Artificial Intelligence in Education. *Computers and Education: Artificial Intelligence*, *1*, 100001. https://doi.org/10.1016/j.caeai.2020.100001

Inan, F. A., & Lowther, D. L. (2010). Factors affecting technology integration in K-12 classrooms: A path model. *Edu technology research and development*, *58*, 137-154.

Indira, E. W. M., Hermanto, A., & Pramono, S. E. (2020, June). Improvement of teacher competence in the industrial revolution era 4.0. In *International conference on science and education and technology (ISET 2019)* (pp. 350-352). Atlantis Press.

Jayaprakash, S. M., Moody, E. W., Lauria, E. J. M., Regan, J. R., & Baron, J. D. (2014). Early alert of academically At-risk students: An open source analytics initiative. Journal of Learning Analytics, 1(1), 6–47.

Kang, J., Kang, C., Yoon, J., Ji, H., Li, T., Moon, H., ... & Han, J. (2023). Dancing on the inside: A qualitative study on online dance learning with teacher-AI cooperation. *Education and Information Technologies*, 1-31.

Kara, N., & Sevim, N. (2013). Adaptive Learning Systems: Beyond Teaching Machines. In *CONTEMPORARY EDUCATIONAL TECHNOLOGY* (Vol. 4, Issue 2).

Käser, T., Klingler, S., Schwing, A. G., & Gross, M. (2017). Dynamic bayesian networks for student modeling. *IEEE Transactions on Learning Technologies, 10*(4), 450–462.

Kent, D. (2022). Artificial Intelligence in Education: Fundamentals for Educators. KOTESOL DCC.

Khosravi, H., Shum, S. B., Chen, G., Conati, C., Tsai, Y. S., Kay, J., ... & Gašević, D. (2022). Explainable artificial intelligence in education. *Computers and Education: Artificial Intelligence*, *3*, 100074.

Kim, J., Merrill, K., Xu, K., & Sellnow, D. D. (2020). My teacher is a machine: Understanding students' perceptions of AI teaching assistants in online education. *International Journal of Human–Computer Interaction*, *36*(20), 1902-1911.

Lindner, A., & Romeike, R. (2019). Teachers' Perspectives on Artificial Intelligence.

Liu, M., Li, Y., Xu, W., & Liu, L. (2017). Automated essay feedback generation and its impact on revision. *IEEE Transactions on Learning Technologies*, *10*(4), 502–513.

Lundie, D. (2016). Authority, Autonomy and Automation: The Irreducibility of Pedagogy to Information Transactions. *Studies in Philosophy and Education*, *35*(3), 279–291.

Manyika, J., Chui, M., Miremadi, M., Bughin, J., George, K., Willmott, P., & Dewhurst, M. (2017). A future that works: AI, automation, employment, and productivity. *McKinsey Global Institute Research, Tech. Rep*, *60*, 1-135.

Matthews, K., Janicki, T., He, L., & Patterson, L. (2012). Implementation of an Automated Grading System with an Adaptive Learning Component to Affect Student Feedback and Response Time.

Mayring, P. (2014). Qualitative Content Analysis Theoretical Foundation, Basic Procedures and Software Solution. www.beltz.de

Mehmood, A., On, B. W., Lee, I., & Choi, G. S. (2017). Prognosis essay scoring and article relevancy using multi-text features and machine learning. *Symmetry*, *9*(1).

McKnight, K., O'Malley, K., Ruzic, R., Horsley, M. K., Franey, J. J., & Bassett, K. (2016). Teaching in a digital age: How educators use technology to improve student learning. *Journal of Research on Technology in Education,48*(3), 194–211.

Miller, W. L., Baker, R., Labrum, M., Petsche, K., Liu, Y-H., Wagner, A. (2015). Automated detection of proactive remediation by teachers in reasoning mind classrooms. Proceedings of the 5th International Learning Analytics and Knowledge Conference, 290–294.

Moharreri, K., Ha, M., & Nehm, R. H. (2014). EvoGrader: An online formative assessment tool for automatically evaluating written evolutionary explanations. *Evolution: Education and Outreach*, *7*(1). https://doi.org/10.1186/s12052-014-0015-2

Moreno-Marcos, P. M., Muñoz-Merino, P. J., Maldonado- Mahauad, J., Pérez-Sanagustín, M., Alario-Hoyos, C., & Delgado Kloos, C. (2020). Temporal analysis for dropout prediction using self-regulated learning strategies in self- paced MOOCs. *Computers & Education, 145*, 103,728.

Mubin, O., Stevens, C. J., Shahid, S., Mahmud, A. A., & Dong, J.J. (2013). A review of the applicability of robots in education. Technology for Education and Learning, 1(1). Resource document.

Morita, T., Akashiba, S., Nishimoto, C., Takahashi, N., Kukihara, R., Kuwayama, M., & Yamaguchi, T. (2018). A practical teacher–robot collaboration lesson application based on PRINTEPS. The Review of Socionetwork Strategies, 12(1), 97–126.

Nehm, R. H., Ha, M., & Mayfield, E. (2012). Transforming Biology Assessment with Machine Learning: Automated Scoring of Written Evolutionary Explanations. *Journal of Science Education and Technology, 21*(1), 183–196. https://doi.org/10.1007/s10956-011-9300-9

Nehm, R. H., & Haertig, H. (2012). Human vs. computer diagnosis of students' natural selection knowledge: Testing the efficacy of text analytic software. *Journal of Science Education and Technology, 21*(1), 56–73.

Ng, D. T. K., Leung, J. K. L., Su, J., Ng, R. C. W., & Chu, S. K. W. (2023). Teachers' AI digital competencies and twenty-first century skills in the post-pandemic world. *Educational technology research and development*, 1-25.

Okojie, M. C., Olinzock, A. A., & Okojie-Boulder, T. C. (2006). The pedagogy of technology integration. *Journal of technology studies*, *32*(2), 66-71.

Onwuegbuzie, A. J., & Frels, R. (2016). Seven steps to a comprehensive literature review: A multimodal and cultural approach.

Ouyang, F., & Jiao, P. (2021). Artificial intelligence in education: The three paradigms. *Computers and Education: Artificial Intelligence*, *2*, 100020.

Paiva, R., & Bittencourt, I. I. (2020). Helping teachers help their students: A human-ai hybrid approach. In *International conference on artificial intelligence in education* (pp. 448-459). Springer, Cham.

Qin, F., Li, K., & Yan, J. (2020). Understanding user trust in artificial intelligence-based educational systems: Evidence from China. *British JouR of Edu Tech, 51*(5), 1693–1710.

Reeves, J. (2016). Automatic for the people: the automation of communicative labor. *Communication and Critical/ Cultural Studies*, *13*(2), 150–165.

Roll, I., & Wylie, R. (2016). Evolution and revolution in artificial intelligence in education. International Journal of Artificial Intelligence in Education, 26(2), 582–599. https://doi.org/10.1007/s40593-016-0110-3.

Ros, R., Oleari, E., Pozzi, C., Sacchitelli, F., Baranzini, D., Bagherzadhalimi, A., Sanna, A., & Demiris, Y. (2016). A Motivational Approach to Support Healthy Habits in Long-term Child–Robot Interaction. *International Journal of Social Robotics*, *8*(5), 599–617.

Serholt, S., Barendregt, W., Vasalou, A., Alves-Oliveira, P., Jones, A., Petisca, S., & Paiva, A. (2017). The case of classroom robots: teachers' deliberations on the ethical tensions. *AI and Society*, *32*(4), 613–631. https://doi.org/10.1007/s00146-016-0667-2

Sharkey, A. J. C. (2016). Should we welcome robot teachers? Ethics and Information Technology, 18(4), 283– 297. https://doi.org/10.1007/s10676-016-9387-z.

Shin, J., Chen, F., Lu, C., & Bulut, O. (2022). Analyzing students' performance in computerized formative assessments to optimize teachers' test administration decisions using deep learning frameworks. *Journal of Computers in Education*, *9*(1), 71-91.

Siler, S. A., & VanLehn, K. (2003). Accuracy of tutors' assessments of their students by tutoring context. In Proceedings of the 25th annual conference of the cognitive science society. Mahwah, NJ: Erlbaum.

Spector, J. M., & Ma, S. (2019). Inquiry and critical thinking skills for the next generation: from AI back to human intelligence. *Smart Learning Environments*, *6*(1), 1-11.

Tegmark, M. (2017). Life 3.0: being human in the age of artificial intelligence. New York: Knopf.

van Ewijk, G., Smakman, M., & Konijn, E. A. (2020). Teachers' perspectives on social robots in education: An exploratory case study. *Proceedings of the Interaction Design and Children Conference*, *IDC 2020*, 273–280. https://doi.org/10.1145/3392063.3394397

Van Leeuwen, A., Janssen, J., Erkens, G., & Brekelmans, M. (2014). Supporting teachers in guiding collaborating students: effects of learning analytics in CSCL. Computers & Education, 79, 28–39.

Van Leeuwen, A., Janssen, J., Erkens, G., & Brekelmans, M. (2015). Teacher regulation of cognitive activities during student collaboration: effects of learning analytics. Computers & Education, 90, 80–94.

Wenger, E. (1987). Artificial Intelligence and Tutoring Systems. Los Altos, CA: Morgan Kauffman.

Westlund, J. K., Lee, J. J., Plummer, L., et al. (2016). Tega: A social robot. *The Eleventh ACE/IEEE International Conference on Human Robot Interaction*, *2016*, 561–561.

Williamson, B. (2016). Boundary brokers: Mobile policy networks, database pedagogies, and algorithmic governance in education. *Research, boundaries, and policy in networked learning*, 41-57.

Woo, J. H., & Choi, H. (2021). Systematic review for AI-based language learning tools. *arXiv preprint arXiv:2111.04455*.

Xu, W., & Ouyang, F. (2021). A systematic review of AI role in the educational system based on a proposed conceptual framework. *Education and Information Technologies*.

Yağci, A., & Çevik, M. (2017). Prediction of academic achievements of vocational and technical high school (VTS) students in science courses through artificial neural networks. *Education and Information Technologies*, *24*, 2741–2761.

Yu, Y. C. (2017). Teaching with a dual-channel classroom feedback system in the digital classroom environment. *IEEE Transactions on Learn- ing Technologies*, *10*(3), 391–402.

Yun, S.-S., Kim, M., & Choi, M.-T. (2013). Easy interface and control of tele-education robots. International Journal of Social Robotics, 5(3), 335–343.

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education – where are the educators? In *International Journal of Educational Technology in Higher Education* (Vol. 16, Issue 1). Springer Netherlands. https://doi.org/10.1186/s41239-019-0171-0

Zhai, X. (2021). Practices and theories: How can machine learning assist in innovative assessment practices in science education. *Journal of Sci Edu and Tech*, *30*(2), 139-149.

Zhai, X., Haudek, Kevin. C., Shi, L., Nehm, R., & Urban-Lurain, M. (2020a). From substitution to redefinition: A framework of machine learning-based science assessment. *Journal of Research in Science Teaching*, *57*(9), 1430–1459. https://doi.org/10.1002/tea.21658

Zhai, X., & Jackson, D. F. (2021). A pedagogical framework for mobile learning in science education. *International encyclopedia of education*.

Zhai, X., Yin, Y., Pellegrino, J. W., Haudek, K. C., & Shi, L. (2020b). Applying machine learning in science assessment: a systematic review. In *Studies in Science Education* (Vol. 56, Issue 1, pp. 111–151). Routledge.

Zhai, X., Shi, L., & Nehm, R. H. (2021). A meta-analysis of machine learning-based science assessments: Factors impacting machine-human score agreements. *Journal of Science Education and Technology*, *30*, 361-379.

CHAPTER 3

DEVELOPING A CONCEPTUAL FRAMEWORK FOR THE TEACHER-AI PEDAGOGICAL PARTNERSHIP: EXPLORING THE EMERGENCE OF AI AGENCY IN TEACHING[2]

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Abstract

Integrating advanced artificial intelligence (AI) technology into instructional practices has the potential to revolutionize teachers' pedagogy. However, this integration also brings about changes and raises concerns regarding the teacher and AI relationships due to AI's human-like cognitive capabilities. Drawing upon theories of actor-network theory, social presence, and distributed cognition, we present an integrated conceptual framework consisting of (a) a three-dimensional Teacher-AI Pedagogical Partnership (TAIPP) model and (b) the corresponding impacts of the Partnership on teachers. The three dimensions of the TAIPP model are (1) two social agents (i.e., teacher, artificial social agent), (2) independence and interdependence, and (3) partnering agency. We proposed four aspects to understand the impacts of the TAIPP on teachers, including (1) changes in teachers' pedagogical approaches, (2) teachers' cognitive affordances, (3) teacher emotion toward AI integration, and (4) emerged changes in classroom interactions. By addressing the social and cognitive aspects of AI and its evolving relationship with teachers, this framework contributes to the ongoing discourse on the role of AI in education. This paper concludes by suggesting potential implications for teachers' mindset shifts, effective design of AI-integrated collaborative instruction, and the future research focus correspondingly.

Keywords: Artificial intelligence, Actor-network theory, social presence, distributed cognition, teacher-AI relationship

Introduction

Over the past decade, one of the most profound areas of educational technology progress has been the development of artificial intelligence (AI) and its increased integration and momentum in teachers' instructional practices. AI is used to label computer programs or systems that perform various tasks, such as learning, thinking, problem-solving, and managing complexity (Russell, 2010; Spector & Ma, 2019), usually demanding human cognition or huge computation. When incorporated into instructional practices, AI has demonstrated the significant potential to participate in pedagogical decision-making processes and influence teachers' behaviors and practices. Numerous studies have reported on the allocation of instructional tasks to advanced AI systems, such as intelligent tutoring systems, educational social robots, and virtual pedagogical agents (e.g., Fang et al., 2020; Geol et al., 2018; Gobert et al., 2015; Gobert et al., 2023) in facilitating student learning, where AI systems act as tutors or teaching assistants, supporting teachers in their instructional endeavors. Moreover, AI has the capacity to monitor student progress in real-time, providing personalized learning experiences that are otherwise challenging to achieve in traditional classroom settings. By analyzing students' behavioral, cognitive, and emotional information (du Boulay, 2019; Kara & Sevim, 2013; Koedinger et al., 2006; Walkington, 2013), AI offers teachers actionable insights into students' learning progress, enabling personalized and targeted scaffolding (Adair et al., 2020; Gobert et al., 2016, 2018, 2023). Additionally, AI-enabled automatic assessment systems can automatically score students' constructed responses and provide personalized feedback (Buttussi & Chittaro, 2020; Fridin, 2014; Gerard et al., 2019; Gobert et al., 2013, 2015; Zhai et al., 2020a), allowing teachers to engage in innovative assessment practices (Zhai, 2021) that incorporate performance-based assessment and authentic tasks. This immediate feedback enables teachers to intervene promptly and tailor their instructional approaches (Ghali, Ouellet, & Zollman, 2016; Haudek et al., 2012; Zhai et al., 2020a). Furthermore, many AI systems provide real-time alerts on students' challenges and engagement, assisting teachers in keeping students on track (Arnold & Pistilli, 2012; Gobert et al., 2015) and recommending effective strategies to scaffold students learning (Adair, Dickler, & Gobert, 2020; Arnold et al., 2012; Gobert et al., 2023).

These diverse pedagogical potentials of AI in supporting and facilitating teachers' instructional activities represent a departure from traditional technologies. Given its ability to assume responsibilities similar to those of teachers in the classroom, AI is referred to as a radical and disruptive innovation (Bughin et al., 2018). This contrasts with the earlier conceptualization of technologies as tools or mediators (Jonassen, 1994; Jonassen et al., 1999; Taylor, 1980), lacking autonomy, decision-making capabilities, and personalization. The implementation of AI in pedagogy challenges this conceptualization as intelligent machines step into formerly human roles. Consequently, the rapid evolution of AI technology results in teachers' fear regarding the blurring of boundaries between their roles and those of AI (Serholt et al., 2017) and even leads to criticism of AI for disrupting their expertise-based roles (Zhai et al., 2021). Consequently, research on human-machine communication has shifted to designate AI as a communicator role rather than a communication channel (Guzman & Lewis, 2020), allowing AI to interact and communicate with teachers in a human-like manner (Nourbakhsh, 2013) through language (i.e., speech, written text), behaviors (e.g., facial expression, head and body movement), and other non-verbal cues (Breazeal, Dautenhahn, & Kanda, 2016; Epley et al., 2007; Van Pinxteren et al., 2019). Our discussion indicates that AI increasingly assumes agency and plays critical roles in impacting teachers' pedagogical practices.

An essential element of social interaction and communication among individuals is relationship building, whereby specific behaviors and social cues are employed to develop collegial relationships that facilitate the achievement of desired objectives for establishing collaboration and interdependence (Argyle, 1990). In the past, research on human-computer interaction focused on the mediator role of technology in fostering human-human relationship building. However, recent advancement in AI technology has spurred scholars to explore the interaction and relationship between human and AI beyond the traditional human-computer interaction paradigm. Consequently, various labels, such as teaming (e.g., Brandt et al., 2018; Brill et al., 2018; Cummings & Clare, 2015; O'Neill et al., 2020), symbiosis (e.g., Jarrahi, 2018; Nagao, 2019), and collaboration (e.g., Ciechanowski et al., 2019; Seo et al., 2018) have been employed to define the relationship between humans and AI technology in various work settings. In line with the emerging research interest and focus on the human-AI relationship in the literature, we are particularly concerned with the teacher-AI relationship, which may share similarities with and exhibit unique characteristics compared to the human-AI relationship in other organizational contexts due to the distinct nature of education. Moreover, understanding the teacher-AI relationship extends beyond semantic considerations (Lewis, Guzman, & Schmidt, 2019) and necessitates theoretical construction and investigation.

Prior research has made meaningful efforts to explore the potential ways in which teachers can collaborate with AI to comprehend their relationship (Popenici & Kerr, 2017; Roll & Wylie, 2016; Zawacki-Richter et al., 2019). However, few studies have developed an integrated and comprehensive framework to conceptualize and outline their potential relationship. Addressing this research gap, we argue that a theoretically based conceptual framework for the teacher-AI relationship can transform the conceptualization and practice of teacher pedagogy in AI classrooms, teacher education, and teacher professional development. This paper is structured as follows. In Section 2, we provide an overview of the key features of integrating AI into teachers' pedagogical practices and discuss the emerging issues associated with this integration. In Section 3, we examine the emerging forms of human-machine relationships in various work settings, including educational contexts, with a theoretical background presented in Section 4, where we argue for AI as an emerging artificial social agent. Section 5 outlines an integrated framework comprising two related components: a three-dimensional teacher-AI pedagogical partnership model and the impact of this relationship on teachers. We conclude by discussing the implications of the proposed conceptual framework and its limitations. In this paper, we address the following research questions: (a) What are the characteristics that describe the teacher-AI relationship in classrooms? (b) How has the emerging teacher-AI relationship impacted teachers?

Artificial Intelligence in Teaching

Integrating artificial intelligence into teachers' pedagogical practice

Advancements in AI technology have promoted the growing prevalent of AI integration across diverse grade bands and subject domains within the realm of education, aiming to transform and innovate teaching practices. This paper investigates the distinctive characteristics of AI and assesses its potential role and impact in the development of teacher-AI relationships. To achieve this objective, we conduct an analysis of the most extensively studied AI technologies in education, aiming to comprehend the potential of AI in facilitating various pedagogical practices for teachers.

Intelligent tutoring and adaptive learning systems act as teaching assistants or virtual tutors, providing personalized learning resources and experiences by adapting to individual needs (Jamsandekar et al., 2020; Lu et al., 2021; Bagheri, 2015; Wang et al., 2020a). These systems assist teachers by delivering personalized instruction and feedback to specific students, reducing teachers' workloads and cognitive demands while enhancing teaching efficiency (Dickler, 2019; Dickler, Gobert, & Sao Pedro, 2021; Gobert et al., 2013, 2023; Moussavi et al., 2016). Moreover, these systems enable teachers to monitor students' cognitive performance (Gobert et al., 2014) and emotional states (Buttussi & Chittaro, 2020; Zeng et al., 2018) in real-time, facilitating instructional adjustments.

Automated assessment systems employ advanced machine learning (ML) approaches, such as natural language processing, automated speech and facial recognition, and computer vision, to recognize and automatically score students' constructed responses (Ahn & Lee, 2016). This encourages teachers to use authentic and performance-based assessments (Spikol et al., 2018) to assess students' performances and competencies across various activities, such as scientific inquiry (Beggrow et al., 2014; Zhai et al., 2020a), reading level and language proficiency (Petersen & Ostendorf, 2009; Settles et al., 2020), and classroom engagement (Goldberg et al., 2021). To perform authentic and performance-based assessments, teachers can encourage students to present their thinking and reasoning utilizing various representations, such as essays (Mehmood et al., 2017), constructed responses (Nehm et al., 2012), drawings (Matayoshi & Cosyn, 2018; Zhai et al., 2020a), simulations (Käser et al., 2017), and games

(Karen et al., 2021). Automated assessment systems offer teachers prompt scoring results and personalized feedback (Jamsandekar et al., 2020; Kara & Sevim, 2013), enabling teachers to make data-informed instructional decisions and take appropriate actions. Thus, these systems are ambitiously positioned in teachers' assessment practices to not only substitute teachers in scoring but also promise teachers innovative assessment practices through performance-based tasks and multimodal representations (Zhai, 2021).

AI-enabled dashboards allow teachers to track student learning progress, identify challenges (e.g., Gobert et al., 2014), and monitor cognitive and emotional engagements (e.g., Zeng et al., 2018). These dashboards present dynamic visualizations, such as text and graphs, enabling teachers to elicit AI insights promptly. One example of a teacher dashboard is Inq-Blotter, embedded in the inquiry intelligent tutoring system (Inq-ITS, Dickler, 2019; Gobert et al., 2013, 2023; Moussavi et al., 2016), which features teacher reports, real-time teacher alerts, and teacher inquiry practice supports (TIPS). The teacher report summary provides classroom-wide and individual performance information on students' competencies at scientific inquiry practices, while real-time teacher alerts identify how students are struggling at distinct stages of scientific inquiry practices, allowing teachers to provide targeted scaffolding, the TIPS provides teachers specific types of pedagogical support for them to incorporate in scaffolding students.

Sophisticated educational social robots have been developed as physical teaching assistants or tutors to enhance and supplement teachers' pedagogical practices (Pai et al., 2021; Yun et al., 2013). These robots engage in conversation-based interactions and exhibit human-like behaviors (Fridin, 2014; Pai et al., 2021) to interact with students and teachers across various domains, such as language (Fridin, 2014), science (Hashimoto et al., 2011), mathematics (Pai et al., 2021), and social studies (Buttussi & Chittaro, 2020; Yun et al., 2013). In addition, educational social robots can tailor their actions to match student's learning styles, personalities, and emotional states, thus facilitating personalized instruction and augmenting teachers' pedagogical practices (Westlund et al., 2016). Educational social robots have been proposed as a solution to teacher shortages due to their pedagogical functionalities and social behaviors (Edwards & Cheok, 2018; Morita et al., 2018; Mubin et al., 2013; Serholt et al., 2017).

Educational chatbots, as virtual or conversational agents, support and substitute interaction and communication between teachers and students in dynamic educational contexts. Chatbots engage in dialogue through text or speech (Luo et al., 2019), answering students' questions, grading assignments, and engaging in personal communications (Gerard et al., 2019; Goel et al., 2018). They can also provide teachers with notifications about students' learning progress (Chocarro et al., 2021). By employing chatbots, teachers can promote student engagement, performance, and motivation (Huang et al., 2022). Jill Watson (Goel et al., 2018), a highly developed virtual AI chatbot for online courses, assists teachers in communicating with students, responding to inquiries, grading assignments, and providing prompt feedback. This allows teachers to allocate more attention and effort to other critical instructional activities.

The exploration of AI technology in teaching highlights its potential to revolutionize traditional educational practices. AI-powered tools and platforms can support teachers in designing personalized instruction, monitoring student progress, promoting engagement and motivation, and providing timely feedback. AI also facilitates effective communication with students based on their cognitive and emotional needs. Furthermore, AI can analyze substantial amounts of data generated by student activities and behavior, offering valuable insights into their learning preferences, strengths, and weaknesses. Given the various potential applications of AI in teaching, teachers are encouraged to incorporate different AI systems into their pedagogy and appropriately allocate their responsibilities.

The emerging issues of AI integration in teachers' pedagogical practices

Intelligent machines, owing to their proficiency in performing diverse cognitive tasks akin to human capabilities and their immense computational capacity (Russell, 2010), possess the potential to supplant numerous routine and pivotal cognitive tasks traditionally undertaken by teachers during instructional activities and decision-making processes. As a result, a notable concern has arisen regarding the potential for AI to replace teachers, thereby raising apprehensions among educators and other stakeholders regarding the potential loss of their competencies, opportunities, and responsibilities (Serholt et al., 2014) linked to the facilitation of personalized learning experiences for their students.

Several studies have explored the concept and feasibility of utilizing robot teachers as a substitute for human teachers, particularly considering the current teacher shortage (e.g., Edwards & Cheok, 2018; Sharkey, 2016). Sharkey (2016) advocated for the use of social robot teachers, as they can provide a unique educational experience that might not otherwise be available. Similarly, Ahmad et al. (2016) reported that most participating teachers perceived educational social robots as having significant potential in engaging students cognitively, emotionally, and socially, surpassing human teachers. Edwards & Cheok (2018) proposed a project to develop an independent robot teacher, contending that fully functional robot teachers will play a crucial role in future classrooms, surpassing human teachers in terms of domain knowledge and cost-effectiveness.

Many researchers have found that students expressed a preference for AI teachers over human teachers due to the personalized and effective learning resources and experiences provided by AI. Moreover, AI presents the potential to promote students' long-term engagement, facilitate constructive learning, and improve communication. For instance, Ahmad et al. (2016) and Hung et al. (2017) found that students appreciated AI's individualized adaptation, while Ceha et al. (2021) emphasized the ability of AI to manage desired communication among different parties. Kim et al. (2020) reported that students perceived the AI teaching assistant as useful and easy to communicate with, which predicted their favorable attitudes toward learning with the AI teaching assistant over human teachers. Furthermore, in a subsequent study, Kim et al. (2021) found that students demonstrated a preference for AI-based education, expressing satisfaction with their relational machine teacher. The findings in these studies intensified the concerns about the potential of AI replacement over human teachers in the future.

The Classroom Relationships between Teachers and Intelligent Machines

To better address the issue of AI replacement in teaching raised and discussed by researchers, it is critical for us to understand how teachers interact and build relationships with AI in their pedagogical activities. We ask (1) to what extent the interaction between teachers and AI differs from their interaction with traditional technologies. And (2) is there a new form of relationship between teachers and AI and what are its features, if so?

An emerging form of human-machine relationship in the era of AI

Traditionally, technologies have been utilized to address specific problems, achieve predefined goals, or serve human-defined purposes to facilitate human-human interactions (Lee et al., 2015). Nonetheless, Schuetz and Venkatesh (2020) posited that the innovation in AI systems has given rise to a new form of human-system-environment interaction, challenging conventional assumptions regarding human-system interactions.

In the field of traditional human-machine interaction (HMI) research, computers have often been treated as a social actor, resulting in the application of social norms and expectations guiding human-human interaction to HMI (Nass et al., 1994; Nass & Moon, 2000). Computers can exhibit certain behaviors that align with users' social expectations, thereby appearing socially adoptive (Schmandt, 1990). However, traditional HMI research has primarily focused on computers serving as assistive tools or active mediators that facilitate human-human communication and relationship development (Ågerfalk, 2020; Fussel et al., 2000; Reeves & Nass, 1996), rather than being independent agents capable of forming relationships with humans.

The evolution of intelligent machines has transformed the attribute of technology from a functional tool or mediator to an active social actor, possessing capabilities such as human-machine dialogue, action, and emotional interaction (Guan et al., 2021). The emergence of intelligent machines as social actors has brought about significant ontological and pragmatic shifts in human-machine interactions (Bian et al., 2020; Wang & Cheng, 2019). Humans seek to establish relationships with intelligent machines, viewing them as relational agents -- the computational artifacts capable of engaging in social-emotional relationships with humans (Bickmore & Picard, 2005).

To explore and conceptualize the emerging form of human-machine relationship involving AI technology, various research agendas have been proposed and conducted across various fields in recent years. Appendix A provides a summary of primary empirical studies investigating the relationship between humans and different AI systems, organized chronologically. It is worth noting that researchers have employed diverse labels to describe their work, such as human-AI teaming (e.g., Brill et al., 2018), human-autonomy teaming (e.g., Brandt et al., 2018; Cummings & Clare, 2015; O'Neill et al., 2020), human-AI symbiosis (e.g., Jarrahi, 2018; Nagao, 2019), and human-robot collaboration (e.g., Ciechanowski et al., 2019; Seo et al., 2018), among others. Within these proposed relationships, AI assumes a dual role of "an assistive tool plus a collaborative teammate" (Xu et al., 2023, p. 496), transitioning from a tool primarily supporting human actions and operations to a potential collaborator and team member (Brill et al., 2018; O'Neill et al., 2020). These diverse labels investigate the interaction between humans and machine agents (e.g., autonomous systems, AI agents, intelligent agents, and social robots) within AI systems (Xu et al., 2023). O'Neill et al. (2020) characterized the emerging human-machine relationship as marked by a high degree of agency and interdependence, encompassing three key aspects: (1) involvement of at least one human and one AI agent, (2) interdependent work from each agent toward a shared goal, and (3) a certain degree of agency exhibited by the agent.

The human-AI relationship is a multi-faceted research area. The empirical findings presented in the Appendix A indicated that this emerging research focus is primarily situated in organizational context, workforce area, and individual's daily life. Several distinct research areas emerged. For some, this involves the intelligent machine's ability to engage with humans using human-like means of representation, such as facial expression, voice, and affect, in order to accompany, encourage, and plan alongside human collaborator and partner (Bickmore & Picard, 2005; Salem et al., 2011). Other studies examined the process and stages of human-AI relationship development (Seo et al., 2018; Skjuve et al., 2021), exploring factors that contribute to relationship development, such as human personality (e.g., user perception and acceptance of AI collaborator) and machine characteristics (Ciechanowski et al., 2019; Van Pinxteren et al., 2019). For others, the impact of the human-AI relationship was researched, such as ethical issue and trust (Ciechanowski et al., 2019; Van Pinxteren et al., 2019), AI system design outcomes (Fang et al., 2020), and human identity reconstruction (Strich et al., 2021). Notably, the review of emerging research on the human-AI relationship highlights a scarcity of studies in educational contexts, especially the relationship between teachers and AI.

The exploration of the relationship between teachers and AI

The integration of AI into educational contexts has given rise to new dynamics in classroom interactions, including the relationships between teachers and students, as well as teachers and technology (Guilherme, 2019). Suchman and Suchman (2007) argued that the insertion of intelligent machines into what was once a teacher-student relationship environment raised queries about so-called “human-machine configurations.” Drawing on Guilherme’s (2019) assertions concerning the relationship between teachers and students in AI-integrated classrooms, we depicted two distinct relationships, as illustrated in Figure 3.1. In addition to the conventional human-human relationship between teachers and students, a new relationship has emerged: the human-AI relationship, encompassing the teacher-AI relationship, student-AI relationship, and the triadic interplays among teachers, students, and AI. The classroom relationship has become complex and dynamic with the inclusion and interaction of AI as a new actor.

This paper specifically investigates the teacher-AI relationship in AI-integrated educational contexts. Given the significant pedagogical roles played by AI, teachers’ responsibilities and roles undergo significant changes, as discussed in Section 2. For instance, Fang et al. (2020) argued that the integration of AI robot assistants in classrooms has created a new teaching mode characterized by a collaborative relationship between humans and robots, wherein both the AI robot assistant and teachers jointly undertook classroom responsibilities. However, an emerging question is correspondingly raised regarding the distribution of labor between the two entities and the elements that should shape their relationship. Liu et al. (2018) suggest that the introduction of intelligent machines in teaching interactions leads to distinct learning experiences for students, characterized by multidimensional human-machine interaction and cooperative work. Furthermore, the potential of AI poses challenges and threats to teachers, leading to growing concerns about the possibility of AI replacing teachers. Therefore, investigating the teacher-AI relationship has emerged as a crucial research question and area, as it will determine the successful development and transformation of the teacher-AI relationship to promote a new educational landscape. Already more than a decade ago, Zhao (2006) called for researchers to pay greater attention to the social implications of human-like technologies, such as AI. However, the literature lacks a theoretical understanding of the teacher-AI relationship with a well-constructed conceptual framework.

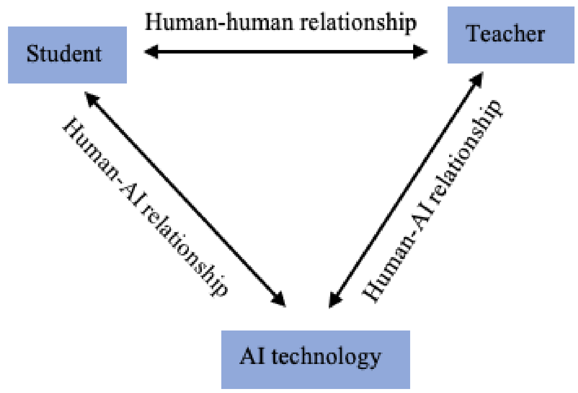

Figure 3.1. The types of relationship between teacher, student, and AI in AI-integrated classrooms, according to Guilherme (2019).

Theoretical Underpinnings

Working within the critical posthumanism inquiry (Hassan, 1977), which challenges the notion of human dominance over the socio-technical system, this paper adopts a perspective that acknowledges the agency of human subjects as products of discursive entanglements with non-human entities (Callon, 1984; Latour, 1987). This perspective aims to explore alternative ways to appraise the social presence of the AI agent and its agency in constituting a novel relationship with teachers in educational settings. Rather than perceiving AI development as a mere solution to address deficiencies or enhance productivity in teaching, this paper discusses how intelligent machines and human educators collaboratively operate within a teaching "assemblage" (Latour, 1987) that rejects hierarchical ontologies governing human-machine relationships.

An emerging artificial social agent and its agency

In the realm of social theory, agency has traditionally connoted a distinctive ability and attribute exclusively possessed by humans (Abdelnour, Hasselbladh, & Kallinikos, 2017; Neff & Nagy, 2018). Campbell (2005) stated human agency refers to "inventions, strategies, authorship, institutional power, identity, subjectivity, practices, and subject positions, and among others" (p. 1). The exclusive human agency in social theory has led to an anthropological, human-centered inquiry approach when investigating phenomena in social-technical systems (Dafoe, 2015), albeit sometimes mediated by and inscribed in physical objects (Latour, 1991). This human-centered approach in HMI research has the potential for bias as it tends to overemphasize humans' control over technologies.

From a posthumanism inquiry perspective, actor-network theory (ANT) (Callon, 1984; Latour, 1987) advocates for the equivalent treatment of humans and non-human objects when assessing the value of technological artifacts and their interactions with humans, challenging presumptions of human agency in science and technology research (Fenwick & Edwards, 2010). According to ANT, both humans and non-human objects are considered actors with equal agency, actively shaping, and transforming their entangled and symbiotic relationships (Faraj et al., 2018; Mclean & Hassard, 2004). In their interactions, humans "have delegated not only physical force but also values, duties, and ethics to non-human actors" (Latour, 1992, p. 232). Conversely, non-human actors "actively intervene to push actions in unexpected directions" (Callon & Law, 1997, p. 178). ANT offers a novel perspective for understanding the roles of heterogeneous actors, such as people, computers, software, and textual message, within complex and dynamic network relationships (Fenwick & Edwards, 2010; Seuwou et al., 2016).

Drawing on ANT, traditional HMI research has acknowledged technology as a non-human actor possessing a certain degree of agency. Empirical studies (Bickmore & Picard, 2005; Kim & Sundar, 2012; Reeves & Nass, 1996) have shown that humans perceive different digital technologies (e.g., social media, wearable devices, smartphones, humanoid robots) as exhibiting distinct social behaviors and agency when interacting with them. The computers are social actors model (Reeves & Nass, 1996) hypothesized that people tend to apply social scripts and rules that govern human-human interaction to human-computer interactions due to the social behaviors and agency exhibited by digital technologies. Accordingly, Ågerfalk (2020) introduced the concept of the digital agency to specifically describe machines' capability to exert agency in their interactions with humans. The notion of digital agency critically emphasizes the social action of machines by staying away from the traditional sense of agency with presupposed consciousness.

ANT and the notion of social action in a digital agency provides the theoretical foundations for us to delve into the discussion of the AI agent and its potential agency and social behavior in forming human-AI relationships. AI simulates, extends, and expands human intelligence through various abilities and behaviors, such as perception ability (e.g., visual perception, auditory perception, and tactile perception) and intelligent behaviors (e.g., learning, thinking, reasoning, and decision-making) (Guan et al., 2021) so it can think and act like people at some degree. For example, AI-enabled social robots and chatbots engage in interactions with humans using verbal, non-verbal, and affective means (Breazeal et al., 2016). Given the advancements in AI perception and cognition, AI systems are capable of interacting and communicating with humans in a manner that resembles human-human interaction (Nourbakhsh, 2013). As a result, AI has emerged as a new type of social agent, with which individuals can engage and interact socially and emotionally. We refer to this entity as an *artificial social agent* to articulate its distinctive agency and social behaviors that shape the HMI paradigm. In what follows, we elucidate the distinctive characteristics of the proposed *artificial social agent.*

AI autonomy

The agency and social behavior of the *artificial social agent* can be observed from a critical feature of AI: AI autonomy. AI autonomy specifically refers to the ability of an AI system to perform specific tasks independently (Xu et al., 2023). Autonomous AI systems possess certain levels of human-like cognitive and intelligent capabilities, including self-adaptation and self-execution. Moreover, they can effectively operate in situations requiring human-like sensing and cognitive abilities, yielding outcomes that are unpredictable and indeterminate (den Broek et al., 2017; Kaber, 2018). In order to develop a more comprehensive understanding of AI autonomy, Xu et al. (2023) have identified multiple dimensions of AI-based autonomous systems in the context of human-machine interaction, encompassing (1) human-like self-adaptive ability to unpredictable environments; (2) human-like self-executing ability; (3) human-like sensing ability; and (4) human-like cognitive ability (e.g., pattern recognition, learning, reasoning). Those characteristics of AI autonomy have been applied to various educational AI systems with the goal of self-adapting to students' learning progress, style, and personality by recognizing unpredictable learner behaviors and cognition, and independently making decisions. The non-deterministic and unexpected nature of the operation outcomes of AI autonomy arises from the diverse independent capabilities of AI systems.

AI automaticity

As an *artificial social agent,* AI presents its agency of automaticity to represent another type of social behavior in human-machine interaction: AI automaticity. AI automaticity can be defined as "the automatic execution of a function by a machine" (Parasuraman & Riley, 1997, p. 231) involving "actively selecting data, transforming information, controlling processes, and making decisions" (Lee & See, 2004, p. 50) that are previously performed by humans. Parasuraman et al. (2000) identified four areas where AI automaticity can manifest: information acquisition, information analysis, decision selection, and action implementation.

Applying Parasuraman et al.'s (2000) categories to AI-supported instructional activities, we can observe diverse types of AI automaticity that fulfill specific roles in teachers' pedagogical practices. For instance, in terms of automatic information acquisition, intelligent tutoring systems and adaptive learning systems can automatically gather multimodal data on students' cognitive, behavioral, and emotional states. Following, those AI systems automatically analyze the dynamic information using fine-tuned machine learning algorithmic models. Another example of automatic information analysis is that AI-enabled automated assessment systems can automatically grade diverse types of student responses in performance-based assessments, such as essays, constructed responses, simulations, and games (e.g., Käser et al., 2017; Mehmood et al., 2017; Nehm et al., 2012; Zhai et al., 2020a). Regarding automatic decision selection, advanced AI systems can automatically determine which information should be provided to teachers, such as personalized progress profiles for individual students and timely feedback. Lastly, AI can automatically implement its actions, such as generating reports on students' progress and challenges for teachers (Gobert et al., 2013, 2018), and recommending the most effective pedagogical strategies (Adair, Dickler, & Gobert, 2020; Arnold & Pistilli, 2012).

Anthropomorphic social behaviors

Humans have a tendency to "assign human-like characteristics, such as motivations, intentions, or emotions to non-human agents" -- a phenomenon known as anthropomorphism (Epley, Waytz, & Cacioppo, 2007, p. 864). When referring to AI technology, two contrasting perspectives have emerged. The first perspective emphasizes the possessing of human-like physical features by AI systems, such as facial expression, voice, and head and body movement (Epley et al., 2007; Van Pinxteren et al., 2019). Resembling human social functioning, such as mental states (e.g., thinking, reasoning, perceiving), non-verbal communication cues, and emotional responses (Ashrafian, 2015; Ceha et al., 2021; Rai et al., 2019) is another perspective. Both perspectives have contributed to an increased tendency to anthropomorphize advanced AI systems, as they promote the perception that AI exhibits social behaviors during interactions with humans. One specific area where this anthropomorphism view has influenced research is in the field of human-machine communication. It has evolved to conceptualize AI as a machine communicator that engages in communication with people through human-like physical and cognitive means (Guzman & Lewis, 2020; Lewis et al., 2019). This marks a departure from the traditional lens of technology as a mere communication channel between human communications.

The copresence of teachers and intelligent machines

Social presence theory (SPT) emerged as a framework to examine the influence of telecommunication media on human interaction (Short et al., 1976), specifically focusing on the extent to which a communicator is perceived as a ‘real person’ in technology-mediated communication contexts (Gunawardena, 1995). Social presence is defined as “the degree of salience of the other person or entity in the interaction and the consequent salience of the interactive relationships” (Short et al., 1976, p. 65). Since its inception, various conceptualizations of social presence have been proposed in the realm of interpersonal communication. For instance, social presence is conceptualized as psychological involvement, representing a deeply immersive connection with others (Biocca et al., 2003; Kelly & Westerman, 2016). While Kim et al. (2021) suggested understanding social presence as copresence, which relates primarily to the feeling of being physically present with another entity in the same location, despite actual physical separation. Grounding on the prior research, social presence encompasses a perception of coexistence with others, psychological or physical, and involves two critical principles: inter-party and interpersonal exchanges (Biocca & Harms, 2002; Biocca, Harms, & Burgoon, 2003; Van Doorn et al., 2017).

In the field of HMI research, researchers have frequently applied SPT and its two critical principles to various technologies, such as online games (Li et al., 2015), virtual learning systems (Hayashi et al., 2004), social media (Cheung et al., 2011; Xu et al., 2012), virtual reality (Schwarz et al., 2012), and chatbots (Ebadi & Amini, 2022), in order to investigate the impact of their social presence on interactions with humans. The literature suggests that individuals' evaluation and response to technology agents are influenced and predicted by their perceived social presence of the technology (Cheung et al., 2011; Pitardi & Marriott, 2021). For example, Pitardi and Marriott (2021) demonstrated that a voice assistant conveying a higher level of social presence could enhance users' trust and positive attitudes, thereby fostering stable and long-term relationships. Similarly, Ebadi and Amini (2022) found that the human likeness of chatbots and their high social presence positively impacted learners' motivation and attitudes. The social presence of various technologies offers a mediation channel for individuals to communicate and interact with others.

With the evolution of intelligent machines and their social presence in human-machine communication and interaction, researchers have posited that humans increasingly engage in "social or quasi-social relationships with the new form of artificially intelligent beings" (Biocca & Harms, 2002, p. 10) by applying the principles of social presence from human-human communication to human-AI communication. Consequently, extant research has strived to examine the presence of social presence by intelligent machines by "establishing and participating competently in dynamic behavioral and affective exchange with humans (Damiano et al., 2015, p. 1). Lee (2004) conceptualized the social presence of intelligent machines as "a psychological state in which machine social actors are experienced as actual human social actors in either physical or virtual ways" (p. 37).

SPT informed us that the physical and psychological copresence of the teacher and intelligent machines in classrooms can lead to a novel teacher-AI relationship, facilitated by AI systems' capability to elicit, to varying degrees, various social responses, such as verbal, gestural, and visual, to engage in inter-party and interpersonal exchanges with teachers.

The distributed intelligence between AI and humans

Distributed cognition (DCog) is a theoretical framework that originated from the work of Edwin Hutchins and colleagues (Hollan, Hutchins, & Kirsh, 2000; Hutchins, 1995). DCog encompasses a broader concept, examining the distribution of cognitive processes across individuals within a social group, as well as the interactions between individuals and the structures within a problem-solving system (Hollan et al., 2000). Hutchins (1995) argued that cognition and problem-solving should be viewed as a collaborative activity involving multiple agents, including both humans and technological entities. Consequently, DCog emphasizes collaborative teamwork, focusing on coordination and interdependency among individuals who employ artifacts collectively.

In the context of DCog, one can expect to find individuals or artifacts that can dynamically configure themselves to support their own activities or collaborative actions (Hollan et al., 2000; Perry, 2003). Problem-solving, in this perspective, is distributed across a network of individuals working together to reach a collective solution (Perry, 2003). Rogers (2006) explained that the DCog approach aims to elucidate the intricate interdependencies between group members and artifacts in their collaborative work activities, particularly the distributed problem-solving processes within the network. Thus, humans engage with and utilize environmental resources and tools, such as computer systems, both as individuals and in support of group behavior. As a result, DCog enables individuals to distribute their cognitive load across a group of people and artifacts, describing the dispersed nature of problem-solving within social space (Perry, 2003). Through the lens of DCog, researchers can articulate how group problem-solving, mediated by artifacts in the environment, can be understood within the cognitive paradigm (Perry, 2003). However, in DCog, technologies are employed to amplify cognition by providing a means to accomplish cognitive tasks that would be challenging or less effective without these tools. Hence, technological artifacts are considered scaffolds or cognitive aids.

We contend that DCog offers a theoretical perspective to comprehend how individuals allocate their cognitive load to both other individuals and artifacts in problem-solving. Therefore, it is valuable for understanding collaborative problem-solving in diverse contexts. However, the advancement of intelligent machines and their cognitive abilities has shifted the focus of HMI research from human interdependence and social organization to collaboration between humans and AI. AI systems exhibit “purposeful and intelligent behaviors to achieve their goals, and their knowledge and actions are learned through experience” (Russell, 2010, p. 2). The AI agents are purposeful and intelligent entities, designed differently from technologies that serve as mediators for group work among users. Thus, HMI research is urged to consider the cognitive properties of individuals and systems when incorporating AI into the problem-solving process. This necessitates the analysis of strategies and mechanisms to support interactions and the distribution of cognition between humans and AI. The DCog approach offers insights into examining the nature of human-AI communication and coordination in distributed cognitive problem-solving.

An Integrated Framework for Outlining the Teacher-AI Relationship

Drawing upon the theoretical underpinnings surrounding AI as an *artificial social agent,* encompassing agency and social behavior, social presence in human-AI interactions, and distributed cognition in collaborative problem-solving, we proposed an integrated framework to conceptualize the relationship between teachers and AI and its subsequent impacts on teachers.

The teacher-AI pedagogical partnership model

In order to explicate the nature of the teacher-AI relationship within AI-integrated educational settings, we proposed a three-dimensional model—the *Teacher-AI Pedagogical Partnership* (TAIPP) model (see Figure 3.2), which, ultimately, as will be described in the following sections, is focused on how the two social agents (i.e., teacher, AI) collaborate to achieve the common pedagogical goal in AI-integrated classrooms.

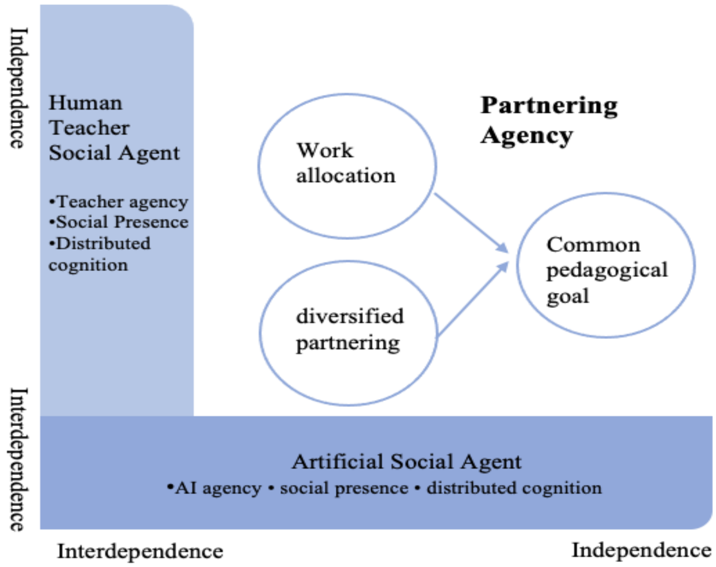

Figure 3.2. The proposed three-dimensional teacher-AI pedagogical partnership model.

Dimension one: two social agents in the teacher-AI relationship

Informed by actor-network theory (ANT) and social presence theory (SPT), we posited the equal treatment of the two crucial social agents, the teacher and AI, in the process of shaping and changing the entangled and dynamic teacher-AI relationship. This perspective acknowledges the reciprocal nature of interactions between the teacher and AI, which adhere to established social norms and rules observed in human-human interactions. Additionally, these interactions are sensitive to the physical, virtual, or psychological manifestations of social presence exhibited by both the teacher and AI.

In AI-integrated classrooms, effective teachers are expected to demonstrate agency (Priestley, 2015; Straub, 2016) by incorporating the social presence of AI into their pedagogical activities personally. They leverage the intelligence and cognitive support provided by AI to inform their decision-making and actions. Rather than perceiving AI as a mere tool or resource, teachers engage with AI as an intelligent social agent, with whom they interact, collaborate, and share responsibilities. As AI takes on certain roles and responsibilities traditionally held by teachers, teachers are no longer the sole authority, classroom manager, decision-maker, and facilitator of student learning.

AI has evolved to possess the ability to “learn” from its environments, reason and conceptualize, and engage in cognitive and emotional conversations with humans (Floridi & Sanders, 2004). In educational settings, AI is increasingly employed as an autonomous decision-maker or facilitator in teachers’ decision-making processes. To distinguish AI from conventional technologies and provide a comprehensive characterization from the ANT perspective, we defined AI as an *artificial social agent*. This designation is based on three distinctive characteristics of AI: autonomous, automaticity, and anthropomorphic social behaviors. As an artificial social agent, AI can exhibit human-like cognitive, emotional, and social behaviors and actions to interact with teachers in pursuit of pedagogical goals. This intelligent agent can facilitate and assume some of the pedagogical activities traditionally performed by teachers, such as instructional preparation, facilitating student learning and skill acquisition, monitoring and assessing student progress, and providing personalized feedback and support.

With the increasing social presence of AI as an artificial social agent in various pedagogical activities, it emerges as a new participant that expands the dynamics of classroom interaction. Whether physically or virtually present, the artificial social agent shares pedagogical responsibilities with the teacher, working towards common pedagogical goals and assuming the roles of a machine teacher or a teacher assistant to facilitate student learning. The shared responsibility and social presence of both the teacher and AI are fundamental features of the two social agents in the proposed TAIPP model.

Dimension two: the independence and interdependence between social agents

To comprehend distribution of pedagogical responsibilities between teachers and AI, we have developed a continuum that illustrates the division of labor (see Figure 3.3). This continuum portrays the extent of interaction between teachers and AI, positioning them horizontally. The left side of the continuum represents complete independence in terms of pedagogical responsibilities between teachers and AI. Leveraging advanced machine learning mechanisms, AI is capable of autonomously executing various pedagogical activities and making decisions. For instance, intelligent tutoring systems and virtual chatbots, powered by advanced AI, can independently track student progress, and engage in personalized communication to enhance the learning experience (Guilherme, 2019; Pelletier et al., 2021). AI-based automated assessment systems can autonomously provide personalized feedback utilizing automatic scoring (Zhai et al., 2020a, b). As AI assumes numerous core tasks traditionally performed by teachers, teachers can focus their attention on other essential aspects of teaching that require human intelligence and care (Holstein et al., 2019; Qin et al., 2020).

On the extreme right end of the continuum, we articulate a fully interdependent relationship between teachers and AI, where both entities rely on each other to achieve pedagogical goals. This level of interdependence involves a two-way dependency, wherein teachers depend on the data and information provided by AI to make informed decisions, and AI relies on teacher input to adapt to the classroom environment. It is important to acknowledge that achieving such a high degree of interdependence in real-world classroom settings is challenging due to factors such as teacher acceptance and trust in AI, as well as technological limitations.

Nonetheless, this scenario presents a possible and highly collaborative relationship between the two entities.

Between the two extremes of the continuum, teacher and AI negotiate the degree of independence and interdependence to accomplish pedagogical goals. While advanced educational AI technologies possess decision-making and action-taking capabilities, they are not fully autonomous and require teacher initiation, intervention, and supervision (Beer, Fisk, & Rogers, 2014; Bigman, Waytz, Alterovitz, & Gray, 2019). Machine-generated insights inform and support teachers in capturing classroom progress and challenges, enabling them to make data-driven instructional adjustments and provide timely personalized assistance. For example, teachers can use real-time alerts from AI systems to provide targeted scaffolding to students, promoting higher-level thinking (Gobert et al., 2013, 2018). The interdependent relationship between the teacher and AI can also be characterized as AI compensating for teachers' weaknesses while teachers address the limitations of AI in pedagogical activities. Teachers may depend on AI for analyzing large volumes of data and receiving real-time insights to inform their pedagogical practices. Conversely, AI may rely on teachers to foster students' social skills, creativity, empathy, and ethical awareness (Vega-Mendoza et al., 2021; Yoon, 2019). Hence, teachers and AI negotiate their pedagogical responsibilities by intertwining various levels of independence and interdependence.

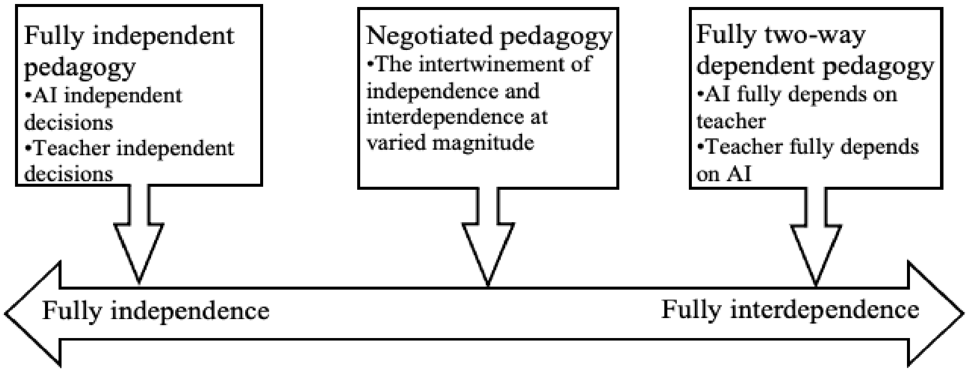

Figure 3.3. The independence and interdependence continuum in the teacher-AI relationship.

Dimension three: partnering agency between social agents

The third dimension of the TAIPP model highlights the collaborative nature of the teacher and AI social agents, who exercise varied forms and levels of agency to promote pedagogical effectiveness. We introduce the concept of 'partnering agency' to capture the cooperative and collaborative efforts of these social agents towards a shared pedagogical goal, with the teacher as the ultimate decision maker (Xu et al., 2023). Partnering agency encompasses the distribution of cognitive tasks between the teacher and AI, enabling collaborative problem-solving. Within this paradigm, the teacher and AI engage in three key aspects of partnering agency: (1) work allocation, (2) diversified partnering, and (3) the shared pedagogical goal.

Work allocation involves the appropriate distribution of cognitive tasks between the teacher and AI to accomplish instructional objectives collaboratively. Unlike in other fields where AI-enabled automated systems may completely replace human roles and decision-making (Lewis et al., 2019; Strich et al., 2021), education necessitates a more nuanced approach. In this context, the teacher and AI are expected to allocate their respective cognitive abilities to activate intelligence in pedagogical activities. For example, Bayne (2015) developed a virtual "teacher bot" that combined automated teacher presence and human teacher input to provide co-teaching within a MOOC environment.

The partnering modes between the teacher and AI can be classified into three types described in the literature. The first mode entails independent roles and responsibilities, where AI guides student learning and offers support independently, such as in the integration of intelligent tutoring systems in classrooms (D'Mello & Graesser, 2012; Lee & Choi, 2018). Meanwhile, the teacher delegates these responsibilities to AI and focuses on other tasks, such as adjusted scaffolding and classroom management. In the second mode, the teacher relies on AI to make instructional decisions. For instance, teachers utilize real-time information provided by AI-enabled teacher dashboards to identify student problems and provide immediate personalized assistance (Gobert et al., 2013, 2014; Yoo & Kim, 2014). Without insights from AI, teachers would be unable to deliver timely and personalized instruction themselves. The third mode involves collaborative problem-solving, where the teacher and AI assume distinct roles at different stages of the pedagogical process. For instance, the automated assessment system provides personalized feedback to students for revising their responses. However, low-performing students may require additional guidance and feedback from teachers to modify their original answers (Gerard et al., 2019; Lee et al., 2019). Moreover, when students struggle to follow machine tips and clues during scientific investigations, the teacher intervenes to provide guidance and keep them engaged (Gobert et al., 2015).

The ultimate objective of a partnering agency is to promote effective pedagogy, desired learning experiences, and achievement through collaborative efforts between humans and intelligent machines. The teacher collaborates with AI instead of merely using it as an additional tool, while AI collaborates with teachers rather than replacing them in facilitating learning and teaching. Regardless of the educational context and the type of AI technology employed, the goal of pedagogical partnering is to distribute cognition between the teacher and AI for problem-solving and desired pedagogical goals.

Based on the concept of partnering agency for their collaborative problem-solving in pedagogy, we defined the relationship between teacher and AI as a *Teacher-AI Pedagogical Partnership (TAIPP),* which presents the view of AI as a collaborative partner that work alongside the teacher to achieve shared pedagogical goals.

The impact of the teacher-AI pedagogical partnership on teachers

Given the distinctive attributes of AI and its growing roles in collaborative pedagogical activities with teachers, it is evident that AI is emerging as a significant partner in teachers' instructional practices, forming a teacher-AI pedagogical partnership. Consequently, it becomes imperative to examine the potential impact of this innovative relationship on teachers. We present four perspectives, namely pedagogy, cognition, emotion, and classroom interactions, to comprehensively investigate the prospective impact of TAIPP on teachers (see Figure 3.4).

The potential change in teachers' pedagogical practice

By incorporating the intelligent machine agent into teachers' processes of making instructional decision and taking action, the teacher-AI pedagogical partnership holds the promise of influencing teachers' conventional pedagogical approaches and practices across various dimensions. Drawing upon an extensive examination of the existing literature on AI in education, we put forth four potential transformations in pedagogy: (1) personalized pedagogy, (2) targeted pedagogy, (3) immediate pedagogy, and (4) data-driven pedagogy.

In AI-integrated classrooms, the provision of personalized instruction and scaffolding assumes crucial significance. The diverse learning styles, abilities, and paces of individual students pose a considerable challenge in delivering tailored support within traditional classroom settings. Nonetheless, the introduction of an AI partner offers teachers the opportunity to access comprehensive performance data pertaining to each student, encompassing measures of progress, engagement, and motivation (Ebadi & Amini, 2022; Huang et al., 2022). This wealth of information empowers teachers to offer personalized scaffolding and targeted interventions. Additionally, teachers can leverage the insights provided by affective AI systems regarding students' emotional states to implement personalized pedagogical strategies in the emotional domain (Buttussi & Chittaro, 2020; Naji Meidani & Khajavy, 2015).

The integration of AI enables teachers to employ targeted pedagogy to cater to the individual needs of students. For example, when implementing intelligent tutoring systems and virtual pedagogical agents to facilitate students' independent learning, teachers can allocate scaffolding and support specifically to those students who require additional assistance, rather than providing it uniformly to all students (Dicker, 2021; Gobert et al., 2014). Moreover, targeted pedagogy also encompasses the ability of teachers to concentrate their instruction in specific domains while collaborating with AI. For instance, in collaborative teaching scenarios involving teachers and AI social robots, Fang et al. (2020) discovered that teachers can transmit requests to the AI social robot, such as obtaining real-time updates on students' learning progress and emotional states, to which the robot promptly responds with relevant information. By delegating certain teaching tasks to AI, teachers can redirect their focus towards guiding and nurturing students' higher-order thinking skills and real-world problem-solving abilities.

The AI partner's exceptional capacity for rapid information processing and prompt generation of results plays a crucial role in facilitating immediate pedagogy within educational settings. In contrast to traditional pedagogical approaches characterized by delayed feedback and actions, teachers now have the ability to dynamically adapt their instructional strategies in real-time based on immediate information on student progress provided by AI. An illustrative example involves the utilization of AI-enabled automatic assessment systems to score and generate timely feedback for performance-based assessments, a particularly valuable tool for large-scale evaluations. This empowers teachers to furnish students with immediate feedback, a task that would be challenging to accomplish without the assistance of an AI social agent.

In AI-integrated classrooms, teachers are increasingly motivated to leverage the data and information furnished by AI pertaining to students' progress and challenges to make informed instructional adjustments and pedagogical decisions. In conventional classroom settings, teachers typically rely on diverse sources such as personal observations, prior experiences, and student behaviors to inform their decision-making process, often lacking precise and comprehensive data to substantiate their choices. However, with the aid of AI as a collaborative partner, teachers gain access to data analytics capabilities that enable the analysis of intricate learning environments, thereby generating actionable insights. These insights, including automatic scores and feedback, facilitate the adoption of an innovative data-driven pedagogy by teachers.

Teacher cognitive affordances

AI technology advances bring teachers to partner with intelligent machines to harness human cognitive power and creativity in pedagogy (Nahavandi, 2019). By incorporating AI into their cognitive decision-making processes, teachers can experience the cognitive affordances of AI, including the reduction of cognitive workload and the enhancement of cognitive focus.

Cognitive workload refers to the amount of effort and cognitive resources that teachers invest in processing pedagogical activities. To examine the impact of partnering with AI on teachers' cognitive workload, two opposing concerns should be considered in future research. On the one hand, AI systems can automatically monitor students' performance and behaviors, assess their progress, and provide personalized feedback (Dickler, 2019; Gobert et al., 2016, 2018; Moussavi et al., 2016), thereby reducing the burden and workload of guiding personalized learning for teachers. On the other hand, some studies have highlighted that teachers may criticize the additional cognitive and administrative work associated with directing the flow of curricula and activities in AI-integrated learning environments (Ahmad et al., 2016; Serholt et al., 2014). Additionally, teachers may experience increased cognitive stress and burden when they fear the potential loss of their competencies and opportunities or when they face challenges in effectively utilizing advanced AI systems (Serholt et al., 2014).

By delegating various pedagogical activities to AI, such as student progress monitoring, question answering, assignment scoring, and providing immediate feedback (Goel & Polepeddi, 2018; Gerard et al., 2019; Gobert et al., 2015), teachers can enhance their cognitive focus on areas that require human qualities, moral care, and ethical considerations (Guilherme, 2019; Holstein et al., 2019; Qin et al., 2020). This allows teachers to better attend to the emotional and social needs of their students, engage in more effective communication and collaboration, and foster critical thinking and creativity. Furthermore, teachers can concentrate on cultivating students' metacognitive and higher-order thinking skills, which are essential for their success in the 21st-century workforce. Therefore, AI integration in classrooms has the potential to liberate teachers' cognitive resources, enabling them to focus on aspects of teaching that demand uniquely human skills and expertise.

Teacher emotion toward AI integration

The emotional process serves a social function as it allows people to form and maintain various social relationships with technologies (Keltner & Kring, 1998) and may affect the emotional tone of human-computer interactions (Wykowska et al., 2012). When AI is perceived as an artificial social agent partnering with teachers, it can evoke strong emotional reactions in them. Studies have documented that positive and negative emotional attitudes can differently modulate teachers' performance when working with AI in classrooms (Gray, 2001; Storbeck & Maswood, 2016). Teachers' emotional reaction to AI is a critical consequence that needs to be discussed. Further research is necessary to explore the affective aspects of teacher-AI interactions and implications for teaching and learning (Mishra et al., 2020; Sabourin & Lester, 2014).

This paper contends that it is crucial to examine teachers' emotional responses to their partnership with AI from both a positive and negative perspective. Positive emotions experienced by teachers can be assessed across various dimensions, such as appreciation, acceptance, and respect. For instance, Fridin and Belokopytov (2014) observed that teachers consistently exhibited positive sentiments when utilizing a human-like robot as an interactive partner in the teaching process, feeling helpful, pleasant, and friendly. However, negative emotions may also emerge as teachers engage with AI, including feelings of fear, perceived threats, and issues related to trust. Trust is particularly significant to examine when exploring teachers' emotions in their relationship with AI, defined as the extent to which a person feels secure and psychologically comfortable about depending on and building relationships with technologies (Komiak & Benbasat, 2006). A lack of trust in AI can give rise to negative emotions and resistance towards its integration in classrooms. Additionally, there may be apprehension regarding the perceived threat posed by AI, especially when machines consistently outperform humans (Dietvorst et al., 2016) and potentially assume many core roles traditionally held by teachers, leading to concerns about job insecurity.

Teachers' classroom interactions with students

The incorporation of autonomous, communicative, and interactive AI technologies into teachers' pedagogical practices has expanded the social dynamics and relationships within classrooms, extending beyond human interactions (e.g., teacher and student, student with peers) to encompass relationships between humans and intelligent machines.

The integration of AI technologies into the pedagogical practices yields transformative effects on teacher-student interactions and relationships within classrooms, distinct from those observed in traditional technology-integrated classrooms. Firstly, teacher-student interactions may shift towards being more teacher-initiated rather than student-initiated, as AI systems can identify struggling students and provide real-time information to the teacher. This enables teachers to proactively approach students and offer personalized assistance, even without the student explicitly seeking help. Secondly, the quality of interactions can be enhanced as AI systems can diagnose problems and provide real-time recommendations, allowing teachers to focus on higher-level thinking and facilitating high-quality interactions. Thirdly, interactions can become more targeted and personalized, as AI-guided learning empowers teachers to concentrate on specific students and provide personalized support in cognitive and emotional domains (Baker

& Inventado, 2014; Du et al., 2018). Furthermore, the emergence of triadic interactions involving teachers, students, and AI represents a novel form of interaction that is reshaping the pedagogical landscape.

By leveraging the potential of AI technologies, teachers can provide more personalized and targeted support to students. They can also dedicate their focus to higher-level thinking and engage in high-quality interactions with their students. However, it is crucial to recognize that these transformations also bring forth new challenges and ethical considerations that necessitate careful examination. Thus, it is imperative for researchers and educators to continue exploring the ramifications of AI integration into pedagogical practices and develop best practices for its effective and ethical implementation in education.

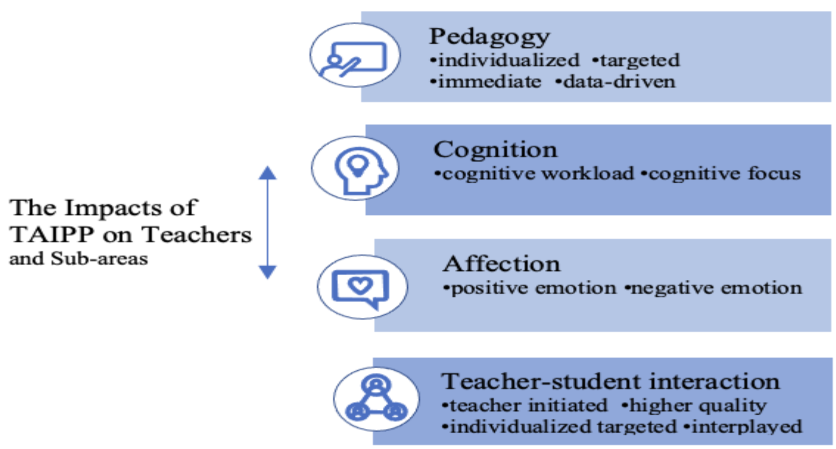

Figure 3.4. The impacts of teacher-AI pedagogical partnership on teachers.

The primary objective of this paper is to construct an integrated conceptual framework that explores the emerging relationship between teachers and AI, along with its consequential effects on teachers (see Figure 3.5). It is essential to highlight that the integrated conceptual framework is designed to be generic, devoid of specific AI systems or applications. It can be utilized to examine the teacher-AI relationship within the context of a particular AI system or to explore the broader human-AI relationship in various other contexts.

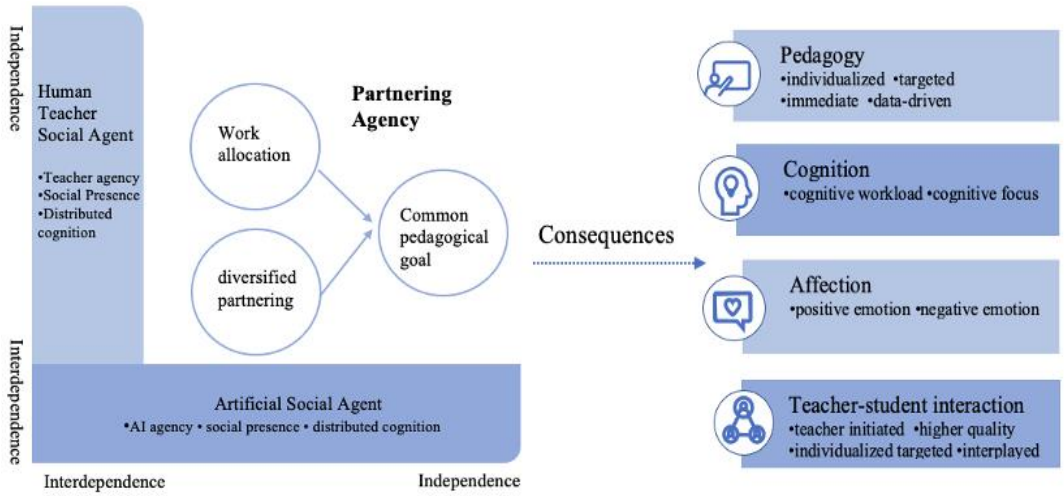

Figure 3.5. An integrated conceptual framework for outlining the teacher-AI relationship.

Implications

Grounding on the theoretical foundations of actor-network theory, social presence, and distributed cognition in the field of HMI research, we proposed an integrated conceptual framework aimed at comprehending the intricate relationship between teachers and AI. The proposed framework comprises two interconnected components: (1) the three-dimensional model of the Teacher-AI Pedagogical Partnership (TAIPP), and (2) the possible impacts of TAIPP on teachers. In this section, we elucidate the implications of our integrated framework in terms of systematic pedagogical design and propose directions for future research endeavors.

Teachers' mindset shifts toward engaging in partnership with AI

In the proposed TAIPP model, AI is conceptualized as an *artificial social agent* that collaborates with teachers in the realm of pedagogy, possessing human-like cognitive abilities and rational action (Russell, 2010). This perspective acknowledges AI as a significant stakeholder and a novel participant in classroom dynamics, which is defined as a "first-class subject" by Wang et al. (2019). The emerging role of AI and its pedagogical partnership with teachers leads to a shift in teachers' mindsets concerning pedagogy.

Within the teacher-AI pedagogical partnership, AI assumes the role of a new player with social agency, capable of assuming many core responsibilities of teachers and engaging in social interactions with students within the classroom. AI's ability to automate numerous repetitive, routine, and administrative tasks allows teachers to allocate their time and efforts to more impactful work. For instance, AI can simulate one-on-one tutoring to tailor instruction to individual students' needs (Ghali et al., 2016; Bagheri, 2015). AI virtual assistants can also assist teachers by answering student queries, facilitating classroom discussions, grading assignments, and delivering timely feedback (Goel et al., 2018). Moreover, AI excels at tasks requiring extensive computation and rapid data processing, surpassing the capacities of human teachers. As an illustration, AI can assume some assessment responsibilities by automatically grading complex responses like essays, constructed responses, and simulations while providing personalized feedback (Zhai et al., 2020a).

The AI player holds the potential to empower teachers in multiple aspects, allowing them to fulfill their roles with enhanced quality, efficiency, and even undertake tasks that were previously unattainable. Leveraging technologies such as learning analytics, machine learning, and affective computing, AI captures and analyzes students' multimodal process data, offering real-time insights into their progress, behavior, engagement, and affective states. By creating individualized digital profiles for each student, teachers gain the ability to provide personalized and targeted scaffolding while making pedagogical adjustments based on student needs (Holstein et al., 2019; Qin et al., 2020). Furthermore, AI enables teachers to embrace innovative assessment practices reliant on automated scoring and data-driven decision-making (Zhai et al., 2021). Through automated scoring of constructed responses and the provision of immediate feedback, AI empowers teachers to evaluate student learning more accurately and efficiently.

Engaging in the pedagogical partnership with AI necessitates a shift in teachers' mindsets, moving beyond mere utilization of technology to active collaboration with AI as a social agent. This partnership can enhance the quality of pedagogical practices, requiring teachers to reframe their roles in this new educational landscape. Teachers must explore how they can effectively collaborate with AI to achieve optimal outcomes for their students. As emphasized by Zhang et al. (2021), teachers should approach AI as a complementary partner rather than a replacement for human teachers, demanding intentional integration of AI in their practices. This entails the development of new skills and adaptations in pedagogical approaches to effectively leverage AI in the classroom. Moreover, as highlighted by Wang et al. (2021), teachers must consider the ethical and societal implications of partnering with AI in education. They should ensure that AI is implemented in a manner that aligns with their educational values, transcending a mere technological solution to existing problems. Consequently, teachers need to approach AI as a social agent through a critical and reflective lens, ensuring its responsible and ethical incorporation. In AI-integrated classrooms, it is essential for teachers to contemplate the potential collaboration with this emerging new player within their pedagogical practices.

The systematic instructional design of the teacher and AI collaborative teaching

In the context of this paper, the teacher-AI pedagogical partnership refers to the collaborative and cooperative relationship between teachers and AI in pursuit of shared pedagogical goals. The integrated conceptual framework presented has significant implications for the systematic design of collaborative teaching between teachers and AI. To enhance the effectiveness and systematic implementation of such pedagogical mode, we offer design guidance and focus by comparing traditional teaching design with AI-integrated collaborative teaching design across eight teaching areas, as shown in Table 3.1.

In designing teacher-AI collaborative teaching, teachers need to differentiate the tasks performed by human teachers from those that can be substituted or enhanced by AI. Traditional teaching design has traditionally focused on a "two players" teaching model, namely the teacher and the student, and how teachers can design activities to support and assess independent and collaborative student learning. However, in teacher-AI collaborative teaching design, AI assumes the role of an emerging new player, partnering with teachers across multiple areas. Therefore, it is crucial for teachers to carefully design learning and teaching activities with a comprehensive understanding of the three dimensions proposed in our TAIPP model. Based on the detailed guidance provided in Table 3, we summarize and argue that the partnership and collaboration between teachers and AI can be reflected in three specific areas.

1. Teaching and learning analysis: Teaching and learning analytics serve as the foundation for effective pedagogy and entails distinct responsibilities for AI and teachers. AI can

provide widely used analyses of teaching materials based on dynamic classroom environment data collected by the system. For example, AI can generate individual and classroom-wide learning reports for teachers based on different knowledge points and students' progress (Gobert et al., 2015). Thus, teachers gain qualitative and quantitative insights into learners' profiles and classroom situations through AI-generated reports. By integrating AI insights with their own knowledge and judgment, teachers can comprehend the hierarchical classroom dynamics and individual students' level of mastery. In AI-integrated classrooms, student progress data is procedural, necessitating teachers' continuous big data awareness and strong information literacy (Liu & Zhang, 2018). The partnership between teachers and AI in teaching and learning analysis highlights the importance for teachers to have timely access to procedural information through AI technology, enabling them to better prepare and implement subsequent classroom activities.

2. Classroom activities. Classroom activities are multifaceted and correspond to teacher activities, student activities, and student support as indicated in Table 3. At the level of teacher activities, it is crucial for teachers to allocate tasks based on independent and interdependent pedagogy. When selecting and incorporating AI technology, teachers need to be cognizant of the functions and pedagogical potential of specific AI technologies. Collaborative teaching is reflected in the division of labor between teachers and AI. Regarding student activities, teachers must clarify the extent to which AI participates in learning activities and whether students engage in autonomous or cooperative learning. AI can provide personalized learning tasks, resources, and feedback to students, resulting in varied learning outcomes and paces. AI can even track and analyze data generated during students' learning activities and provide feedback to teachers. In designing these learning activities, teachers need to determine the level of AI and

teacher involvement, the points of collaboration between them, and the resultant consequences. Making informed decisions about leveraging AI's information and expertise in supporting students is critical in designing AI-integrated lessons. Holstein et al. (2019) reported enhanced student learning outcomes when human teachers effectively and appropriately collaborated with machine intelligence.

3. Collaborative performance evaluation. The multimodal learning data generated throughout the learning process offers opportunities for collaborative performance evaluation between teachers and AI. Conducting performance-based assessments requires strong collaboration between teachers and AI. For instance, AI can monitor students' progress, challenges, and emotional states to generate learner profiles and reports for teachers (Wang & Vásquez, 2020). Teachers gain insights into students' progress and challenges, allowing them to provide personalized guidance and support. Therefore, in design practice, it is crucial for teachers to clearly define the purpose and goals of performance evaluation and subsequently identify corresponding performance-based assessment strategies. Additionally, when incorporating AI-enabled automatic systems into their designs, teachers should determine which tasks can be automatically scored. Moreover, they must consider whether the system can provide personalized feedback and how teachers can effectively utilize it.

The implication for future research foci

This paper represents one of the pioneering works in the educational context that aims to conceptualize the relationships between teachers and AI, which is an emerging area of focus in recent human-machine interaction research. The integrated conceptual framework proposed in this study holds considerable implications for future research endeavors in two key areas. First, it calls for investigations into how teachers engage and interact with AI systems to establish their relationships. Secondly, it emphasizes the need to explore the consequential impacts of these teacher-AI relationships on various aspects of educational practice.

In terms of future research on teacher-AI interaction and their relationship formation, one promising avenue is the implementation of a longitudinal, phenomenological study (Farr & Nizza, 2019) in which teachers integrate different AI systems into their instructional practices to pursue their pedagogical goals. Researchers can employ the experience sampling method (Csikszentmihalyi, Csikszentmihalyi, & Larson, 2014) by asking teachers to record their observations and perceptions of AI usage in various lessons, followed by subsequent expositional interviews with investigators. Building and maintaining relationships require time, and a longitudinal approach allows teachers to engage with and reflect upon their experiences with AI in an integrated environment, offering rich insights compared to their prior use of conventional technologies. Moreover, the longitudinal design enables researchers to depict the teacher-AI relationship on a continuum, capturing variations at different time points.

Another viable method to investigate teachers' interaction with AI and relationship formation is through exploratory case studies (Edwards, 1998; Waters, 2007), centering on descriptive analyses of emerging themes in teachers' pedagogical practices involving AI. Given that teachers' interaction with AI and relationship development is a relatively novel and under-researched phenomenon, detailed observations and the identification of fundamental concepts and distinctions are necessary to accurately describe the observed phenomena (Edwards, 1998). The aim of exploratory case studies is to examine teachers' natural experiences in AI-integrated environments, allowing for cross-case analysis to reveal coherent and consistent narratives that highlight emerging themes.

Furthermore, future research can delve into the factors influencing teachers' interactions and relationships with AI, such as their pedagogical beliefs regarding technology integration, pedagogical approaches to AI integration, and their AI competence. Large-scale surveys and structural equation modeling can be employed for data collection and analysis. By exploring the impact of these factors on teachers' interactions and relationships with AI, future research can contribute to our understanding of the diverse behaviors and perceptions of teachers in the context of human-AI interaction and relationships.

Examining the potential impacts of the teacher-AI pedagogical partnership (TAIPP) represents a promising avenue for future research in this domain. Within the proposed integrated conceptual framework, we have identified four key areas that warrant investigation, namely teachers' pedagogical change, cognitive affordability, affective responses toward AI integration, and classroom interactions. It is noteworthy that the existing literature in this field primarily focuses on assessing the efficacy and effectiveness of AI in relation to student learning outcomes, with relatively limited attention given to the impact on teachers resulting from the emergence of AI and its novel relationship with them. By exploring the influence of teacher-AI pedagogical partnerships in each of these areas, the field can gain an understanding of the advantages and disadvantages associated with the integration of AI in teaching. Such knowledge can subsequently inform the development of more effective teacher professional development programs aimed at facilitating their successful integration of AI into instructional practices.

Table 3.1. The comparison of traditional teaching design and teacher-AI collaborative teaching design

Design focuses	Traditional teaching design activities	Teacher-AI collaborative teaching design
Teaching and learning objectives identification	Starting from knowledge and skills, method, and process.	Considering the independent learning ability, information process ability, high-level thinking ability, and cooperation and communication skills, the required knowledge and skills, methods, and processes.
Learner analysis	Teachers analyze students' learning situations based on assessing, self-feeling, and observation of students.	The classroom and individual evaluation reports provided by AI systems provide information on students' situations, which can be used by teachers to conduct learner analysis before and during classes.
Teaching material and media selection	Teachers operate and select teaching materials and media.	When teachers decide on teaching materials, they need to consider which resources can be provided by AI, and which should be supported by teachers. Teachers also need to understand who needs to be responsible for selecting and manipulating the material and media.
Teacher activities	Teachers are responsible for all teaching activities using language scripts and teaching behaviors for facilitation, guidance, encouragement, etc.	Teaching activities should be divided between teachers and AI. Many AI systems can be subdivided into the presentation of video, audio, reference documents, tests, discussions, assignments, etc. It can answer questions, communicate with students, and provide feedback. Teachers' activities are more about questioning, communication, emotional support, and personalized scaffolding.
Student activities	Students conduct various activities independently and collaboratively, such as doing exercises, answering questions, and group cooperation.	Students can refine the activities between students and AI, and between students and teachers. Additionally, they can seek support and feedback from AI and teachers.

Student support	Teachers scaffold students based on students' requests and teachers' observations.	Teachers need to decide when and how to support students by leveraging the information and expertise of AI and self.
Classroom progress and difficulty	Most of the classroom progress and difficulty are fixed, teachers process the teaching based on pre-designed lesson plans.	AI monitors students' progress and detects their cognitive difficulties and emotional states to generate learners' profiles and teacher reports. Teachers gain insights into students' progress and challenges and provide personalized guidance and support.
Classroom assessment practice	Teachers use traditional assessment formats, such as multiple choice and short answer questions. Teachers provide delayed feedback when using writing in assessment.	Teachers conduct performance-based assessment using various constructed response tasks and provide timely and personalized feedback.

Conclusion and Limitations

AI technology has emerged as a collaborative tool that people can rely on to accomplish tasks requiring human cognition, representing a significant departure from traditional technologies used as means to achieve goals. This shift in technology's role from a tool people work through or by to a collaborator people work with presents both theoretical challenges and opportunities for scholars studying human-machine interaction (Rogers & Paay, 2014). The key challenge lies in the fact that AI disrupts the prevailing roles of technology in human-machine interaction, leading to a transformation of the human-machine relationship. As a result, research on human-machine relationships has shifted its focus to explore the emerging relationships between humans and intelligent machines. In the educational context, we are particularly interested in investigating how teachers can integrate AI into their pedagogical practices and develop relationships with this technology. Our work has culminated in the development of an integrated conceptual framework known as the TAIPP model, which sheds light on the teacher and AI relationship in AI-integrated educational environments. This conceptualization of the teacher-AI relationship is essential as it promotes the appropriate use of AI by teachers, addresses the imbalance between teachers and machines, and contributes to the theoretical understanding of human-technology relationships in the AI era.

The proposed TAIPP model consists of three dimensions, involving two social agents (i.e., the first dimension) and their relationships in two dimensions (i.e., independent, and interdependent partnering agency). With the increasing implementation of AI in classrooms, there is a need for a new form of teacher-machine symbiosis, resulting in a shift in the division of labor between teachers and AI. Considering the significant pedagogical affordances and social presence of AI technology in teachers' pedagogical practices, this paper transcends the traditional notion of teacher-technology interaction and advances the concept of a TAIPP by emphasizing the agency and distributed cognition of AI in AI-integrated classroom dynamics. The partnership signifies the independent and interdependent relationships between teachers and AI, with the aim of enhancing human intelligence through machine intelligence.

Aligned with the vision of the TAIPP, it is more meaningful to view AI as a new player that augments and complements teachers' capabilities rather than as a means of automation intended to replace them. This perspective provides a more effective guide for integrating AI into classrooms, rather than fixating on the notion of intelligent machines that replicate teachers' intelligence and eventually replace them. To achieve successful TAIPP partnerships, it is crucial to understand how this partnership might impact teachers. Accordingly, we have suggested four areas and lenses for researching the resulting impacts of TAIPP on teachers, including pedagogy, cognition, affection, and the teacher-student relationship.

This paper has several known limitations. Firstly, the proposed framework does not account for contextual factors that influence the interaction and relationship between teachers and AI. Humans and AI must align their roles and interactions with contextual affordances. For instance, different AI systems may demand different pedagogical partnerships with teachers across various contextual settings. Further research is needed to comprehend the impact of context on teacher and AI relationships. Secondly, while the proposed framework is developed within the educational context, it may have relevance to other domains. Exploring human-AI relationships in other fields, such as healthcare, organizations, and business, require careful attention to the types of AI technology and organizational factors that may explain human-AI relationships. Thirdly, although we have outlined the potential impacts of TAIPP on teachers, these factors may influence the formation of teacher and AI relationships. Given the focus of this paper, we did not consider the factors that influence the development of teacher and AI relationships. Lastly, the current framework is proposed on a theoretical basis. Empirical studies will be necessary to validate and refine this framework. Future research could incorporate the role of context in teacher and AI relationships and expand the study of human-AI relationships to other professional domains, thereby elucidating various patterns of human-AI relationships across fields and contributing to the development of a comprehensive theory to explain this crucial phenomenon — the relationships between humans and machines in the AI era.

References

Abdelnour, S., Hasselbladh, H., & Kallinikos, J. (2017). Agency and institutions in organization studies. Organization Studies, 38(12), 1775–1792.

Adair, A., Dickler, R., & Gobert, J. (2020). Supporting teachers supporting students: evidence-based TIPS in a dashboard to guide inquiry scaffolding. In, *Proceedings of the International Conference of the Learning Sciences 2020* (pp. 1769-1770). ISLS.

Ågerfalk, P. (2020) Artificial intelligence as digital agency, European Journal of Information Systems, 29:1, 1-8, DOI: 10.1080/0960085X.2020.1721947

Ahmad, M. I., Mubin, O., & Orlando, J. (2016). Understanding behaviors and roles for social and adaptive robots in education: Teacher's perspective. *HAI 2016 Proceedings of the 4th International Conference on Human Agent Interaction*, 297–304.

Ahn, T. Y., & Lee, S. M. (2016). User experience of a mobile speaking application with automatic speech recognition for EFL learning. *British Journal of Educational Technology*, *47*(4), 778–786. https://doi.org/10.1111/bjet.12354

Arnold, K. E., Pistilli, M. D. (2012) Course Signals at Purdue: Using learning analytics to increase student success. Proceedings of the 2nd International Conference on Learning Analytics and Knowledge. New York, NY: ACM, pp. 267–270.

Ashrafian, H. (2015). AionAI: A Humanitarian Law of Artificial Intelligence and Robotics. *Science & Engineering Ethics*, *21*(1), 29–40. https://doi.org/10.1007/s11948-013-9513-9

Bagheri, M. M. (2015). Intelligent and adaptive tutoring systems: How to integrate learners. *International Journal of Education*, *7*(2), 1-16.

Baker, R. S., & Inventado, P. S. (2014). Educational data mining and learning analytics. In Handbook of research on educational communications and technology (pp. 385-397).

Bayne, S. (2015). Teacherbot: interventions in automated teaching. *Teaching in Higher Education*, *20*(4), 455-467.

Beer, J. M., Fisk, A. D., & Rogers, W. A. (2014). Toward a framework for levels of robot autonomy in human-robot interaction. *Journal of human-robot interaction*, *3*(2), 74.

Beggrow, E. P., Ha, M., Nehm, R. H., Pearl, D., & Boone, W. J. (2014). Assessing Scientific Practices Using Machine-Learning Methods: How Closely Do They Match Clinical Interview Performance? *Journal of Science Education and Technology*, *23*(1), 160–182.

Bian, F., Ren, D., Li, R., Liang, P., Wang, K., & Zhao, L. (2020). An extended DMP framework for robot learning and improving variable stiffness manipulation. *Assembly Automation*, *40*(1), 85-94.

Bickmore, W., & Picard, R. W. 2005. Establishing and maintaining long-term human-computer relationships. *ACM Transactions on Computer-Human Interaction* 12(2):293– 327.

Bigman, Y. E., Waytz, A., Alterovitz, R., & Gray, K. (2019). Holding robots responsible: The elements of machine morality. *Trends in cognitive sciences*, *23*(5), 365-368.

Biocca, F., Harms, C., & Burgoon, J. K. (2003). Toward a more robust theory and measure of social presence: Review and suggested criteria. *Presence: Teleoperators & virtual environments*, *12*(5), 456-480.

Biocca, F., & Harms, C. (2002). Defining and measuring social presence: Contribution to the networked minds theory and measure. *Proceedings of PRESENCE*, *2002*, 7-36.

Brandt, S. L., Lachter, R. R., & Shively, R. J. (2018). A human-autonomy teaming approach for a flight-following task. In C. Baldwin (Ed.), Advances in neuroergonomics and cognitive engineering advances in intelligent systems and computing. Springer International Publishing AG.

Breazeal, C., Dautenhahn, K., & Kanda, T. (2016). Social robotics. In B. Siciliano, & O. Khatib (Eds.). Springer handbook of robotics (pp. 1935–1972). Cham: Springer.

Brill, J. C., Cummings, M. L., Evans, A. W.III, Hancock, P. A., Lyons, J. B., & Oden, K. (2018). Navigating the advent of human-machine teaming. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 62(1), 455–459.

Bughin, J., Hazan, E., Ramaswamy, S., Chui, M., Allas, T., Dahlstrom, P., ... & Trench, M. (2017). Artificial intelligence: The next digital frontier?

Buttussi, F., & Chittaro, L. (2020). Humor and Fear Appeals in Animated Pedagogical Agents: An Evaluation in Aviation Safety Education. *IEEE Transactions on Learning Technologies*, *13*(1), 63–76. https://doi.org/10.1109/TLT.2019.2902401

Callon, M. (1984). Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay. *The Sociological Review*, *32*(1-suppl), 196–233.

Callon, M., & Law, J. (1997). After the individual in society: Lessons on collectivity from science, technology and society. *Canadian Journal of Sociology/Cahiers canadiens de sociologie*, 165-182.

Campbell, K. K. (2005). Agency: Promiscuous and Protean. *Communication and Critical/Cultural Studies*, 2(1), 1-19.

Ceha, J., Law, E., Kulić, D., Oudeyer, P. Y., & Roy, D. (2021). Identifying Functions and Behaviors of Social Robots for In-Class Learning Activities: Teachers' Perspective. *International Journal of Social Robotics*. https://doi.org/10.1007/s12369-021-00820-7

Cheung, C. M., Chiu, P. Y., & Lee, M. K. (2011). Online social networks: Why do students use Facebook? Computers in Human Behavior, 27(4), 1337–1343.

Chocarro, R., Cortiñas, M., & Marcos-Matás, G. (2021). Teachers' attitudes towards chatbots in education: A technology acceptance model approach considering the effect of social language, bot proactiveness, and users' characteristics. *Educational Studies*, 1–19.

Ciechanowski, L., Przegalinska, A., Magnuski, M., & Gloor, P. (2019). In the shades of the uncanny valley: An experimental study of human–chatbot interaction. *Future Generation Computer Systems*, *92*, 539-548.

Csikszentmihalyi, M., Csikszentmihalyi, M., & Larson, R. (2014). Validity and reliability of the experience-sampling method. *Flow and the foundations of positive psychology: The collected works of Mihaly Csikszentmihalyi*, 35-54.

Cummings, M. L., & Clare, A. S. (2015). Holistic modelling for human autonomous system interaction. Theoretical Issues in Ergonomics Science, 16(3), 214–231.

Dafoe, A. (2015). On Technological Determinism: A Typology, Scope Conditions, and a Mechanism. *Science Technology and Human Values*, *40*(6), 1047–1076.

Damiano, Luisa, Paul Dumouchel, and Hagen Lehmann (2015), Artificial Empathy: An Interdisciplinary Investigation, *International Journal of Social Robotics*, 7 (1), 3-5.

D'Mello, S. K., & Graesser, A. C. (2012). Dynamics of affective states during complex learning. Learning and Instruction, 22(2), 145-157.

den Broek, H. V., Schraagen, J. M., Te Brake, G., van Diggelin, J. (2017). Approaching full autonomy in the maritime domain: Paradigm choices and human factors challenges. In Proceedings of the MTEC, 26–28 April 2017.

Dicker, R. (2019). *An intelligent tutoring system and teacher dashboard to support students on mathematics in science inquiry*. (Doctoral dissertation, Rutgers the State University of New Jersey, School of Graduate Studies).

Dickler, R., Gobert, J., & Sao Pedro, M. (2021). Using Innovative Methods to Explore the Potential of an Alerting Dashboard for Science Inquiry. Journal of Learning Analytics, 8(2), 105-122.

Dietvorst, B., Simmons, J.P. and Massey, C. (2016), “Overcoming algorithm aversion: people will use imperfect algorithms if they can (even slightly) modify them”, Management Science, Vol. 64 No. 3, pp. 1155-1170.

du Boulay, B. (2019). Escape from the Skinner Box: The case for contemporary intelligent learning environments. *British Journal of Educational Technology*, *50*(6), 2902–2919.

Du, J., Zhang, J., Wei, H., Zhang, Y., & Zhao, Y. (2018). Enhancing personalized learning with an intelligent tutoring system based on fuzzy logic. IEEE Access, 6, 25717-25725.

Ebadi, S., & Amini, A. (2022). Examining the roles of social presence and human-likeness on Iranian EFL learners’ motivation using artificial intelligence technology: a case of CSIEC chatbot. *Interactive Learning Environments*, 1-19.

Edwards, B. I., & Cheok, A. D. (2018). Why Not Robot Teachers: Artificial Intelligence for Addressing Teacher Shortage. *Applied Artificial Intelligence*, *32*(4), 345–360.

Edwards, D. J. (1998). Types of case study work: A conceptual framework for case-based research. *Journal of humanistic psychology*, *38*(3), 36-70.

Epley, Nicholas, Adam Waytz, and John T. Cacioppo (2007). On Seeing Human: A Three-Factor Theory of Anthropomorphism. *Psychological Review*, 114 (4), 864-886.

Fang, H., Wang, S., Xue, S., & Wang, X. (2020). Research on human-computer cooperative teaching supported by artificial intelligence robot assistant. *Artificial intelligence supported educational technologies*, 45-58.

Faraj, S., Pachidi, S., & Sayegh, K. (2018). Working and organizing in the age of the learning algorithm. *Information and Organization*, *28*(1), 62–70.

Farr, J., & Nizza, I. E. (2019). Longitudinal Interpretative Phenomenological Analysis (LIPA): A review of studies and methodological considerations. *Qualitative Research in Psychology*, *16*(2), 199-217.

Fenwick, T., & Edwards, R. (2010). *Actor-Network Theory in Education*. Routledge.

Floridi, L., & Sanders, J. W. (2004). *On the Morality of Artificial Agents*.

Fridin, M. (2014). Storytelling by a kindergarten social assistive robot: A tool for constructive learning in preschool education. *Computers and Education*, *70*, 53–64.

Fridin, M., & Belokopytov, M. (2014). Acceptance of socially assistive humanoid robot by preschool and elementary school teachers. *Computers in Human Behavior*, *33*, 23-31.

Fussell, S. R., Kraut, R. E., & Siegel, J. (2000). Coordination of communication: Effects of shared visual context on collaborative work. ACM Transactions on Computer-Human Interaction (TOCHI), 7(3), 323-349. https://doi.org/10.1145/351492.351495

Gerard, L., Kidron, A., & Linn, M. C. (2019). Guiding collaborative revision of science explanations. *Inter Journal of Computer-Supported Collaborative Learning*, 14, 1–34.

Ghali, R., Ouellet, S., & Frasson, C. (2016). LewiSpace: An Exploratory Study with a Machine Learning Model in an Educational Game. *Journal of Education and Training Studies*, *4*(1), 192-201.

Gobert, J. D., Baker, R., & Wixon, M. B. (2015). Operationalizing and detecting disengagement within online science microworlds. Educational Psychologist, 50(1), 43–57.

Gobert, J. D., Baker, R.S., & Sao Pedro, M.A. (2014). *Inquiry skills tutoring system.* U.S. Patent No. 9,373,082. Washington, DC: U.S. Patent and Trademark Office.

Gobert, J. D., Moussavi, R., Li, H., Pedro, S., & Dickler, R. (2018). Real-time scaffolding of students' online data interpretation during inquiry with Inq-ITS using educational data mining. *Cyber-physical laboratories in engineering and science education* (pp.191–217).

Gobert, J., & Sao Pedro, M. (2016). Inq-Blotter: A real time alerting tool to transform teachers' assessment of science inquiry practices (NSF-IIS-1629045). Awarded from the National Science Foundation.

Gobert, J. D., Sao Pedro, M.A., Betts, C.G. (2023). An AI-Based Teacher Dashboard to Support Students' Inquiry: Design Principles, Features, and Technological Specifications. In N. Lederman, D. Zeidler, & J. Lederman (Eds.), Handbook of Research on Science Education, (Vol. 3, pp. 1011-1044). Routledge. https://doi.org/10.4324/9780367855758

Gobert, J. D., Sao Pedro, M., Raziuddin, J., & Baker, R. S. (2013). From log files to assessment metrics: Measuring students' science inquiry skills using educational data mining. *Journal of the Learning Sciences*, 22(4), 521-563.

Goel, A. K., & Polepeddi, L. (2018). Jill Watson: A virtual teaching assistant for online education. In *Learning engineering for online education* (pp. 120-143). Routledge.

Goldberg, P., Sümer, Ö., Stürmer, K., …& Trautwein, U. (2021). Attentive or Not? Toward a Machine Learning Approach to Assessing Students' Visible Engagement in Classroom Instruction. In *Educational Psychology Review* (Vol. 33, Issue 1, pp. 27–49). Springer.

Gray, J. R. (2001). Emotional modulation of cognitive control: Approach–withdrawal states double-dissociate spatial from verbal two-back task performance. *Journal of Experimental Psychology: General*, 130(3), 436.

Guan, H., Chen, Q., Han, S., & Zhang, B. (2021). The influence of "artificial intelligence+ human–computer interaction" on teachers' psychological changes in academic management in colleges. *Frontiers in Psychology*, *12*, 730345.

Guilherme, A. (2019). AI and education: the importance of teacher and student relations. *AI and Society*, *34*(1), 47–54. https://doi.org/10.1007/s00146-017-0693-8

Gunawardena, C. N. (1995). Social presence theory and implications for interaction and collaborative learning in computer conferences. International Journal of Educational Telecommunications, 1(2), 147–166.

Guzman, A. L., & Lewis, S. C. (2020). Artificial intelligence and communication: A Human–Machine Communication research agenda. *New Media and Society*, *22*(1), 70–86.

Hashimoto, T., Kato, N., & Kobayashi, H. (2011). Development of educational system with the android robot SAYA and evaluation. *International Journal of Advanced Robotic Systems*, *8*(3), 28.

Hassan, I. (1977). Prometheus as performer: Toward a posthumanist culture?. *The Georgia Review*, *31*(4), 830-850.

Haudek, K. C., Prevost, L. B., Moscarella, R. A., Merrill, J., & Urban-Lurain, M. (2012). What are they thinking? Automated analysis of student writing about acid-base chemistry in introductory biology. *CBE Life Sciences Education*, *11*(3), 283–293.

Hayashi, A., Chen, C., Ryan, T., & Wu, J. (2004). The role of social presence and moderating role of computer self efficacy in predicting the continuance usage of e-learning systems. Journal of Information Systems Edu- cation, 15(2), 139–154.

Hollan, J., Hutchins, E., & Kirsh, D. (2000). Distributed cognition: toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *7*(2), 174-196.

Holstein, K., McLaren, M., & Aleven, V. (2019). Codesigning a real-time orchestration tool to support teacher–ai complementarity. *Journal of Learning Analytics*, *6*(2), 27–52.

Huang, R., & Chen, G. (2021). The role of ethics in AI adoption and integration in education: A systematic review. Computers & Education, 163, 104051.

Huang, R., Liu, D., & Chen, G. (2021). Trust in AI in education: A review and research agenda. Computers & Education, 167, 104154.

Huang, W., Hew, K. F., & Fryer, L. K. (2022). Chatbots for language learning—are they really useful? A systematic review of chatbot-supported language learning. *Journal of Computer Assisted Learning*, *38*(1), 237–257. https://doi.org/10.1111/jcal.12610

Hung, J. C. S., Chiang, K. H., Huang, Y. H., & Lin, K. C. (2017). Augmenting teacher-student interaction in digital learning through affective computing. *Multimedia Tools and Applications*, 76(18), 18361–18386. https://doi.org/10.1007/s11042-016-4101-z

Hutchins, E. (1995). *Cognition in the Wild*. MIT press.

Jamsandekar, S. S., Kamath, R. S., & Badadare, V. L. (2020). Adaptive Learning System enabled by Machine Learning: An Effective Pedagogical Approach.

Jarrahi, M. H. (2018). Artificial intelligence and the future of work: Human-AI symbiosis in organizational decision making. *Business Horizons*, *61*(4), 577-586.

Jonassen, D. H. (1994). Technology as Cognitive Tools: Learners as Designers. *ITForum Pape*, *1*(1), 67–80. https://it.coe.uga.edu/itforum/paper1/paper1.html

Jonassen, D. H., Peck, K. L., & Wilson, B. G. (1999). *Learning with technology: A constructivist perspective*. Upper Saddle River, NJ: Merrill.

Kaber, D. B. (2018). A conceptual framework of autonomous and automated agents. *Theoretical Issues in Ergonomics Science*, 19(4), 406–430.

Kara, N., & Sevim, N. (2013). Adaptive Learning Systems: Beyond Teaching Machines. In Contemporary Educational Technology (Vol. 4, Issue 2).

Käser, T., Klingler, S., Schwing, A. G., & Gross, M. (2017). Dynamic bayesian networks for student modeling. *IEEE Transactions on Learning Technologies, 10*(4), 450–462.

Keltner, D., & Kring, A. M. (1998). Emotion, social function, and psychopathology. *Review of General Psychology*, 2(3), 320. https://doi.org/10.1037/1089-2680.2.3.320.

Kelly, S. E., & Westerman, D. K. (2016). New technologies and distributed learning systems. In P. L. Witt (Ed.), *Handbook of communication and learning, 16: Communication and learning* (pp. 455-480). De Gruyter.

Kim, J., Merrill, K., Xu, K., & Sellnow, D. D. (2020). My Teacher Is a Machine: Understanding Students' Perceptions of AI Teaching Assistants in Online Education. *International Journal of Human-Computer Interaction*, *36*(20), 1902–1911.

Kim, J., Merrill Jr, K., Xu, K., & Sellnow, D. D. (2021). I like my relational machine teacher: An AI instructor's communication styles and social presence in online education. *International Journal of Human–Computer Interaction*, *37*(18), 1760-1770.

Koedinger, K., Mclaren, B., Koedinger, K. R., & Corbett, A. (2006). Cognitive Tutors: Technology bringing learning science to the classroom. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 61–77). Cambridge University Press.

Komiak, S. and Benbasat, I. (2006), "The effects of personalization and familiarity on trust and adoption of recommendation agents", MIS Quarterly, Vol. 30 No. 4, pp. 941-960.

Latour, B. (1987). *Science in action*. Cambridge MA: Harvard university press.

Latour, B. (1991). Technology is society made durable. In J. Law (Ed.), A sociology of monsters. (pp. 103–131). London, New York: Routledge.

Latour, B. (1992). Where are the missing masses? The sociology of a mundane artifacts. *Shaping technology/building society: Studies in sociotechnical change, 1*, 225-258.

Lee, A. S., Thomas, M., & Baskerville, R. L. (2015). Going back to basics in design science: From the information technology artifact to the information systems artifact. *Information Systems Journal*, *25*(1), 5–21. https://doi.org/10.1111/isj.12054

Lee, J., & Choi, B. (2018). Development of an AI-based intelligent tutoring system and its effectiveness in a primary school mathematics class. International Journal of Human-Computer Interaction, 34(7), 651-657.

Lee, H.-S., Pallant, A., Pryputniewicz, S., Lord, T., Mulholland, M., & Liu, O. L. (2019). Automated text scoring and real-time adjustable feedback: Supporting revision of scientific arguments involving uncertainty. Science Education, 103(3), 590–622.

Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors*, *46*, 50–80.

Lee, K. (2004). Presence, explicated. *Communication Theory*, *14*(1), 27–50.

Lewis, S. C., Guzman, A. L., & Schmidt, T. R. (2019). Automation, journalism, and human–machine communication: Rethinking roles and relationships of humans and machines in news. *Digital journalism*, *7*(4), 409-427.

Li, H., Liu, Y., Xu, X., Heikkilä, J., & van der Heijden, H. (2015). Modeling hedonic is continuance through the uses and gratifications theory: An empirical study in online games. Computers in Human Behavior, 48, 261–272.

Liu, D., Du, J., Jiang, N., & Huang, R. (2018). The development trend of AI in school education. *Open Education Research, 24*(04), 33–42.

Liu, R., Zhang, X., Liu, T., & Zou, Y. (2021). Exploring trust in artificial intelligence for education: A literature review. Interactive Learning Environments, 1-17.

Liu, Y., & Zhang, D. (2018). Big Data and Education. In J. Voogt, G. Knezek, R. Christensen, & K.-W. Lai (Eds.), The Handbook of Information Technology in Primary and Secondary Education (pp. 81-95). Springer.

Luo, X., Tong, S., Fang, Z., & Qu, Z. (2019). Frontiers: Machines vs. humans: The impact of artificial intelligence chatbot disclosure on customer purchases. *Marketing Science, 38*(6), 937–947. https://doi.org/10.1287/mksc.2019.1192

Matayoshi, J., & Cosyn, E. (2018). Identifying Student Learning Patterns with Semi-Supervised Machine Learning Models. In Proceedings of the 26th International Conference on Computers in Education (pp.11-20).

Mehmood, A., On, B. W., Lee, I., & Choi, G. S. (2017). Prognosis essay scoring and article relevancy using multi-text features and machine learning. *Symmetry*, *9*(1).

Mishra, P., & Koehler, M. (2020). Introduction to the TPACK framework. In Handbook of technological pedagogical content knowledge for educators (pp.1-8). Springer, Cham.

Moussavi, R., Gobert, J., & Sao Pedro, M. (2016). The Effect of Scaffolding on the Immediate Transfer of Students' Data Interpretation Skills Within Science Topics. In Proceedings of the 12th International Conference of the Learning Sciences. Singapore (pp. 1002-1006).

Morita, T., Akashiba, S., Nishimoto, C., Takahashi, N., Kukihara, R., Kuwayama, M., & Yamaguchi, T. (2018). A practical teacher–robot collaboration lesson application based on PRINTEPS. The Review of Socionetwork Strategies, 12(1), 97–126.

Morrison, B. B., & Lowther, D. L. (2021). Trusting the algorithm: A review of research on artificial intelligence and trust in education. Jou of Res on Tech in Edu, 53(2), 204-224.

Mubin, O., Stevens, C. J., Shahid, S., Mahmud, A. A., & Dong, J.J. (2013). A review of the applicability of robots in education. Technology for Education and Learning, 1(1). Resource document.

Nagao, K. (2019). Symbiosis between humans and artificial intelligence. In Artificial Intelligence Accelerates Human Learning (pp. 135–151). Springer.

Nahavandi, S. (2019). Industry 5.0—A human-centric solution. *Sustainability*, *11*(16), 4371.

Naji Meidani, R., & Khajavy, E. (2015). Language Teachers' Conceptions of Intelligence and their Roles in Teacher Care and Teacher Feedback. In *Australian Journal of Teacher Education* (Vol. 40, Issue 1).

Nass, C., & Moon, Y. (2000). Machines and Mindlessness: Social Responses to Computers. In *Journal of Social Issues* (Vol. 56, Issue 1).

Nass, C., Steuer, J., & Tauber, E. R. (1994). Computers are Social Actors. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 72–78.

Neff, G., & Nagy, P. (2018). Agency in the digital age: Using symbiotic agency to explain human–technology interaction. In A networked self and human augmentics, artificial intelligence, sentience (pp. 113–123). London: Routledge.

Nehm, R. H., Ha, M., & Mayfield, E. (2012). Transforming Biology Assessment with Machine Learning: Automated Scoring of Written Evolutionary Explanations. *Journal of Science Education and Technology*, *21*(1), 183–196.

Nourbakhsh, I. R. (2013). *Robot futures*. Cambridge, Massachusetts: MIT Press.

O'Neill, T., McNeese, N., Barron, A., & Schelble, B. (2020). Human–Autonomy Teaming: A Review and Analysis of the Empirical Literature. *Human Factors*.

Pai, K. C., Kuo, B. C., Liao, C. H., & Liu, Y. M. (2021). An application of Chinese dialogue-based intelligent tutoring system in remedial instruction for mathematics learning. *Educational Psychology*, *41*(2), 137–152.

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. IEEE *Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, *30*, 286–297

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human factors*, *39*(2), 230-253.

Pelletier, K., Brown, M., Brooks, D. C., McCormack, M., Reeves, J., Arbino, N., & Mondelli, V. (2021). *2021 EDUCAUSE horizon report. Teaching and learning edition.*

Perry, M. (2003). Distributed cognition. HCI models, theories, and frameworks: Toward a multidisciplinary science, 193-223.

Petersen, S. E., & Ostendorf, M. (2009). A machine learning approach to reading level assessment. *Computer Speech and Language*, *23*(1), 89–106.

Pitardi, V., & Marriott, H. R. (2021). Alexa, she's not human but unveiling the drivers of consumers' trust in voice-based AI. Psychology & Marketing, 38(4), 626–642.

Popenici, S. A., & Kerr, S. (2017). Exploring the impact of artificial intelligence on teaching and learning in higher education. *Research and Practice in Technology Enhanced Learning*, *12*(1), 1-13.

Priestley, M. 2015. Teacher agency: What is it and why does it matter? British Educational Research Association Blog, September. London: Routledge.

Qin, F., Li, K., & Yan, J. (2020). Understanding user trust in artificial intelligence-based educational systems: Evidence from China. *British Jour of Edu Tech,* 51(5), 1693–1710.

Rai, A., Constantinides, P., & Sarker, S. (2019). Next Generation Digital Platforms: Toward Human-AI Hybrids. *Management Information Systems Quarterly*, *43*(1), iii–ix.

Reed, M. (2018). The Classification of Artificial Intelligence as "Social Actors."

Reeves, B., & Nass, C. (1996). The media equation: How people treat computers, television, and new media like real people. *Cambridge, UK*, *10*, 236605.

Rogers, Y. (2006) Distributed Cognition and Communication. In The Encyclopedia of Language and Linguistics 2nd Edition. Oxford, pp. 181-202.

Rogers, Y., & Paay, J. (2014). Reimagining Human-Computer Interaction in the Age of Pervasive Computing. In J. Simonsen & C. Stappers (Eds.), The Encyclopedia of Human-Computer Interaction (2nd Ed.). Aarhus, Denmark: The Interaction Design Foundation.

Roll, I., & Wylie, R. (2016). Evolution and revolution in artificial intelligence in education. *International Journal of Artificial Intelligence in Education*, 26(2), 582-599.

Russell, S. J., (2010). *Artificial intelligence: a modern approach*. Pearson Education.

Salem, M.; Rohlfing, K.; Kopp, S.; and Joublin, F. 2011. A friendly gesture: Investigating the effect of multimodal robot behavior in human-robot interaction. *2011 IEEE*, 247–252.

Schmandt, C. (1990). Illusion in the interface. In The art of human-computer interface design, edited by B. Laurel and S. J. Mountford. Addison-Wesley Pub. Co. 335-343.

Schuetz, S. W., & Venkatesh, V. (2020). The Rise of Human Machines: How Cognitive Computing Systems Challenge Assumptions of User-System Interaction. *Journal of AIS*, *21*(2), 460–482.

Schwarz, A., Schwarz, C., Jung, Y., Pérez, B., & Wiley-Patton, S. (2012). Towards an understanding of assimilation in virtual worlds: The 3C approach. European Journal of Information Systems, 21(3), 303–320.

Seo, S. H., Griffin, K., Young, J. E., Bunt, A., Prentice, S., & Loureiro-Rodríguez, V. (2018). Investigating people's rapport building and hindering behaviors when working with a collaborative robot. *International Journal of Social Robotics*, *10*, 147-161.

Serholt, S., Barendregt, W., Leite, I., ... & Castellano, G. (2014, August). Teachers' views on the use of empathic robotic tutors in the classroom. In *The 23rd IEEE International Symposium on Robot and Human Interactive Communication* (pp. 955-960). IEEE.

Serholt, S., Barendregt, W., Vasalou, A., Alves-Oliveira, P., Jones, A., Petisca, S., & Paiva, A. (2017). The case of classroom robots: teachers' deliberations on the ethical tensions. *AI and Society*, *32*(4), 613–631.

Settles, B., Laflair, G. T., & Hagiwara, M. (2020). *Machine Learning-Driven Language Assessment*. https://doi.org/10.1162/tacl

Seuwou, P., Banissi, E., Ubakanma, G., Sharif, M. S., & Healey, A. (2016). Actor-network theory as a framework to analyse TAM''s external variables. In Jahankhani (Ed.), *ICGS3* (pp. 1–16). Springer International Publishing.

Sharkey, A. J. C. (2016). Should we welcome robot teachers? *Ethics and Information Technology*, *18*(4), 283–297.

Short, J., Williams, E., & Christie, B. (1976). *The social psychology of telecommunications* (Vol. 19, No. 4, pp. 451-484). London: Wiley.

Sabourin, J. L., & Lester, J. C. (2014). Affect and learning: an exploratory look into the role of affect in learning with AutoTutor. Journal of Edu Computing Research, 50(3), 277-301.

Spector, J. M., & Ma, S. (2019). Inquiry and critical thinking skills for next generation: from AI back to human intelligence. *Smart Learning Environments*, *6*(1), 1-11.

Spikol, D., Ruffaldi, E., Dabisias, G., & Cukurova, M. (2018). Supervised machine learning in multimodal learning analytics for estimating success in project-based learning. *Journal of Computer Assisted Learning*, *34*(4), 366–377.

Storbeck, J., & Maswood, R. (2016). Happiness increases verbal and spatial working memory capacity where sadness does not: Emotion, working memory and executive control. *Cognition & Emotion*, 30(5), 925–938.

Straub, I. (2016). 'It looks like a human!' The interrelation of social presence, interaction and agency ascription: A case study about the effects of an android robot on social agency ascription. Springer London: 553–71. doi:10.1007/s00146-015-0632-5

Strich, F., Mayer, A. S., & Fiedler, M. (2021). What do I do in a world of artificial intelligence? Investigating the impact of substitutive decision-making AI systems on employees' professional role identity. *Journal of the Association for Information Systems*, *22*(2), 9.

Suchman, L., & Suchman, L. A. (2007). *Human-machine reconfigurations: Plans and situated actions*. Cambridge university press.

Taylor, R. P. (1980). The computer in the school: Tutor, tool, tutee. In *Contemporary Issues in Technology and Teacher Education* (Vol. 3, Issue 2).

Van Doorn, J., Mende, M., Noble, S. M., Hulland, J., … & Petersen, J. A. (2017). Domo arigato Mr. Roboto: Emergence of automated social presence in organizational frontlines and customers' service experiences. *Journal of service research*, *20*(1), 43-58.

Van Pinxteren, M. M., Wetzels, R. W., Rüger, J., Pluymaekers, M., & Wetzels, M. (2019). Trust in humanoid robots: implications for services marketing. *Journal of Services Marketing*.

Vega-Mendoza, S., Cañada-Cañada, F., & López-Sánchez, J. L. (2021). The Role of AI in the Promotion of Creativity and Critical Thinking in Education. Sustainability, 13(10), 5647.

Waters, C. K. (2007). The nature and context of exploratory experimentation: An introduction to three case studies of exploratory research. *History and Phi of the Life Sciences*, 275-284.

Walkington. (2013). Using adaptive learning technologies to personalize instruction to student interests: The impact of relevant contexts on performance and learning outcomes.

Wang, X., & Cheng, Y. (2019). Lane departure avoidance by man-machine cooperative control based on EPS and ESP systems. *Jour of Mechanical Science and Tech*, *33*, 2929-2940.

Wang, S., Christensen, C., Cui, W., Tong, R., Yarnall, L., Shear, L., & Feng, M. (2020a). When adaptive learning is effective learning: comparison of an adaptive learning system to teacher-led instruction. *Interactive Learning Environments*.

Wang, S., & Vásquez, C. (2020). Artificial Intelligence in Education: Promises and Implications for Teaching and Learning. In M. Khosrow-Pour, D.B.A. (Ed.), Encyclopedia of Information Science and Technology (5th ed.). IGI Global.

Wang, J., Zhao, Y., Zhang, Y., & Yang, J. (2021). Artificial intelligence in education: A review and future directions. Journal of Educational Technology & Society, 24(1), 221-235.

Westlund, J. K., Lee, J. J., Plummer, L. (2016). Tega: A social robot. *The Eleventh ACE/IEEE International Conference on Human-Robot Interaction, 2016*, 561–561. IEEE Press.

Wilson, S. M., & Schwarz, N. (2019). Toward ethical review of algorithms in education. Educational Researcher, 48(1), 38-48. https://doi.org/10.3102/0013189X18821236

Wykowska, A., Chellali, R., Al-Amin, M. M., & Müller, H. J. (2012). Does observing artificial robotic systems influence human perceptual processing in the same way as observing humans?. In *Social Robotics: 4th International Conference, ICSR 2012, Chengdu, China, October 29-31, 2012. Proceedings 4* (pp. 327-337). Springer Berlin Heidelberg.

Xu, C., Ryan, S., Prybutok, V., & Wen, C. (2012). It is not for fun: An exami- nation of social network site usage. Information & Management, 49(5), 210–217.

Xu, W., Dainoff, M. J., Ge, L., & Gao, Z. (2023). Transitioning to human interaction with AI systems: New challenges and opportunities for HCI professionals to enable human-centered AI. *International Journal of Human–Computer Interaction*, *39*(3), 494-518.

Yoo, J., & Kim, J. (2014). Can online discussion participation predict group project performance? Investigating the roles of linguistic features and participation patterns. International Journal of Artificial Intelligence in Education, 24(1), 8–32.

Yoon, S. Y. (2019). Student Readiness for AI Instruction: Perspectives on AI in University EFL Classrooms. *Multimedia-assisted Language Learning*, 22(4), 134-160.

Yun, S.-S., Kim, M., & Choi, M.-T. (2013). Easy interface and control of tele-education robots. International Journal of Social Robotics, 5(3), 335–343.

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). A systematic review of research on AI applications in higher education–where are the educator? *International Journal of Educational Technology in Higher Education*, *16*(1), 1-27.

Zeng, Y., Zhao, Y., Bai, J., & Xu, B. (2018). Toward Robot Self-Consciousness (II): Brain-Inspired Robot Bodily Self Model for Self-Recognition. *Cognitive Computation*, *10*(2), 307–320.

Zhai, X. (2021). Practices and Theories: How Can Machine Learning Assist in Innovative Assessment Practices in Science Education. *Journal of Science Education and Technology*, *30*(2), 139–149.

Zhai, X., Chu, X., Chai, C. S., Jong, M. S. Y., Istenic, A., Spector, M., Liu, J. B., Yuan, J., & Li, Y. (2021). A Review of Artificial Intelligence (AI) in Education from 2010 to 2020. In *Complexity* (Vol. 2021). Hindawi Limited. https://doi.org/10.1155/2021/8812542

Zhai, X., Haudek, Kevin. C., Shi, L., Nehm, R., & Urban-Lurain, M. (2020b). From substitution to redefinition: A framework of machine learning-based science assessment. *Journal of Research in Science Teaching*, *57*(9), 1430–1459. https://doi.org/10.1002/tea.21658

Zhai, X., Yin, Y., Pellegrino, J. W., Haudek, K. C., & Shi, L. (2020a). Applying machine learning in science assessment: a systematic review. In *Studies in Science Education* (Vol. 56, Issue 1, pp. 111–151). Routledge.

Zhang, Y., Liu, C., Li, H., & Li, Y. (2021). Understanding teachers' attitudes toward the use of artificial intelligence in education: a review of the literature. Journal of Educational Technology Development and Exchange, 14(1), 1-18.

Zhao S (2006) Humanoid social robots as a medium of communication. *New Media & Society* 8(3): 401–419.

CHAPTER 4

EXPLORING TEACHERS' PEDAGOGICAL PRACTICES AND EXPERIENCES OF INTEGRATING ARTIFICIAL INTELLIGENCE INTO TEACHING: A QUALITATIVE CASE STUDY[3]

[3] Shi, L. Ding, A. C. E. and Choi, I. To be submitted to the *International Journal of Artificial Intelligence in Education*.

Abstract

This exploratory study investigated a group of six science teachers' teaching practice and experience with an advanced artificial intelligence (AI)-supported science learning and assessment system. Through inductive thematic analysis, this study revealed that AI provides substantial support to teachers, while concurrently, teachers actively support the work of AI during their engagement with and utilization of AI. Moreover, within the dynamic levels of teachers' engagement with AI, two distinct perceptions of the roles of AI emerged among teachers, including considering AI as a facilitating tool and recognizing it as an interactive collaborator. Furthermore, three notable changes in classroom interactions were identified, including the implementation of individualized and personalized instruction and scaffolding, the adoption of data-driven and targeted pedagogical approaches, and shifts in teachers' roles. The findings of this study indicate that the integration of AI in teaching practices has the potential to transcend the conventional roles of educational technology as a mere supportive tool, evolving it into a collaborative partner that fosters a supportive and reciprocal relationship between teachers and AI systems. Furthermore, the study underscores the necessity for teachers to cultivate new mindsets and highlights the significance of professional learning opportunities focused on the effective integration of AI into teaching practices. Finally, we recommend that future research endeavors the interplay between teachers' pedagogical practices and their perceptions of AI within AI-integrated classrooms, thereby advancing our understanding of this subject matter.

Keywords: Artificial intelligence, Human-AI interaction, Teacher experience, Qualitative case study

Introduction

The progressive advancement of artificial intelligence (AI) has enhanced intelligent machines with the capability for engaging in dialogue, exhibiting cognitive and emotional interactions with human users (Guan et al., 2021), and undertaking cognitive tasks traditionally associated with humans, such as learning, thinking, and decision-making (Russell, 2010; Spector & Ma, 2019). Recent studies in AI technology have attracted considerable attention from diverse sectors of society, including the field of education. A broad spectrum of AI systems and tools, such as intelligent tutoring systems, educational chatbots, and automated scoring systems, have been increasingly integrated to facilitate and innovate teachers' instructional practices. For instance, AI-enabled automatic scoring systems enable teachers to assess students' dynamic sensemaking processes by leveraging a variety of constructs, such as essays (Mehmood et al., 2017), constructed responses (Nehm et al., 2012), scientific models (Matayoshi & Cosyn, 2018; Zhai, He, & Krajcik, 2022), and simulations (Gobert et al., 2016, 2023; Käser et al., 2017) and provide teachers with automatic scores and timely feedback, allowing instructional adjustments in a timely fashion (Zhai et al., 2020). Moreover, artificial intelligence (AI) has the capability to undertake multiple responsibilities and fulfill various roles that have traditionally been performed by teachers during the instructional process, including but not limited to monitoring student progress, guiding student learning, delivering personalized feedback, and even engaging in cognitive and emotional communication with students. Consequently, the field of AI in education exhibits a strong enthusiasm for utilizing AI to revolutionize the pedagogical paradigm.

The emerging pedagogical potential of AI in teaching practices enables intelligent machines to step into many roles previously performed by teachers within the classroom setting. Zhao (2006) characterized AI as not only an innovative but also a disruptive technology, thereby challenging the conventional conceptualization of technologies as mere tools or mediators (Jonassen, 1994; Jonassen et al., 1999; Taylor, 1980) for facilitating teaching. The integration of the innovative and disruptive AI technology into teaching practices has the potential to disrupt and transform the dynamics of interaction between teachers and technology. Correspondingly, a body of research has highlighted teachers' apprehension and concerns pertaining to AI, including issues related to trust and the potential displacement of their professional roles by AI (i.e., Ciechanowski et al., 2019; Choi, Jang, & Kim, 2023; Van Pinxteren et al., 2019). Teachers experience a sense of threat emanating from AI's consistent outperformance across multiple domains (Dietvorst et al., 2016), which in turn jeopardizes their competencies and opportunities and blurs the boundaries between the roles of teachers and AI (Serholt et al., 2014). Given the emergent concerns expressed by teachers, it is paramount to investigate how teachers encompass various AI systems in teaching and their experiences pertaining to integrating this nascent technology into their pedagogical realm.

Through a comprehensive literature analysis, some scholarly inquiries have been conducted to understand the potential of an emergent relationship between teachers and AI (Holmes et al., 2019; Seufert et al., 2020) and identified two major research focuses in this emerging research area. Firstly, many studies focused on the design and effectiveness evaluation of AI systems that potentially promote human-AI collaboration (Holstein & Aleven, 2022; Holstein, McLaren, & Aleven, 2018; Horvitz & Paek, 2007; Wilder, Horvitz, & Kamar, 2020).

For instance, Holstein et al. (2018, 2022) developed and tested the effectiveness of smart glasses regarding their functionalities in promoting teachers' complementary with AI and the implications for improving the design. Some studies reported the technical features of designing educational robotics to promote a collaborative modality involving human-robot interaction (i.e., Brink & Wellman, 2020; Edward & Cheok, 2018; Fang et al., 2020; Sharkey, 2016). Even though those AI systems have the features to support the complementary between teachers and AI, a lack of knowledge is generated regarding teachers' experiences and perceptions of AI technology in their teaching practices.

Secondly, the literature suggested some conceptual and empirical efforts in investigating the impacts of AI integration on the emergent relationship between teachers and AI. For instance, Schofield, Eurich-Fulcer, and Britt (1994) conducted an empirical investigation to explore the impact of integrating an AI tutor on classroom social presence. Their study identified the distinct roles of AI and teachers perceived by students, as well as the interplay mechanism among teachers, AI and students. Some recent studies have examined teachers' experience of AI integration in different contexts. For instance, studies have explored the phenomenon of co-teaching between machine tutors and teachers, as observed in the works of Bayne (2015), Holstein et al. (2019), and Kim et al. (2022b). Furthermore, investigations (i.e., Edwards et al., 2018; Guilherme, 2019) have explored the dynamics of teacher-AI communication and its consequent influence on classroom relationships. Some researchers have conceptualized a transition from human-human interaction to a prospective human-AI interaction within AI-integrated educational settings (Guilherme, 2019; Sharkey, 2016). Despite these efforts in investigating the potential influence of AI on classroom dynamics, the current state of scholarly understanding in this field remains limited. There is a dearth of knowledge concerning how the integration of AI technology into pedagogical practices shapes teachers' experiences and perceptions regarding the emergent roles of AI, as well as its potential for fostering a novel teacher-AI relationship. More importantly, according to a recent review study by Prahani et al. (2022) on the research trends of AI in education, only one of the six identified research trends (i.e., teaching method) directly addressed AI implementation in teaching, but with a specific emphasis on how teachers approach instruction in AI-integrated environments.

This study explores the experiential and perceptual aspects of teachers' emergent relationships with advanced AI technology within the context of classroom teaching. To achieve this research objective, we observed teachers' classroom practices incorporating AI and conducted interviews to gather insights into their experiences and perceptions regarding the roles of AI in teaching. Specifically, the study was conducted in middle school science classrooms where teachers incorporated the Inquiry Intelligent Tutoring System (Inq-ITS) as a means of facilitating their science instruction. Inq-ITS is an advanced AI-supported system designed to support middle and high school science inquiry instruction, assessment, and scaffolding (Gobert et al., 2013, 2014, 2023). Inq-ITS encompasses (a) a virtual assistant that provides timely and personalized suggestions and feedback to support students' inquiry practices and (b) a teacher interface that aids and facilitates teachers' immediate and appropriate instructional adjustments. By examining this unique case of AI integration, the study aims to explore teachers' perceptions of the roles of AI and the changes in classroom interactions resulting from the integration of AI into teaching practices. Through an in-depth analysis of teachers' interactions with various features of Inq-ITS during their teaching practices, the study illuminates the dynamic nature of the relationship between teachers and AI and its impact on classroom interactions. Acquiring this knowledge is of utmost importance for researchers, educators, and stakeholders in effectively designing and promoting the integration of AI, thereby ensuring the implementation of innovative instructional practices. The following three research questions guide the study:

(1) How do teachers utilize and interact with an AI-supported science inquiry, assessment, and scaffolding system within their teaching practices?

(2) How do teachers perceive the evolving roles of AI in facilitating and supporting their teaching?

(3) What changes in classroom interactions emerge from integrating the AI-supported science inquiry, assessment, and scaffolding system?

Literature Review

Incorporating artificial intelligence into teachers' instructional practices

Artificial intelligence (AI) distinguishes itself from conventional computer programs as it draws inspiration from human neural systems to comprehend, learn, reason, make decisions, and take appropriate actions (Kok et al., 2009; Russell, 2010). The foundation of AI lies in the assumption and belief that human intelligence can be accurately described to the extent that a machine can emulate it (AI Darayseh, 2023) to perform complex tasks across various domains and tasks, such as smart homes, personalized healthcare, security systems, and self-driving vehicles (Spector & Ma, 2019). As AI continues to advance, it has increasingly been recognized as a crucial pillar in education and holds the potential to support teachers' instruction and bring about transformative changes in their pedagogical practices.

In conjunction with integrating AI into educational settings, extensive research has been conducted to explore how teachers might integrate and interact with various AI systems to assist their instructional practices. Virtual teaching assistants (VTAs) and humanoid social robots have been the focus of many studies, investigating their functionalities and capacities to assist teachers and transform their instructional approaches in different educational contexts (e.g., Arruda et al., 2019; Goel & Polepeddi, 2018; Topal et al., 2021). Conversational chatbots like Jill Watson (Goel et al., 2018) have been developed to autonomously make decisions in responding to student queries, grading assignments, and providing feedback through text or dialogue-based communication and interactions. Similarly, humanoid social robots functioned to adapt actions to students' learning styles, personalities, and emotional states, offering personalized assistance (Fridin, 2014; Morita et al., 2018; Westlund et al., 2016). The literature suggests that VTAs and social robots engage in conversation-based interactions and exhibit human-like behaviors (Fridin, 2014) to assume roles such as tutors and teaching assistants, thereby substituting certain responsibilities and roles traditionally held by teachers, necessitating adjustments in teachers' pedagogical paradigm.

The literature on AI in education indicates that educators have increasingly utilized intelligent tutoring and adaptive learning systems to facilitate personalized learning resources and experiences for students, track their progress, and offer immediate feedback (Jamsandekar et al., 2020; Bagheri, 2015; Wang et al., 2020). The integration of those systems into formal and informal teaching contexts has significantly reduced teachers' workloads and cognitive demands associated with assessment, and providing personalized scaffolding and feedback (Dickler, 2019; Gobert et al., 2013; Moussavi et al., 2016). Moreover, they enable teachers to monitor students' cognitive performance (Gobert et al., 2014, 2023b) and emotional states (Buttussi & Chittaro, 2020; Zeng et al., 2018) in real-time, performing tasks that were previously unattainable by teachers.

Integrating automated assessment systems into the teaching and learning process has brought about significant innovation and transformation in teachers' instructional practice, particularly in assessment activities. These systems have the capacity to recognize and automatically score students' dynamic responses (Ahn & Lee, 2016, Gobert et al., 2023b), such as essays (Mehmood et al., 2017), constructed responses (Li et al., 2019 a, b, c; Nehm et al., 2012), drawings (Matayoshi & Cosyn, 2018; Zhai et al., 2020), simulations (Gobert et al., 2023b, Käser et al., 2017), and games (Karen et al., 2021). This encourages teachers to employ authentic and performance-based assessments (Spikol et al., 2018) instead of relying primarily on traditional multiple-choice items to assess students' complex cognitive skills and higher-order thinking. Automated assessment systems offer teachers prompt scoring and personalized feedback (Jamsandekar et al., 2020; Kara & Sevim, 2013), enabling them to make data-informed pedagogical adjustments. Thus, these systems ambitiously position themselves within teachers' classroom assessment practices, not only as substitutes for teachers in scoring but also as promoters of AI-based innovative assessment practices, and in turn, instructional practices (Zhai, 2021).

The integration of various AI systems into teachers' instructional practices aims to pursue desired and transformative pedagogy. Unlike conventional technologies, AI is manifested to participate in classroom decision-making processes, either by autonomously making decisions through interaction with the environment or by supporting teachers' data-driven decision-making. Educational AI systems strive to generate optimal decision algorithms (Peng & Zhu, 2019) and employ intensive learning techniques to facilitate effective human-computer collaboration (Fang et al., 2020). By engaging in decision-making processes, both teachers and AI systems leverage their respective strengths and synergistically contribute to personalized education.

Teachers' perceptions of the roles of artificial intelligence

The pedagogical potentials of artificial intelligence (AI) in transforming and supporting teachers' instructional activities represent a notable departure from the functionalities typically associated with traditional technologies. Unlike traditional technologies, which have traditionally been employed as tools or mediators to address specific problems or achieve predefined goals in facilitating human-human interactions (Jonassen, 1994; Jonassen et al., 1999; Taylor, 1980), AI possesses the capacity to undertake human cognitive tasks and assume responsibilities akin to those of teachers in classroom settings (Bughin et al., 2018; Lee et al., 2015). Consequently, the advancement of AI systems has given rise to a new form of human-system interaction, prompting the need to investigate how teachers perceive the emergence of AI in their pedagogical practices (Schuetz & Venkatesh, 2020).

Teachers' perception plays a crucial role in understanding their technology implementation and practices (Ghavifekr et al., 2016; Ibili et al., 2019). In the context of AI integration in education, several studies have investigated teachers' perceptions of AI using the technology acceptance model (TCM). For example, Chocarro et al. (2023) identified that teachers' perceived ease of use and usefulness of chatbots lead to higher engagement with chatbots. Similarly, Choi et al. (2023) proposed a revised TCM by incorporating teachers' perceived trust and found that the perceived usefulness, perceived ease of use, and perceived trust of educational AI tools are determinants in understanding teachers' acceptance and use of AI. AI Darayseh (2023) and Wang (2021) used TCM to explain how teachers' perceived ease of use and expected benefits positively correlated with their behavioral intentions with AI in science classrooms.

While the TCM model can explain the correlation between components of teachers' perception of AI and their adoption and behavioral intentions towards AI, previous investigations have primarily focused on teachers' attitudes towards AI accessibility, without providing information on how teachers experience and perceive the unique nature of advanced AI technology. To address this gap, Serholt et al. (2014) conducted a teacher interview and concluded that teachers viewed robot tutors as tools to engage students in group learning and gather information on students' learning progress. Similarly, through a large-scale survey, Chounta et al. (2022) reported that the majority of participating teachers perceived AI as a teacher-facing tool to support them in accessing, adapting, and using multimodal content. The limited research on teachers' perceptions of the roles of AI mainly supports the claim that teachers view AI as a helpful tool in supporting their instructional practices. Therefore, further exploration is crucial to understanding how teachers perceive the roles of AI through their interactions with AI technology, thereby advancing our comprehension of the emergent teacher-AI relationship.

The teacher and AI relationship for dynamic classroom interactions

In traditional educational settings, a teacher-guided approach is typically employed, wherein educators address the entire class as a collective entity, utilizing conventional technologies as tools or mediators. However, the integration of AI in education has demonstrated its potential to surpass other instructional methods in enhancing students' learning outcomes, primarily attributable to its personalized nature (du Boulay, 2016). As a result, students have exhibited a preference for AI assistance over teacher guidance across a range of tasks (Goel & Polepeddi, 2018; Schofield et al., 1994). The "guide-feedback" interaction between teachers and students is altered due to the participation of AI in classroom relationship dynamics and teachers' collaborative teaching with AI (Fang et al., 2020).

Empirical research has begun to delve into the mechanisms through which teachers and AI form a collaborative teaching mode. For example, Divekar (2020) investigated learners engaging in conversation with an AI-supported chatbot while teachers supported the learning process by providing feedback and managing group dynamics. Hsu et al. (2021) discovered that the chatbot played the role of a conversational partner, while teachers assumed the roles of needs analysts and group process managers. Holstein et al. (2019) developed an AI-based classroom orchestration tool to assist teachers in classroom management and decision-making processes. In AI-enhanced learning communities, some researchers have posited that classroom orchestration fosters collaboration between teachers and intelligent machines, with teachers occupying a central role in driving learning activities (Ji et al., 2023; Roschelle et al., 2013). Humble and Mozelius (2019) exemplified systems of AI-supported teaching and teacher-supported AI. However, Ji et al. (2023) and Roschelle et al. (2020) have argued that the existing literature lacks robust evidence to substantiate the mechanism of human-AI collaboration in classrooms, particularly from the perspective of teachers' perceptions and experiences.

The integration of AI is anticipated to bring about transformative changes in teachers' many roles in classrooms (Baker, 2016; Holstein et al., 2020; Kim et al., 2022a). AI systems can effectively address repetitive and time-consuming tasks (Bryant et al., 2020), thereby enabling teachers to allocate their effort to provide personalized scaffolding and make instructional adjustments utilizing AI insights (Wang, 2021). Prior field studies have found that as student work with AI systems, teachers are liberated to provide one-on-one guidance to students who require additional assistance as they circulate through the classrooms (Holstein, McLaren & Aleven, 2017; Kessler, Boston, & Stein, 2019; Miller et al., 2015; Schofield et al., 1994). However, Ji et al. (2023), in their systematic review, found a lack of comprehensive discussion and definition regarding teachers' roles in AI-integrated contexts, highlighting the need for further exploration of this construct to understand the potential shifts in teachers' roles.

To depict the teacher and AI relationship and the corresponding changes in classroom dynamics, we proposed a teacher-AI pedagogical partnership (TAIPP) conceptual framework in Chapter 3 (see Figure 4.1). In the proposed conceptual framework, we outlined the TAIPP in three dimensions: (1) two social agents (i.e., teacher, AI); (2) the interdependent and independent relationship, and (3) the partnering agency between teachers and AI for desired pedagogical goals. We further conceptualized the impacts of TAIPP on teachers in four areas, including pedagogy, cognition, emotion, and classroom interaction. The proposed conceptual framework is comprehensive, demanding a series of studies to investigate the emergent teacher-AI relationship when integrating various AI systems into teaching practices and unpack the consequences in each area. In the current study, we focused on Inq-ITS, a particular AI system that supports teachers in scientific inquiry instruction, assessing students' performance in practice, and providing individualized and timely scaffolding to understand teachers' perceptions of their relationship with AI. In addition, we explored the impact of the teacher-AI relationship in two areas—pedagogy and classroom interaction.

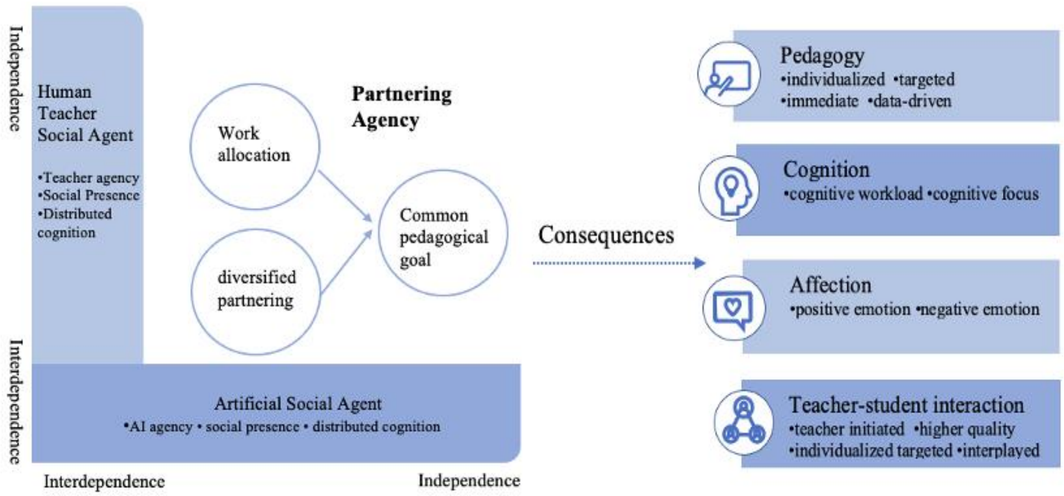

Figure 4.1. The proposed teacher-AI pedagogical partnership framework, see Chapter 3.

Method

The understanding of teachers' teaching practices and experiences concerning technology integration is widely regarded as a subjective, dynamic, and social process, rather than an objective reality that can be examined experimentally (Guetterman & Fetters, 2018). Therefore, a qualitative research methodology was deemed suitable for this study (Baxter & Jack, 2018; Creswell & Creswell, 2017). Specifically, a qualitative exploratory case study approach (Yin, 2014) was employed with the aim to "search for the discovery of meaning and essence in significant human experience with technology" (Douglass & Moustakas, 1985, p. 40). The focus of this investigation was on an in-depth exploration of teachers' engagement with an advanced

AI system and their corresponding perceptions and experiences, an understudied area with limited theoretical understanding and empirical knowledge. Hence, an exploratory case study design was proposed to shed light on this topic. In this study, a case referred to an individual participating teacher, with an emphasis on the significance and dynamic nature of their practices and experiences related to AI integration rather than the frequency of such occurrences (Van Maanen, 1979).

The inquiry intelligent tutoring system

In this study, the Inquiry Intelligent Tutoring System (Inq-ITS, https://www.Inq-ITS.com) served as the designated AI system for examining teachers' practices in integrating AI and exploring their corresponding relationship with AI. Inq-ITS represents an AI-supported virtual environment designed to facilitate science learning, assessment, and scaffolding environment (Gobert et al., 2013; 2014). It incorporates advanced AI technologies, including machine learning, natural language processing, and knowledge engineering. Notably, Inq-ITS offers support to students in engaging in authentic scientific inquiries through the use of virtual labs that can track their progress and provide timely and individualized guidance and feedback (Gobert et al., 2013, 2023b). In addition to its focus on student users, Inq-ITS distinguishes itself by providing teacher support, enabling effective monitoring of student progress and identifying their challenges to provide personalized scaffolding. Figure 4.2 displays the workflow of the Inq-ITS system. The effectiveness of the system has been extensively evaluated through various field testing involving approximately 17,000 teachers and their students, with a primary focus on assessing its impact on science learning outcomes and assessment practices. Given the increasing popularity of this advanced AI system among teachers, this study aims to specifically explore teachers' experiences with Inq-ITS, particularly on their interactions with AI and the emergent teacher-AI relationship. In what follows, we introduce the key features of Inq-ITS.

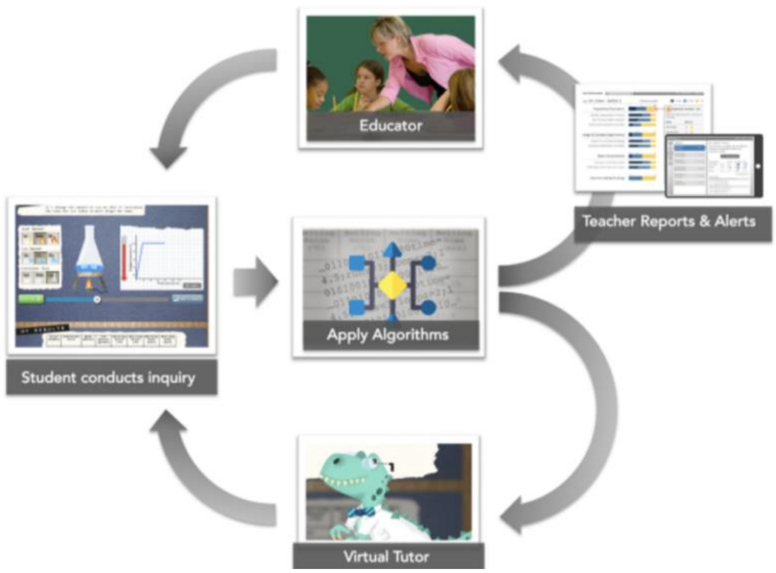

Figure 4.2. The workflow of the Inquiry Intelligent Tutoring System.
Note: Students conduct scientific inquiry in the virtual learning environment. AI algorithms automatically assess their inquiry activities. The virtual tutor supports students' learning in real-time. The AI-generated teacher reports and alerts in the teacher dashboard support teachers' instruction, scaffolding, and assessment practices. Adopted from Gobert et al. (2023b).

The *Virtual Learning Environment* within Inq-ITS offers an extensive range of simulation labs, covering earth science, life science, and physical science for middle and high school levels. Each lab includes several activities, providing students with opportunities to engage in diverse virtual scientific inquiry investigations. These simulations adhere to a structured framework that encompasses various stages, including hypothesis formulation, data collection through multiple trials, evidence analysis, and report communication following the claim-evidence-reasoning format (Dickler, 2019; Gobert et al., 2013; Paquette et al., 2014).

Notably, Inq-ITS leverages advanced AI capabilities to automatically analyze and score students' performance at each stage of the virtual lab, facilitating timely and personalized feedback (Gobert et al., 2013; Moussavi et al., 2016).

The *Virtual Tutor*, as an integral part of Inq-ITS, leverages insights from student interactions with the virtual learning environment to effectively guide students in their scientific investigations (Dickler, 2019). It identifies individual students' challenges encountered at various stages of the inquiry process, offering tailored hints and feedback. These prompts designed and incorporated in the virtual tutor aim to direct and hone students' skill acquisition of specific sub-components of inquiry practices to progress further. By analyzing students' interactions with the system, the Virtual Tutor customizes hints according to each student's unique inquiry path. Students who are progressing well with inquiry proceed with the provided hints and tips as needed.

Inq-ITS integrates the *Teacher Dashboard* as a means of facilitating the communication between teachers and the system, as well as providing teachers with AI-driven insights and support (Dickler, 2019; Gobert et al., 2016; Gobert et al., 2018). The feature equips teachers with three distinct types of actionable data (i.e., teacher reports, real-time teacher alerts, and teacher inquiry practice support), enabling them to enhance their pedagogical approaches and deliver personalized instruction and scaffolding. The teacher reports, using color coding to display students' different levels of proficiency in scientific inquiries, allows teachers to easily visualize students' progress and identify their weaknesses (see Figure 4.3), such as those who were struggling or not performing as expected. The generated teacher reports in Inq-ITS offer valuable insights into the progress of individual students as well as the overall classroom, enabling informed decision-making.

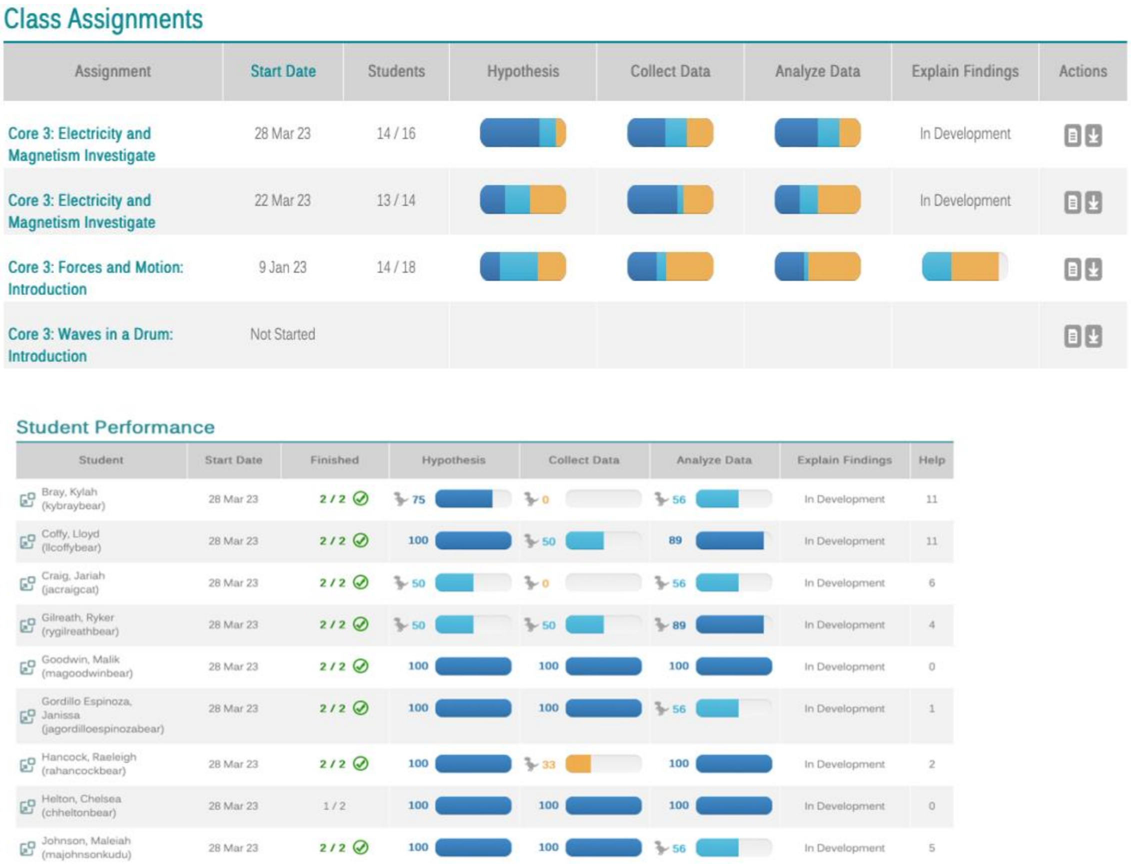

Figure 4.3. The screen captures of classroom-wide (upper) and individual-level (bottom) teacher reports from participating teachers' teacher interface in Inq-ITS, copyright permission was granted.

The second feature of the teacher dashboard is the real-time teacher alerts, which provide timely alerts regarding students who require assistance and identify specific areas in which they are facing challenges, empowering teachers to address student needs promptly (Dickler, 2019). (see Figure 4.4). The third feature is the Teacher Inquiry Practice Support (TIPS, Adair et al., 2020), which encompasses four types of pedagogical strategies and suggestions to guide teachers in effectively instructing inquiry practices, particularly when teachers are confronted with challenges in scaffolding students (Adair et al., 2020; Gobert, 2019) (see Figure 4.5).

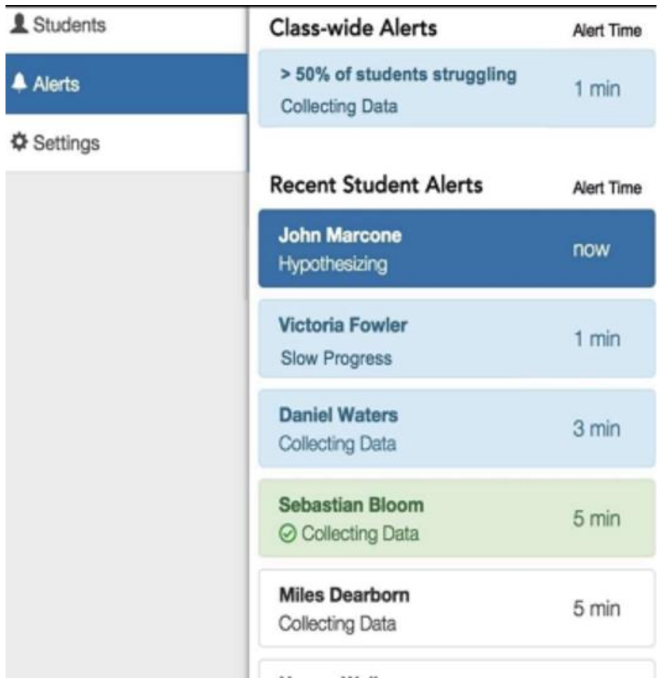

Figure 4.4. The screen captures of real-time teacher alerts from participating teachers' teacher interface in Inq-ITS, copyright permission was granted.

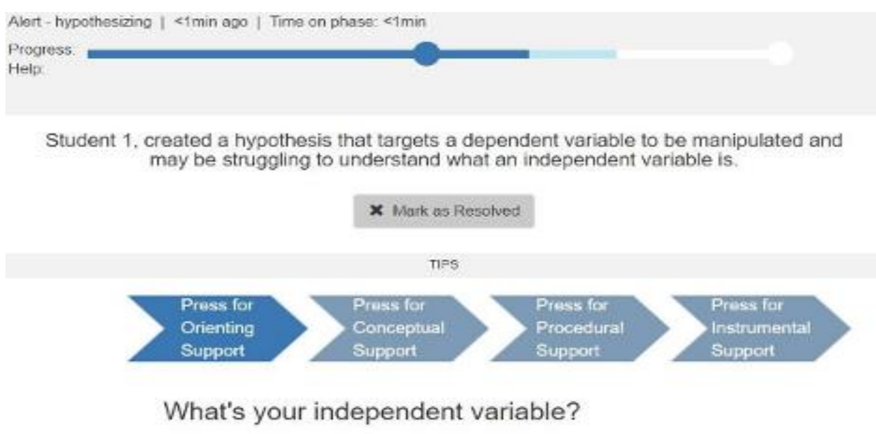

Figure 4.5. The screen captures of TIPS from participating teachers' teacher interface in Inq-ITS, copyright permission was granted.

Research site

This study was conducted in a medium-sized public middle school located in the southeast region of the United States. The school, referred to as Whittemore Middle School to ensure anonymity and confidentiality, serves approximately 650 students in grades six, seven, and eight from diverse racial and socioeconomic backgrounds, including 59% white students, 20% Hispanic students, 14% African American students, and 7% from other backgrounds, primarily Asian. Moreover, approximately 57% of the students are classified as economically disadvantaged, and 6% are identified as English language learners. Whittemore is acknowledged as a well-functioning educational institution for integrating advanced educational technologies. Each classroom is equipped with interactive whiteboards, providing interactive and engaging learning experiences for students. Additionally, both students and teachers have access to Chromebooks and the Internet, which enables them to utilize various technology programs and resources to enhance the teaching and learning process. The school has nine science teachers. As part of its commitment to enhancing science teaching and learning, Whittemore introduced Inq-ITS into science classrooms during the current academic year.

Participants

Participant recruitment

Utilizing a convenience sampling approach (Etikan, Musa, & Alkassim, 2016) to target a particular group of interest (Pedhazur & Schmlkin, 1991), six science teachers from Whittemore were recruited as participants in this study. All nine science teachers expressed their enthusiasm for incorporating AI into their science classrooms and voluntarily provided their consent to participate in this study at the very beginning of the academic year. However, due to considerations of the alignment of Inq-ITS lab topics with their ongoing science classrooms, only six teachers actively incorporated Inq-ITS into their science lessons, thus being eligible to be the participants of this study. This selection ensured that the study captured a representative sample of teachers who had hands-on experience with Inq-ITS and could provide valuable insights based on their practical engagement with the AI-supported learning environment.

The professional background of participants

Participating teachers completed a survey to provide their demographic and professional information at the very beginning of the study. Table 4.1 provides an overview of the collected data, with pseudonyms used to maintain participant confidentiality. The surveyed teachers exhibit a range of experience levels in science teaching, with two teachers categorized as novices (with less than five years of teaching experience) and four teachers classified as seasoned (with more than six years of teaching experience). The survey particularly asked teachers to identify the technology tools they typically utilized to support their teaching practice. The reported technologies included Chromebooks, Google Classroom tools, and various popular programs such as Quizizz and simulations. These tools were commonly employed to prepare and deliver science lessons, as well as to engage students in interactive science activities. Additionally, the teachers were surveyed regarding their prior knowledge of AI. Interestingly, only one teacher, Chelton, indicated having a basic understanding of AI and some previous experience with its application. Specifically, Chelton mentioned utilizing an AI-supported lesson plan automatic generator called Curipod during lesson planning.

Table 4.1. The demographic and professional backgrounds of the participants

Name	Gender	Grade	Science teaching	Traditional technologies used in teaching	Prior AI knowledge
Anna	Woman	Six	More than 15 years	Microsoft tools, Google tools, Generation Genius, Infinite Campus	No
JaFull	Woman	Six	6-10 years	google classroom, progress learning	No
Sarer	Woman	Six	3-5 years	interactive tv, Chromebooks, google slides, EdPuzzle	No
Tidams	Man	Eight	10-15 years	Chromebook, quizizz	No
Chelton	Woman	Eight	6-10 years	online quiz, game, Nearpod	Some knowledge
Rapless	Woman	Eight	1-2 years	PhET Simulation quizizz, quizlet, Canvas	No

The teaching practice features of participants before implementing Inq-ITS

Given the study's focus on exploring teachers' innovative practices with Inq-ITS and the evolving classroom interactions, it is imperative to comprehend the teaching practices within regular classrooms. Thus, we observed teachers' traditional classroom practices and conducted pre-interviews before their implementation of Inq-ITS. Following the inductive coding approach, four features of participating teachers' teaching practices in regular classrooms were identified from the two datasets, even though some variation among teachers.

First, science teaching primarily took place in group-based settings, using a lecture-oriented approach, where all students worked on the same materials regardless of their performance level. Teachers had control over the content and learning activities, functioning as the "strategic pivotal figure in the group" (Goodlad, 1984). The classroom routine typically involved reviewing previous content through activities like online review games. Teachers then continued with lecture-style of teacher-guided group work, using slides. Following this, students were given individual activities or problems related to the lesson, while the teacher managed the classroom order, inspected students' work, and provided explanations when needed.

Second, classroom norms emphasized teacher control, with teachers managing student behavior and enforcing rules. Task-oriented discussions among students were not encouraged, although it was tolerated when students worked on their individual work. Third, it was observed that the teacher-student interaction predominantly manifested as unidimensional, characterized by teachers assuming the role of facilitators through the use of questioning techniques, while students primarily engaged in interaction when seeking assistance or guidance. Teachers rarely actively approached students to provide targeted assistance. More importantly, most questions students asked were simple, such as task clarification and procedures. Fourth, the emotional tone in the classrooms was generally flat, with one teacher, Chelton, bringing a level of enthusiasm to her class by using hands-on activities and various technology tools to engage students. No teacher significantly differed in pedagogical practices or technology use from their peers.

Data collection

To answer the research questions, we collected two sources of data, including Inq-ITS-integrated classroom observations and semi-structured teachers interviews after Inq-ITS implementation. Those methods were chosen to accommodate the limited understanding of teachers' natural experiences with advanced AI systems, necessitating a flexible and exploratory approach.

Classroom observations

Participant classroom observations served the purpose of providing first-hand knowledge and verifying and complementing data obtained from individual teacher interviews. A team of three observers utilized the AI Classroom Observation Sheet (AI-COS) (see Appendix B) to observe each Inq-ITS-integrated classroom. The AI-COS was developed iteratively following a 10-minute interval observation approach (Parker et al., 2019). Observations were conducted using the *full field note method* of data collection (Olson, 1976), which involved taking field notes as factual and correctly descriptive as possible to avoid unwarranted inferences. The observation focused on the classroom context, teachers' and students' actions and interactions, and the utilization of various features of Inq-ITS by teachers and their reactions.

Each teacher taught multiple levels of classes, such as Advanced and Regular classes, throughout the day. The observed classrooms were not purposefully selected based on students' performance levels but on logistical considerations. Teachers were given the flexibility to integrate Inq-ITS into their classrooms at a time they deemed convenient based on their curriculum and timetables. Their choices regarding student groups, learning environments, lesson topics, teaching materials, and methods provided insights into how they utilized Inq-ITS to promote scientific inquiry activities in their specific contexts. Before the observations, four teachers had baseline practices with Inq-ITS. We observed that teachers in the same grade implemented the same lab topic and assigned different numbers of lab activities to their students. In total, we observed 15 classes on two different lab topics (see Table 2). Immediately after each classroom observation, the reflection notes were written to reflect the fresh memory of the observed events.

It is essential to acknowledge the "two-realities problem" (Smith & Geoffrey, 1968), which refers to the possibility that the recorded notes may not capture everything that occurred in the classrooms. Hence, a source of potential bias is the possibility of selectively recording certain types of events, which is impossible to avoid completely in qualitative observations. To minimize potential bias, two observers were assigned to observe the same lab activities happening in some teachers' different classrooms. Comparisons and discussions between observers helped identify individual biases and preconceptions.

Table 4.2. The Inq-ITS-integrated classroom observation information

Teacher	Lab topic	# of lab activities observed *	# of classes observed	Baseline Practice
Anna	Flower	2	2	Yes
JaFull	Flower	1	2	No
Sarer	Flower	2	2	Yes
Tidams	Electricity & Magnetism	2	2	No
Chelton	Electricity & Magnetism	3	4	Yes
Rapless	Electricity & Magnetism	2	3	Yes

Note: *Each Inq-ITS lab topic has three to four lab activities for achieving different goals.

Interviews

All six teachers participated in the pre-and post-interviews. Given the scarcity of literature on interviewing teachers about their AI integration practices, we iteratively developed and revised the interview protocols based on the purpose of the study. The pre-interview invited teachers to reflect on their regular science teaching practice and technology use and lasted on average 16 minutes (see Appendix C).

The post-interview, took on average 40 minutes, aimed to explore how teachers used and interacted with different features of Inq-ITS, as well as their perceptions and experiences regarding the emerging roles of AI and the subsequent changes in classroom interactions (see Appendix D). To gather detailed information, we formulated questions that encouraged teachers to provide descriptions and examples. For example, we asked questions such as, "How does Inq-ITS impact your support and interaction with students?" and followed up with a request for specific examples to illustrate their viewpoints. All interviews were conducted face-to-face at the teachers' convenience within the school premises, and audio recordings were made with the teachers' consent.

Data analysis

The research questions guided the analysis of interview and classroom observations by coding the data based on teachers' engagement with Inq-ITS, as well as their experiences and perceptions. For RQ1, which examined teachers' use and engagement with Inq-ITS features, the post-interview and classroom observations data were analyzed to extract different engagements. For RQ2, which aimed to classify the perceived roles of AI by teachers, the post-interview data were analyzed. Finally, as RQ3 identified emergent changes in classroom interactions that were promoted by teachers' Inq-ITS implementation, classroom observation and post-interview data were used.

Before coding, audiotaped interviews were transcribed. Classroom observation sheets and observer reflection notes for each teacher were organized and indexed. We then read all data for each case several times before actual coding for data familiarization. Given the exploratory research design of this study, we adopted an inductive coding thematic analysis approach (Braun & Clarke, 2006), following the framework and procedures proposed by Miles and Huberman (1984) with two major cycles: initial coding and pattern coding.

Initial coding phase. The first coder independently conducted line-by-line coding using the post-interview and Inq-ITS-integrated classroom observation data from the first case, generating initial descriptive codes. The second coder verified these initial codes, and any discrepancies were discussed until a consensus was reached. Subsequently, the first coder codes the remaining cases, applying initial codes or generating new ones. To ensure the rigor and trustworthiness of the initial coding, the first-cycle coding results were debriefed with a third coder. In total, we generated 125 codes.

Pattern coding phase. After completing the initial coding process, we proceeded to search for themes by conducting code grouping and categorization. For example, within our dataset, we observed clusters of some codes around the interactions between teachers and Inq-ITS. Upon closer examination, we determined that these codes either focused on AI providing support to teachers, or on teachers' responses to additional support for AI, which resulted in two themes for answering the research question one. After iterative classifications and recognition of codes and removing some codes unrelated to our exploration, Eventually, we generated nine distinctive themes, two around teachers' engagement with AI, two around teachers' perception of AI roles, and three around the emerging changes in classroom interactions. These themes provided a mapping of the interview and observation data in relation to our research questions. Upon the completion of this phase, we proceeded to engage in member checking with a cohort of four participating teachers via Zoom and phone. This process involved sharing the themes we had identified and engaging in discussions to address any disparities or inconsistencies pertaining to the utilization of their respective quotes as evidentiary support for each theme. Appendix E presents the data analysis process with examples of initial codes and overarching themes. The frequency of codes and excerpts among the themes and categories is depicted in Appendix F.

Trustworthiness. To respond to the uncertainty of data quality and lack of reliability of case studies (Yin, 2014), we employed specific criteria and rules to establish the trustworthiness of our findings, namely credibility, transferability, dependability, and conformability (Lincoln & Guba, 1985). To ensure credibility, we employed *data triangulation* (Denzin, 2017), comparing and contrasting the findings from individual teacher interviews and classroom observations to ensure consistency. This approach entailed minimizing potential issues with each data source and allowed us to analyze and interpret the data while being mindful of any biases that could arise. Additionally, extensive *peer debriefing* (Lincoln & Guba, 1985) sessions were conducted among three coders to discuss and reach a high level of agreement on data coding, analysis, and interpretation. We further employed the method of *member checking* (Lincoln & Guba, 1985), seeking clarifications and interpretations from the participants throughout the process of meaning-making, thereby ensuring a comprehensive and collaborative exploration of the data. For transferability and dependability, we sought to provide a *thick description* of the context of the investigation (Geertz, 1973), allowing readers to assess the degree of similarity between the study's sites and the receiving ones. This comprehensive description enables readers to determine the applicability of our findings to different contexts. Conformability was achieved through *peer debriefing*, which involved seeking input and feedback from peers using various formats. This iterative process ensured that different perspectives were considered and that the findings accurately represented the data collected.

Findings

To answer the research questions on participants' engagement with Inq-ITS, their perceptions of the evolving roles of AI within teaching practices, and the emergent changes on classroom interactions as a result of AI integration, we reported the emerging themes and corresponding sub-themes from our inductive thematic analysis in this findings section, supported by interview excerpts and classroom observation notes.

Regarding the various features of Inq-ITS, all six teachers included the virtual tutor when assigning the lab activities to their classes. They all utilized real-time teacher alerts in classes to seek AI insights on student challenges. Four teachers (Anna, Sarer, Chelton, Rapless) extensively utilized the teacher report both within the class setting and after class, Sarer and Chelton actively elicited pedagogical support from TIPS.

A mutual and supportive engagement between teachers and Inq-ITS

To answer RQ1 regarding teachers' meaningful utilization and interaction with the advanced AI system within their teaching practices, we identified two primary themes across all participants, through a comprehensive analysis of teacher post-interview and Inq-ITS-integrated classroom observation data, including (1) *AI offers teachers substantial supports* and (2) *teachers actively support the work of AI*. Within each theme, we identified three sub-themes to describe the interaction between teachers and AI.

AI offers teachers substantial supports

The theme was identified through our analysis of teachers' engagement with each individual feature (i.e., real-time teacher alerts, teacher reports, and TIPS) within the Teacher Dashboard.

The teacher alerts support teachers in identifying student challenges in real-time. All six teachers actively employed and engaged with the real-time teacher alerting feature of Inq-ITS to provide scaffolding support to students during their scientific inquiry processes, as exemplified in Figure 4.6. They acknowledged that real-time teacher alerts support their prompt identification of students encountering substantial difficulties or hesitating to seek assistance. Sarer stated that, “I like that even when kids are doing stuff, it helps me figure out who actually needs help… I did have alerts that were popping up constantly of this kid needing help with this. So that helps especially when some students are too afraid to ask.” Consequently, teachers proactively approached particular students and offered specific assistance before students sought their help.

Our analysis further revealed the variations among teachers on their engagement with real-time teacher alerts. Three teachers, namely JaFull, Anna, and Tidams, were observed to have a relatively low level of incorporation of the data from real-time teacher alerts into their instructional and assessment practices in classrooms. They either scaffolded a smaller number of students in one class or checked the real-time teacher alerts less frequently compared to other teachers. This can be attributed, to some extent, to their absence of personal laptops or iPads within classrooms, impeding their ability to access AI data while mobile. Additionally, Tidams expressed physical and cognitive challenges in constantly remaining on the screen due to his low preference in integrating technology into teaching.

The other teachers (Chelton, Sarer, Rapless) were observed to demonstrate a high level of involvement of real-time data and AI insights from teacher alerts into their individualized scaffolding and instruction. They carried personal laptops while mobile and constantly monitored and checked the latest alerts throughout the entire class session. These teachers took a proactive and responsive approach to address individual students’ needs based on the information offered by the real-time teacher alerts. During the interview, Chelton emphasized how she used the real-time teacher alerts to identify students’ specific needs even before they sought assistance, stating, “it would tell me, which kid needed what and when, ... It helps me know which kids need my help faster than they know that they even need help.” Likewise, Rapless reported that this function constantly informed her about a student who repeatedly modified the incorrect variable, enabling her to provide direct assistance.

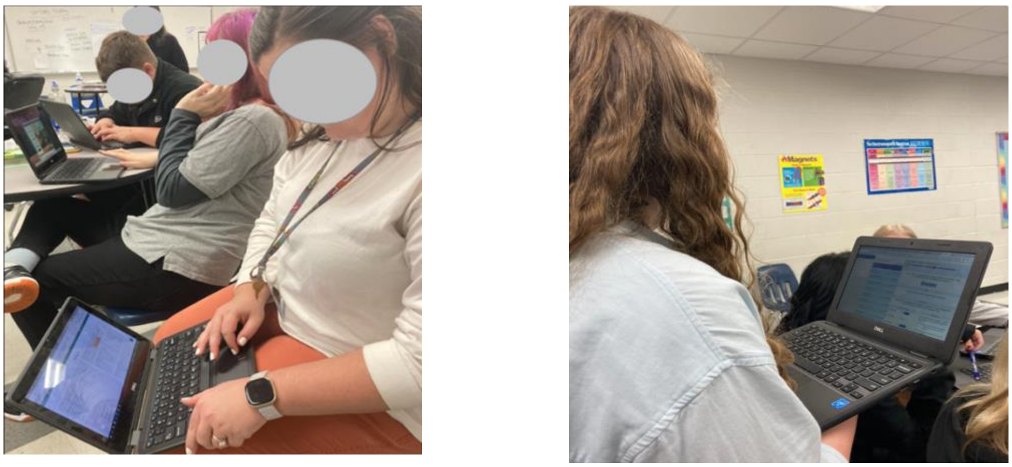

Figure 4.6. Real-time teacher alerts provide teacher support in classrooms.

The teacher reports provide teachers information on student progress. Our data analysis indicated that four out of six teachers (i.e., Anna, Serar, Chelton, Rapless) proactively sought insights on student progress from teacher reports, primarily prior to or after conducting one lab inquiry.

Anna primarily reviewed students’ written responses and the AI-generated feedback available in teacher reports to provide students with corresponding feedback, typically delivered on the following day of the class.

The other three teachers demonstrated a high level of engagement with the teacher reports feature, utilizing its data with various purposes. Firstly, by leveraging the information extracted from teacher reports regarding the observed common challenges among students, these teachers were able to deliver specific and targeted guidance and instruction to the entire class. Sarer, for instance, after noticing their persistent struggles in forming hypotheses and collecting data across multiple labs, "has been doing warmups in the regular classrooms for the past two weeks on identifying independent and dependent variables and formulating hypotheses based on a goal." Similarly, Repless explained that "I think the after reports help drive the instruction of where I should go afterward. Do they get it? Do I feel like they understood the topic? Or do I need to readdress something, or can I extend the topic in some way?" Those post-lab instructions demonstrated how teachers actively used the teacher report feature to acquire valuable information to prepare for future lessons.

Secondly, teacher reports support teachers in understanding students' progress curves and providing particular support to individual students or specific classes in preparation for future lessons. Chelton noted that,

> From the beginning months to the ones we did, and being able to see, I get it like, now my kids are dark blue instead of orange with like hypothesis, data collection. Some kids are still struggling, as a whole, they are getting the growth in understanding the scientific process, and they can prove it with the data. (*Note: dark blue color indicates a higher score, orange color indicates a lower score*).

Teacher reports, for instance, informed Rapless that a high-performing student obtained zero scores in every step of an inquiry activity, enabling her to promptly engage in communication with the student to identify and address the underlying problems immediately in class.

Teacher inquiry practice support provides teachers with expert advice. The data revealed that Sarer and Chelton actively utilized and engaged with TIPS during their classroom instruction and scaffolding activities. They primarily implemented one or more types of pedagogical suggestions from TIPS to support their scaffolding efforts. Sarer specifically expressed her appreciation for the expert advice provided by TIPS, which she could incorporate directly into her scaffolding of students. She mentioned that this distinct feature sets Inq-ITS apart from traditional technologies that often fall short in offering solutions to teachers, stating,

> It helped me know as a first-year science teacher what I need to be telling them to fix it. Instead of me trying to figure out what they're supposed to know. It tells me what they’re supposed to know.” Whereas “other technology programs just assume that teachers know how to help students without offering solutions. – *Sarer (post-interview)*

Chelton expressed that she directly utilized sentences from TIPS to initiate conversations with individual students and deliver instructions to the entire class when faced with challenges in scaffolding students, drawing upon her professional expertise in addressing specific difficulties. Figure 4.7 is an example, capturing teachers’ utilization of TIPS within the classroom setting while providing scaffolding support to a particular student.

Additionally, our findings revealed challenges that teachers encountered in integrating TIPS into their instructional practices. Some teachers expressed concerns regarding the reliance on predetermined instructions provided by TIPS for each step, posing a challenge to the integration of their knowledge and experience into the instructional process. Moreover, certain teachers reported frequent overlooking of TIPS due to the small size and light color of the TIPS button, as well as its placement within the constantly changing teacher dashboard interface.

Figure 4.7. Classroom photo of teachers scaffolding students using TIPS.

Teachers actively support the work of AI

Three sub-themes emerged from the data, highlighting the active support provided by teachers in facilitating the work of AI.

Teachers preparing students with sufficient prior knowledge prior to using Inq-ITS. The classroom observation revealed that teachers prepared students with important prior knowledge (e.g., key inquiry terminology) and appropriate procedure to conduct scientific inquiries prior to lab activities in Inq-ITS. Five teachers, except for Tidams, imparted the necessary prior knowledge to students by utilizing varied experimental scenarios and guiding questions at the very beginning of the class (see Figure 4.8). For example, teachers instructed students to understand critical terminologies in Inq-ITS, such as understanding what the hypothesis is, how to test the hypothesis, and the proper way to conduct scientific experiments by changing one variable each time.

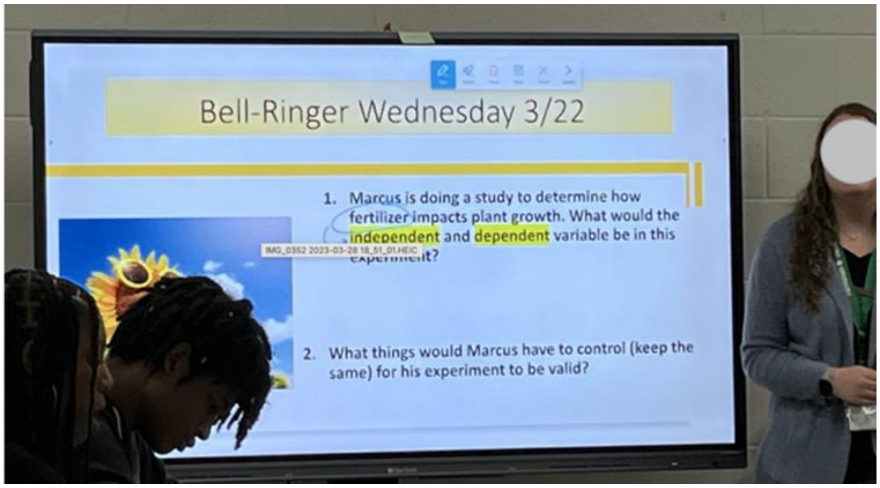

Figure 4.8. Teachers prepare students for Inq-ITS by providing some key inquiry terminology.

Teachers facilitate Inq-ITS during its guidance of students' independent learning. The data analysis indicated that teachers provided continuous support for Inq-ITS by frequently reminding students of the appropriate steps in working on Inq-ITS. In particular, teachers provided guidance to students on essential procedures and demonstrated proper scientific inquiry practices as needed. When students were off track, teachers advised them to "collect data to match what you are looking for" (Chelton classroom observation) and "try to obtain as much data as possible to support your hypothesis" (Rapless classroom observation). Furthermore, teachers modeled proper scientific inquiry techniques for the entire class by guiding them to reiterate the lab goal, structure their hypotheses, and modify one variable each time to collect data.

Additionally, all teachers constantly directed students to follow the feedback and tips provided by the virtual assistant, Rex. Rapless advised students, "There is a dinosaur called Rex, you should listen to him." Chelton encouraged and suggested students to trust Rex and read the feedback from it carefully. She commented that Rex will guide students to the appropriate direction of the inquiry practices. Sarer advised students to "read carefully about the tips from

Rex, click what should you do next instead of clicking ok." Likewise, JaFull referred to Rex as a "virtual tutor" who would provide assistance if students failed to make scientific sense.

Teachers step in to help when Inq-ITS is insufficient in guiding students' learning. The data indicated the low accessibility of Inq-ITS for certain groups of students, such as English language learners (ELLs) and those with low reading abilities, who struggled to understand and apply the tips provided by the virtual assistant, Rex. Some students even perceived Rex as disruptive and annoying when they encountered difficulties to solve their problems following the feedback from Rex. Some students even experienced nervousness and discomfort when receiving many comments from Rex.

In those cases, students preferred seeking help from teachers instead of relying on AI-based instruction and perceived teacher assistance as more specific and useful. Teachers intervened proactively and provided individualized assistance to support the work of AI.

Teachers indicated that they possess a personal understanding of their students, allowing them to accommodate their professional knowledge and experiences with the feedback from Inq-ITS, as well as students' unique personalities, to provide tailored and personalized help. Teachers mentioned that they usually support AI's work by assisting a few students during each lab activity, as the majority were able to work effectively with the AI system. Chelton stated,

> First, the students can work with the AI system, and other than that, teachers can jump in to help… When it was not working for that kid, I stepped in, which, again, were only three or four kids consistently, the majority of students were enough to read and go. – *Chelton (post-interview)*

Two distinct perceptions of the roles of AI among teachers

Regarding RQ2 of teachers' perceptions of the evolving roles of AI in facilitating and supporting their teaching, the data analysis revealed a continuum, ranging from considering AI as a *facilitating tool* to recognizing it as *an interactive* collaborator.

Inq-ITS is considered a facilitating tool

Inq-ITS was considered as an additional *facilitating tool* by three teachers, namely Anna, JaFull, and Tidams, in enhancing their teaching methodologies.

While acknowledging the distinct purpose of Inq-ITS, as articulated by Anna, "Inq-ITS just has its own purpose as a strategy, a tool," these teachers placed emphasis on the functional similarities between Inq-ITS and conventional technologies. This viewpoint is reflected in the following excerpts:

> I think of it more as a useful tool. We have so many things, lots of platforms that I see as being apart. To me, Inq-ITS is just one part of science. I am still doing similar things… But I still want to have my teacher role in the classroom, … I get to be a real teacher to students. It is a good tool to help me do things better than I was doing them before.— *JaFull (post-interview)*
>
> It Is definitely a good, really good supportive tool to help me do those things better than I was doing them before. But I am going to keep doing things I would be doing anyway. – *Tidams (post-interview)*

These teachers underscored that Inq-ITS integration would not significantly alter their existing teaching strategies and routines. This was particularly evident in the case of Tidams, who acknowledged a lack of technical proficiency and demonstrated less motivation to incorporate new technologies that might disrupt his established teaching routine.

Inq-ITS is recognized as an interactive collaborator

The data revealed that other teachers (Chelton, Rapless, and Sarer recognized Inq-ITS as an emerging *interactive collaborator*, encompassing two categories: (1) *a collaborative partner* and (2) *a consultant.*

Collaborative partner. Inq-ITS was perceived as *a collaborative partner,* actively involved in guiding students' independent inquiry, monitoring their progress, and assisting them with personalized feedback. In this regard, Rapless expressed excitement, stating, "He is definitely like a teacher's assistant. He is able to watch every student at the same time. Like another teacher to assist the classroom." The collaborative role enabled teachers to redirect their attention to other important tasks, such as providing targeted support to low-performing students and those in need of additional guidance. Chelton acknowledged that she could dedicate her focus to struggling students while other students followed Inq-ITS's guidance and feedback. Sarer mentioned that she no longer had to spend excessive time providing individual assistance to students, allowing her to engage in other meaningful activities such as reviewing lab reports and offering valuable feedback.

Furthermore, Inq-ITS was perceived as a collaborative partner due to its capability to undertake tasks that were previously deemed impossible for teachers to accomplish independently, including the provision of certain lab materials and content, facilitation of individual-based scientific inquiry, and the delivery of immediate and personalized feedback, suggested by teachers. For instance, Chelton stated,

> We could not put the TV up and expect kids to do what they need to do. But I think this is definitely true. It takes over a lot of the work and during the lab, it does the majority of the work for you. … It is more than what we would do normally. Because there is no way that I can meet with all of my children, specifically about whatever they are struggling with, that is impossible. But this makes it to where it can – *Chelton (post-interview)*

Consultant. Inq-ITS was also perceived as *a consultant*, an intelligent expert that teachers could rely on and consult for valuable support. Teachers regarded Inq-ITS as a reliable entity that keeps them informed with valuable insights on each student's progress. Rapless expressed, "It is nice to kind of feel like I have a second person to like, they are not doing that right, you might want to go check on them." Moreover, teachers valued Inq-ITS as a pedagogical expert capable of offering guidance on appropriate pedagogical strategies to scaffold student challenges. Sarer enthusiastically remarked, "That is what really makes it feel like there is another person. Like I have someone to consult. He is telling me they have a problem. He is going to help me fix it."

Three emergent changes in classroom interactions

Three overarching themes pertaining to shifts in classroom interactions emerged across six participants: (1) *individualized and immediate instruction and scaffolding*, (2) *data-driven and targeted pedagogical approach*, and (3) *shift in teachers' roles*.

The implementation of individualized and personalized instruction and scaffolding

Regarding their traditional classroom paradigm, most teachers shared that they typically followed a teacher-directed or group-based activities format, where individual assessment and feedback were challenged due to "time constraints and the collaborative nature of group work"

(Chelton). Another challenge was to accurately assess each student's degree of contribution within the group, particularly when "there was a clear leader in the group who represented the work of their group", as noted by Rapless.

In Inq-ITS-integrated classrooms, a shift towards individualized and personalized instruction and scaffolding emerged through a collaborative interaction among the teacher, student, and AI, transforming the traditional group-based instruction.

Firstly, the virtual tutor, Rex, popped up constantly when students encountered problems at various stages of their inquiry, delivering personalized hints, tips, and feedback to each student. Most teachers stated that the majority of students were able to effectively engage with Inq-ITS for independent scientific inquiry, progressing at their own pace. In our classroom observations, we witnessed students actively utilizing the immediate and personalized feedback provided by the virtual assistant, Rex, at an individual level to facilitate their ongoing learning. Rapless articulated the individualized feedback from AI, stating, "As if I were able to watch students type every word and give feedback every time like, I think his feedback is great. And it is what I would want to give each student at the individual level."

Secondly, the analysis of classroom observations provided compelling evidence of teachers' adoption of individualized pedagogy when integrating AI into their teaching practices. All teachers reported being able to acquire individual student progress immediately, given the automatic assessment of student performance by Inq-ITS. Notably, no one student could represent the other students anymore, as highlighted by Sarer, which demands the address of students' needs at individual levels. By leveraging individual student progress, teachers were excited that they could address students' problems and provide teacher-adjusted feedback at the individual level. Chelton noted that there were more mini sessions, such as 30 seconds, and 45 seconds, for her to interact with more individual students within the same amount of time.

The adoption of data-driven and targeted pedagogical approaches

Another notable change in classroom interactions was the shift toward teachers' adoption of data-driven and targeted pedagogical approaches.

Firstly, The data revealed a significant utilization of AI-generated insights by teachers to identify learners who were encountering difficulties and necessitated additional instructional support, thereby exemplifying a shift away from traditional reliance on subjective observations and student self-reporting. The majority of teachers reported swift identification and consistent focus on a select group of students who exhibited the greatest struggles within each class. These students typically included ELLs, low-performing students, and those who displayed off-task behaviors. As elucidated by Chelton, the utilization of Inq-ITS enabled her to "interact with the students who needed me most rather than usually I am addressing every student and I am not sure whom to target necessarily." Likewise, Rapless expressed that "I also enjoy how it told me that this student has a more serious alert, which helps me kind of narrow down whom to focus on. It did, it definitely helped me, like I said, with the more serious alert helping me pick the kind of critical kids who really needed my focus, who and whom Rex wasn't helping enough, and who needed that teacher intervention."

Secondly, upon the utilization of real-time data from Inq-ITS, we found that teachers can accurately identify specific challenges faced by individual students to deliver precise and tailored assistance. Four teachers (Tidams, Chelton, Rapless, Sarer) particularly highlighted their ability to offer targeted scaffolding as they possess the knowledge of students' struggles according to the data and insights provided by Inq-ITS. Chelton mentioned, “Most of the time, I am just reviewing what the kids are struggling with while they are doing it…I am just kind of looking through the data to see where the kids are at.” Consequently, teachers are able to gain a comprehensive understanding of students’ difficulties as they approach them, reducing the time spent on problem identification and allowing more focus on problem-solving, promoting higher-order thinking skills. Serer’s statement further supports this notion, “I am spending less time with each kid. And I already know what they need help with, so I can provide better help for solving their problems.” Particularly, Tidams emphasized that,

> Because of the way the system guides you through. It helps you answer the questions that they have. ... Because in your mind, you are thinking that it is very simplistic, but in their mind, it’s not. …the system directs you on where you need to go and tells you this is what they actually need.

Moreover, in classrooms where Inq-ITS was integrated, teachers also engaged in targeted interactions with the entire class when multiple alerts were received regarding a majority of students’ struggles with a particular concept or task. Consequently, teachers proactively address the issue by making announcements to the whole class, maintaining a focused pedagogy. Rapless expressed this by stating, “I would notice if I had five alerts all for students struggling with the hypothesis, I can make an announcement to the whole class.”

Shifts in teachers’ roles

By analyzing the classroom interactions in Inq-ITS-integrated classrooms, a notable shift in teachers’ roles emerged, including three aspects, (1) focusing more on actual teaching, (2) becoming students’ final source of assistance, and (3) conducting more data analytics work.

Teachers focused more on actual teaching and less on classroom management. In regular classroom settings, many teachers perceived one of their primary roles as that of "a classroom manager and a guide" (Rapless) to manage the classroom order and keep students on track. This sentiment is echoed by Sarer, who expressed the feeling that, "A lot of times teaching can feel a lot, like you're just maintaining, maintaining order and making sure like keeping students on task. And I don't always feel like I'm actually getting to teach them like impart knowledge on".

However, when integrating Inq-ITS to help them keep students on tasks, teachers emphasized their roles and responsibilities have been shifted to "help students be deeper thinkers" (Rapless), to "assist higher-order thinking" (Chelton), and to "be the teacher to help students with their specific needs" (Sarer), to "be involved with particular students" (Tidams). Thus, teachers can be less on the procedure of what they should do, but more on the content of what they are actually doing and how well, as stated by JaFull.

Teachers become students' final source of assistance. Upon integrating Inq-ITS into classrooms, a notable observation was the active engagement of students with the virtual assistant, Rex, seeking feedback and assistance throughout various stages of their independent inquiry practice. It became evident that teachers became the ultimate source of support for students. Students typically seek help from teachers when they are unable to solve their problems under the guidance of the virtual tutor, Rex. This shift in student reliance showcased a departure from teachers' role in traditional classrooms, where teachers typically serve as the sole resource.

Teachers conduct more data analytics work. With the integration of Inq-ITS into classrooms, analyzing various data generated by the AI system to gain insights into students' progress and challenges has emerged to be teachers' crucial responsibility. For instance, Rapless demonstrated her utilization of teacher report data across multiple labs to track students' progress over an extended period, which allowed her to adjust instruction accordingly. Tidams also acknowledged the need to adapt teachers' data analysis practices, stating, "My responsibility would be to learn how to identify and analyze data differently... My role would have to change, and I would need to approach data differently than I have in the past."

However, teachers also faced challenges and experienced a sense of being overwhelmed when dealing with substantial amounts of data, particularly in classrooms with a significant number of students, evidenced by the following excerpts:

> I was almost overwhelmed with all the real-time alerts coming up. At the moment, there were more alerts than I expected to address. I mean, so many alerts and there is no way I could address every student. So definitely stress in that way. – *Rapless (post-interview*)
>
> The more data you have, the more things you have to look at….If you did this with every class, you would take a long time to get through it if you had to evaluate each student. We do not have that time. – *Tidams (post-interview*)

Discussion

Despite the burgeoning adoption of AI technology in the field of education and the emergence of AI in education as a multidisciplinary research field, there remains a conspicuous paucity of in-depth understanding regarding the evolving relationship between teachers and AI, particularly through teachers' engagement with AI and related experiences. Without such comprehensive understanding, the effective promotion of teachers' acceptance of AI and the successful integration of AI into pedagogical practices would be significantly impeded. The current study employed an exploratory case study design methodology to explore how in-service teachers utilized and engaged with Inq-ITS, an AI-support science inquiry instruction, assessment, and scaffolding (Gobert et al., 2013, 2014, 2023) system and their corresponding perceptions and experiences. We reported three major themes from teachers' practices with Inq-ITS (see Figure 9). To understand teachers' interaction and engagement with AI, we discovered (1) a mutual and supportive engagement between teachers and Inq-ITS, with respect to AI offers teachers substantial support and teachers support the work of AI. Within teachers' teaching practice with Inq-ITS, two distinct perceptions of the roles of AI emerged among teachers. Additionally, in Figure 4.9, we highlight the interplay between teachers' engagement with AI and their perceptions of AI roles. Specifically, our findings indicate that teachers tend to view AI as an interactive collaborator when they demonstrate a high level of engagement with the diverse features offered by Inq-ITS. From teachers' engagement with and perceptions of AI, three changes in classroom interactions emerged. In what follows, we discuss our findings in four aspects with knowledge generation and empirical implications.

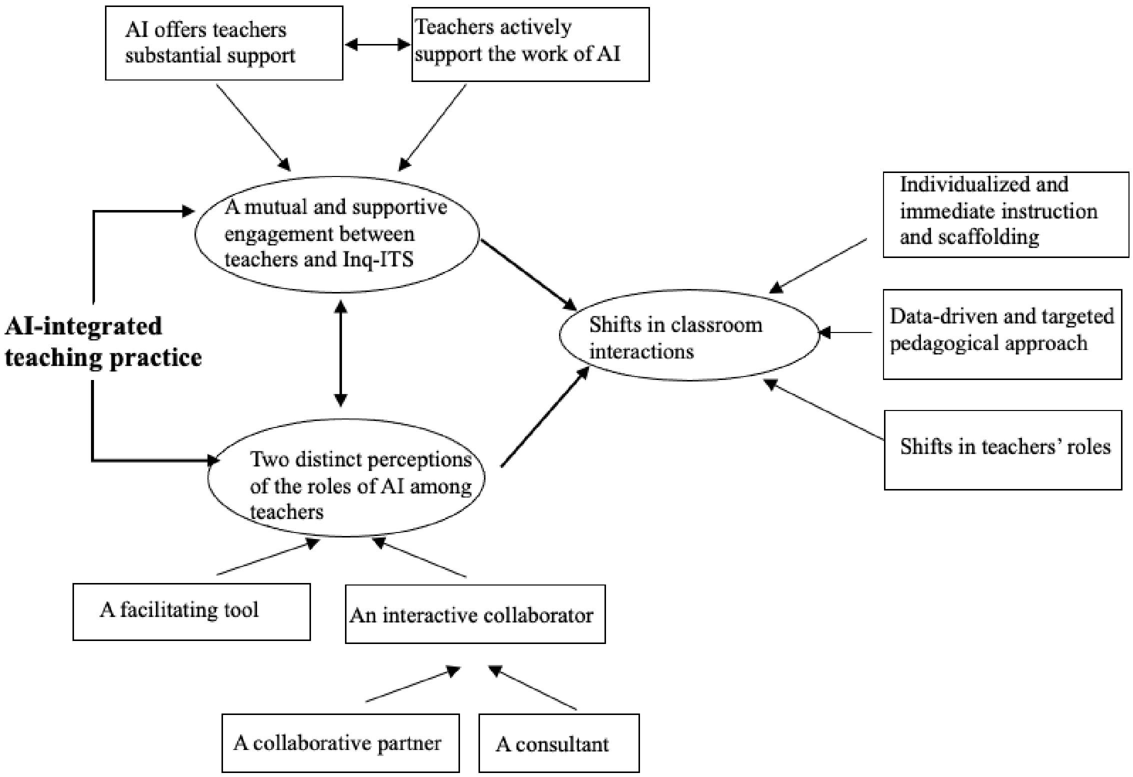

Figure 4.9. The emerging themes regarding teachers' practices and experiences in AI-integrated classrooms.

The emergent supportive and mutual relationship between teachers and AI

Schuetz and Venkatesh (2020) have posited that the rapid advancements of AI technology, with its capabilities to perform various cognitive tasks, have challenged conventional assumptions regarding technology as a medium for human-human interactions. Researchers have reported that AI-enabled automated systems are progressively replacing human roles and decision-making processes (Lewis et al., 2019; Strich et al., 2021), essentially excluding humans from these tasks. Consequently, the emerging relationship between humans and AI has become a pressing research issue, given the pervasive integration of AI across every sector of society and its transformative impact on the human-human and human-technology relationship dynamics. To address this issue, a recent line of research across diverse academic disciplines has endeavored on examining the evolving relationship between humans and AI in the context of completing diverse tasks in dynamic environments. Various labels, such as human-AI teaming (e.g., Brill et al., 2018), human-autonomy teaming (e.g., Brandt et al., 2018; Cummings & Clare, 2015; O'Neill et al., 2020), human-AI symbiosis (e.g., Jarrahi, 2018; Nagao, 2019), and human-robot collaboration (e.g., Ciechanowski et al., 2019; Seo et al., 2018), have been employed to characterize this evolving relationship.

In the context of education, Zhao (2006) long ago called for researchers' attention to the social implications of human-like AI technology. Some research has been conducted to focus on the effectiveness of human-AI collaboration that leveraged the strengths of humans and AI systems (Holstein & Aleven, 2022; Holstein, McLaren, & Aleven, 2018; Horvitz & Paek, 2007; Wilder, Horvitz, & Kamar, 2020). However, limited scholarly knowledge is known about the dynamic process of human and AI relationship formation and its potential consequence, particularly through the lens of teachers' instructional practices.

In the present study, the data revealed a reciprocal and mutually beneficial interaction between the AI system and teachers, wherein they effectively supported and complemented each other's work. Particularly, during teachers' engagement and interaction with various features of Inq-ITS, Inq-ITS proactively offers teachers substantial support to facilitate their instructional activities. For example, real-time teacher alerts provide teachers latest alerts for them to track student progress, identify the student with the most challenge, and employ a proactive and responsive approach for targeted scaffolding. In addition, teacher reports are employed by teachers both in class and after class for them to identify students' progress curves and deliver specific instruction to individual students or the entire class. Furthermore, TIPS supplies teachers with consultative information for them to adapt and incorporate into their instruction and scaffolding. Meanwhile, the relationship between teachers and AI is a two-way interdependent relationship. Teachers actively support the work of AI in three aspects, including preparing students with sufficient inquiry knowledge for them to work on Inq-ITS, guiding and mentoring students the appropriate way to use the feedback from Inq-ITS, and stepping in when Inq-ITS is insufficient in guiding student inquiry. The emerging mutually supportive relationship between teachers and AI signifies an interdependent dynamic in pedagogy, aligned with the proposed teacher-AI pedagogical partnership in Chapter 3 to a great degree. While previous studies have emphasized the collaborative efforts of teachers and AI in providing different forms of support to students for their effective learning (Fang et al., 2020; Holstein et al., 2019; Kim et al., 2022b), our findings indicate mutual support between teachers and AI, departing from prior perspective. Mutual support signifies a harmonious balance and complementary between the AI system and teachers to support each other. This finding holds significant implications in conceptualizing AI as an emerging player in teaching practice. It underscores the collaborative nature of the partnership between AI and teachers, as they divide their responsibilities and provide mutual support to achieve desired pedagogical goals.

AI emerges from merely a supportive tool to a collaborative partner

Conventional technologies, although useful in certain aspects, are limited in their capabilities to independently guide students' learning and support teachers in effectively monitoring individual students' progress simultaneously for them to provide personalized and targeted scaffolding and make instructional adjustments, especially in larger classrooms. Moreover, conventional technologies typically serve as a channel for human-human communication and interaction, rather than actively participating in human-machine communication (Guzman & Lewis, 2020). Thus, within the field of science and technology research in educational contexts, conventional technologies have traditionally conceptualized and utilized as a mere assistive tool or mediator (Jonassen, 1994; Jonassen et al., 1999; Taylor, 1980). Teachers and students are the primary players in conventional technology-integrated classrooms.

Given the increasing integration of AI in various educational contexts, there has been a growing interest in exploring teachers' perceptions of AI roles. Several studies have reported that some teachers tend to view AI primarily as a tool for their own support in accessing, adapting, and utilizing multimodal content (Baker & Smith, 2019; Chounta et al., 2022; Ouyang & Jiao, 2021). Our findings regarding teachers' perceptions of AI roles contribute significantly to the existing body of research in this field by identifying the evolving roles of AI within teaching practice. In our study, we discovered that AI is not merely perceived as a tool but rather holds an emerging role as a collaborator. Teachers began to realize the unique functionalities of AI in teaching and perceived it as an emerging interactive collaborator, encompassing the roles of a collaborative partner and a consultant. As an emerging collaborator in the classroom, AI allows teachers to divide their labor, seek assistance and insights, and rely on AI for recommendations. Furthermore, teachers perceive their own roles as shifting towards a focus on teaching, with AI serving as a supplementary resource for guiding students' learning and providing feedback. In light of these emerging roles of AI as perceived by some teachers, we argue that AI distinguishes itself from traditional technologies, which mainly serve as tools or mediators without the ability to automate or make decisions. As AI gradually assumes the role of a collaborator and partner in classrooms, it becomes actively involved in the decision-making process, as exemplified by the functionalities of Rex and TIPS in Inq-ITS, where independent decisions are made to support students and teachers. Consequently, teachers collaborate with AI in a manner similar to collaborating with another human teacher in the classroom, facilitating appropriate instructional adjustments and scaffolding.

The findings of this exploratory study on teachers' perceptions of the roles of AI aligns with Xu et al.'s (2023) conceptualization of AI's dual role as "an assistive tool plus a collaborative teammate" (p. 496), transitioning technology from a tool primarily supporting human actions and operations to a potential collaborator and team member (Brill et al., 2018; O'Neill et al., 2020). This emerging collaborator and team member can interplay with teachers for personalized support and improved student learning outcomes (Jacobson et al., 2020; Xiong et al., 2019) in various educational contexts. Furthermore, the AI partner actively engages in both human-human communication and human-machine communication, serving the role in identifying student issues and creating opportunities for teachers to assist in problem-solving. This active involvement of the AI partner contributes to fostering a more positive and constructive conversation between students and teachers.

As AI evolves to be a partner and collaborator with teachers in their instructional practices, it is contended that AI emerges to be a new player, engaging in human-machine interactions and communications and performing tasks that traditionally demand human cognition (Guzman & Lewis, 2020). This departure from the traditional assumption of a two-player paradigm consisting of teacher and students in classrooms necessitates a shift in teachers' mindsets, emphasizing the concept of working *with* AI technology rather than solely working *through/by* it (Rogers & Paay, 2014). It is particularly evident when teachers perceived AI as a partner, a consultant, and a second person in classrooms. Nevertheless, further empirical investigations are warranted to examine the dynamics of this emerging AI participant in pedagogy and its interactions with teachers.

The interplay between teachers' perception of AI and their pedagogical practice

To date, a considerable body of research has focused on exploring teachers' attitudes toward the integration of AI technology in education. These studies have investigated various aspects, including (1) the impacts of teachers' AI competence on their perceptions of the roles of AI (Indira, Hermanto, & Pramono, 2020; Ng et al., 2023), (2) the relationship between self-efficacy beliefs and acceptances and AI use in classrooms (Al Darayseh, 2023; Banzon, Walker-McKnight, & Taub, 2022; Choi, Jang, & Kim, 2023), and (3) the relationship between teachers' AI trust and their classroom practices (Lindner & Romeike, 2019; Serholt et al., 2017; Sharkey, 2016; van Ewijk et al., 2020). Missing from the literature, notably, are the investigations for examining the relationship between teachers' perceptions of the roles of advanced AI technology and their actual classroom practices.

The findings of this study revealed variations in teachers' engagement with the features of Inq-ITS, leading to the categorization of teachers into two distinct groups: low-level engagement and high-level engagement. Additionally, these two groups of teachers held contrasting perceptions regarding the roles of AI. Specifically, teachers who demonstrated a high inclination to engage with various features of Inq-ITS perceived AI as a collaborative partner and consultant, while those with low engagement viewed AI merely as a facilitating tool.

Furthermore, considering the influence of teachers' attitudes and teaching experience on the successful use of technology and their perceptions (Al Darayseh, 2023; Giordano, 2007; Wong & Li, 2008), we found that teachers who perceived AI as a collaborative partner had fewer years of experience in science teaching and were more open to exploring and embracing new technology to transform their regular teaching routines. As a result, those teachers had a high level of engagement with different features of Inq-ITS , thus promoting their recognition of the distinctive roles of AI in pedagogy.

The current study suggests a certain potential relationship between teachers' practices and their perceptions of the roles of AI. However, due to the qualitative nature of this study, establishing a definitive correlation between teachers' pedagogical practices and their perceptions of the roles of AI is not feasible. Further research employing rigorous methodologies is necessary to gain a better understanding of the nature of this relationship.

One suggested approach to investigate this relationship is the implementation of serial design-based activities in PL, involving teachers with opportunities to design and implement different AI-integrated instructional scenarios, while also measuring their perceptions of AI's roles. This approach would help explore whether changes in teachers' practice can influence their perceptions of AI's roles. Additionally, the design-based activities can provide insights into whether teachers with similar perceptions will employ similar pedagogical practices with AI.

Addressing the demand for professional learning in teachers' AI integration

Our findings indicated that the integration of AI into teachers' instructional practices leads to three distinct changes in classroom interactions: individualized instruction and scaffolding, data-driven and targeted pedagogical approach, and shifts in teachers' roles. These changes significantly transform traditional classroom paradigms, placing emphasis on individual problem-solving and higher-order thinking skills. The incorporation of AI-driven classroom interactions promotes the advancement of educational equity by fostering teachers' awareness of individual students' progress and facilitating the implementation of effective pedagogical adjustments. However, these changes also pose new requirements and challenges for teachers. From our findings, we identify the following potential challenges in AI-integrated teaching, including (1) addressing the needs of every student who requires additional teacher assistance, (2) utilizing complex and huge amount of data generated by AI systems for timely decision-making and action taking, (3) adjusting pedagogical approaches to work effectively with the emerging AI partner, and (4) improving interactions with ELLs and students with low language proficiency to address their specific needs and questions.

Providing teachers with appropriate and sufficient professional learning (PL) opportunities promoting their AI literacy and effective AI integration is deemed an effective way to address teachers' challenges in AI-integrated classrooms. Most participants had little to no prior knowledge of AI and limited experience in integrating AI into their instructional practices prior to this study. We suggest that it is essential to expand teachers' knowledge and skills in AI integration through a PL program based on the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006). This PL program can focus on supporting teachers' understanding of AI concepts, developing AI integration skills, and fostering AI integration competency.

A design-based approach can be integrated into the TPACK framework, allowing teachers to design diverse pedagogical scenarios that incorporate various AI systems. This approach engages teachers in comprehensive exploration of their pedagogical practices, facilitating a deeper understanding of their experiences, challenges, and opportunities associated with AI integration. By employing this comprehensive PL program, teachers can enhance their pedagogical practices and effectively overcome the identified challenges in AI-integrated classrooms.

Conclusion and Limitations

This study provides an in-depth exploration of teachers' utilization and interaction with AI technology, shedding light on their experiences and perceptions of their relationship with AI. It specifically focuses on the integration of AI within science classrooms and identifies several promising indicators of how teachers can effectively employ AI to facilitate science learning. The findings of this study underscore the evolving nature of the relationship between teachers and AI wherein AI emerges as a partner and collaborator in pedagogy, resulting in an interdependent dynamic between two entities in supporting students' individualized science learning. Thus, the findings in this study align with the proposed three-dimensional teacher-AI pedagogical partnership in Chapter 3 and highlights the importance of exploring the relationship between teachers and AI, as AI increasingly becomes a prevalent partner in educational settings.

However, the integration of AI into instructional practices presents several significant challenges for teachers as they must adapt their mindset and reconstruct an emergent relationship with AI technology. The participation of AI in pedagogical decision-making challenges traditional approaches and requires a more collaborative effort between teachers and technology to better support student learning. Thus, teachers have to adjust their pedagogical approaches and embrace data-driven, targeted, and individualized scaffolding to enhance student learning through the interplay with AI. Our findings emphasize the need for teacher professional development in this area to better incorporate AI insights and promote effective use of technology in the classroom. By gaining a deeper understanding of the interplay among teachers, students, and AI, educators can create a more supportive learning environment that promotes student engagement and achievement.

We acknowledge some limitations to our work and outline some areas for future research. First, our data was collected on middle school science teachers' use of an intelligent tutoring system that features teacher support and AI-teacher collaborative work. The findings might not be generalizable to other types of AI systems with distinctive features or other educational contexts. Future studies should investigate teachers' practice and experience with various types of AI systems in diverse educational contexts to gain a comprehensive understanding of their experience with AI. Second, while the study found that teachers had varied perceptions of the roles of AI, it remains unclear whether these differences are related to their diverse pedagogical practice or other factors. Investigating what factors contribute to these different perceptions would be a worthy question for future studies. Finally, although our data suggested that teachers had different emotions and attitudes toward using AI in classrooms, we did not report on this finding due to the research focus of the study. Future studies should employ rigorous research methods, such as longitudinal studies to uncover teachers' emotional and attitudinal change over a longer period. This knowledge is fundamental for promoting AI integration in classrooms.

References

Adair, A., Dickler, R., & Gobert, J. (2020). Supporting teachers supporting students: evidence-based TIPS in a dashboard to guide inquiry scaffolding. In, *Proceedings of the International Conference of the Learning Sciences 2020* (pp. 1769-1770). ISLS.

Ahn, T. Y., & Lee, S. M. (2016). User experience of a mobile speaking application with automatic speech recognition for EFL learning. *British Journal of Educational Technology*, *47*(4), 778–786. https://doi.org/10.1111/bjet.12354

Al Darayseh, A. (2023). Acceptance of artificial intelligence in teaching science: Science teachers' perspective. *Computers and Education: Artificial Intelligence*, *4*, 100132.

Alsoliman, B. S. H. (2018). The utilization of educational robotics in Saudi schools: potentials and barriers from the perspective of Saudi teachers. Inter Edu Studies, 11(10), 105–111.

Arruda, D., Marinho, M., Souza, E., & Wanderley, F. (2019). A Chatbot for goal-oriented requirements modeling. In Computational Science and Its Applications–ICCSA 2019: 19th International Conference, Saint Petersburg, Russia, July 1–4, 2019, Proceedings, Part IV 19 (pp. 506-519). Springer International Publishing.

Bagheri, M. M. (2015). Intelligent and adaptive tutoring systems: How to integrate learners. *International Journal of Education*, *7*(2), 1-16.

Baker, R. S. (2016). Stupid tutoring systems, intelligent humans. *International Journal of Artificial Intelligence in Education*, *26*(2), 600–614.

Banzon, A., Walker-McKnight, L., & Taub, M. (2022). AI and Teacher Education: Surveying Pre-Service Teachers’ Acceptance and Future Use of Artificial Intelligence. In *Society for Information Technology & Teacher Education International Conference* (pp. 1571-1575).

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The qualitative report*, *13*(4), 544-559.

Brandt, S. L., Lachter, R. R., & Shively, R. J. (2018). A human-autonomy teaming approach for a flight-following task. In C. Baldwin (Ed.), Advances in neuroergonomics and cognitive engineering advances in intelligent systems and computing. Springer International Publishing AG.

Brill, J. C., Cummings, M. L., Evans, A. W.III, Hancock, P. A., Lyons, J. B., & Oden, K. (2018). Navigating the advent of human-machine teaming. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 62(1), 455–459.

Brink, A., & Wellman, H. M. (2020). Robot teachers for children? Young children trust robots depending on their perceived accuracy and agency. *Develop Psychology*, *56*(7), 1268.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3, 77–101. doi:10.1191/1478088706qp063oa

Bryant, J., Heitz, C., Sanghvi, S., & Wagle, D. (2020). *How artificial intelligence will impact K-12 teachers*. McKinsey & Company.

Bughin, J., Hazan, E., Ramaswamy, S., Chui, M., Allas, T., Dahlström, P., Henke, N., & Kostka, V. (2018). Artificial Intelligence: The Next Digital Frontier? McKinsey Global Institute.

Buttussi, F., & Chittaro, L. (2020). Humor and Fear Appeals in Animated Pedagogical Agents: An Evaluation in Aviation Safety Education. *IEEE Transactions on Learning Technologies*, *13*(1), 63–76. https://doi.org/10.1109/TLT.2019.2902401

Chevalier, M., Riedo, F., & Mondada, F. (2016). How do teachers perceive educational robots in formal education? A study based on the Thymio robot. IEEE Robotics and Automation Magazine, 1070(9932/16), 1–8.

Chocarro, R., Cortiñas, M., & Marcos-Matás, G. (2023). Teachers' attitudes towards chatbots in education: a technology acceptance model approach considering the effect of social language, bot proactiveness, and users' characteristics. *Edu Studies*, *49*(2), 295-313.

Choi, S., Jang, Y., & Kim, H. (2023). Influence of pedagogical beliefs and perceived trust on teachers' acceptance of educational artificial intelligence tools. *International Journal of Human–Computer Interaction*, *39*(4), 910-922.

Chounta, I. A., Bardone, E., Raudsep, A., & Pedaste, M. (2022). Exploring teachers' perceptions of Artificial Intelligence as a tool to support their practice in Estonian K-12 education. *International Journal of Artificial Intelligence in Education*, *32*(3), 725-755.

Ciechanowski, L., Przegalinska, A., Magnuski, M., & Gloor, P. (2019). In the shades of the uncanny valley: An experimental study of human–chatbot interaction. *Future Generation Computer Systems*, *92*, 539-548.

Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, quantitative, and mixed methods approach. Sage publications.

Cummings, M. L., & Clare, A. S. (2015). Holistic modelling for human autonomous system interaction. Theoretical Issues in Ergonomics Science, 16(3), 214–231.

Denzin, N. K. (2017). The research act: A theoretical introduction to sociological methods. Transaction publishers.

Dickler, R. (2021). *An Intelligent Tutoring System and Teacher Dashboard to Support Students on Mathematics in Science Inquiry.* (Doctoral dissertation, Rutgers The State University of New Jersey, School of Graduate Studies).

Dietvorst, B., Simmons, J.P. and Massey, C. (2016), "Overcoming algorithm aversion: people will use imperfect algorithms if they can (even slightly) modify them", Management Science, Vol. 64 No. 3, pp. 1155-1170.

Divekar, R. R., Lepp, H., Chopade, P., Albin, A., Brenner, D., Ramanarayanan, V. (2021). Conversational agents in language education: Where they fit and their research challenges. International Conference on Human-Computer Interaction (pp. 272–279).

du Boulay, B. 2016. "Artificial Intelligence As an Effective Classroom Assistant." *IEEE Intelligent Systems*, 31(6): 76–81.

Edwards, B. I., & Cheok, A. D. (2018). Why not robot teachers: artificial intelligence for addressing teacher shortage. Applied Artificial Intelligence, 32(4), 345–360.

Edwards, C., Edwards, A., Spence, P. R., & Lin, X. (2018). I, teacher: using artificial intelligence (AI) and social robots in communication and instruction. *Communication Education*, *67*(4), 473-480.

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American journal of theoretical and applied statistics*, *5*(1), 1-4.

Fang, H., Wang, S., Xue, S., & Wang, X. (2020). Research on human-computer cooperative teaching supported by artificial intelligence robot assistant. *Artificial intelligence supported educational technologies*, 45-58.

Fridin, M. (2014). Storytelling by a kindergarten social assistive robot: A tool for constructive learning in preschool education. *Computers and Education*, *70*, 53–64.

Geertz, C. (1973). *The interpretation of cultures* (Vol. 5043). Basic books.

Ghavifekr, S., Kunjappan, T., Ramasamy, L., & Anthony, A. (2016). Teaching and Learning with ICT Tools: Issues and Challenges from Teachers' Perceptions. *Malaysian Online Journal of Educational Technology*, *4*(2), 38-57.

Giordano, V. A. (2007). A professional development model to promote Internet integration into p-12 teachers' practice: A mixed methods study. *Comp in the Schools*, *24*(3-4), 111-123.

Gobert, J. (2019) Inq-Blotter: Designing Supports for Teachers' Real Time Instruction (NSF-IIS-1902647). Awarded by the. National Science Foundation.

Gobert, J. D., Moussavi, R., Li, H., Sao Pedro, M., & Dickler, R. (2018). Real-time scaffolding of students' online data interpretation during inquiry with Inq-ITS using educational data mining. *Cyber-physical laboratories in engineering and science education*, 191-217.

Gobert, J., & Sao Pedro, M. (2016). Inq-Blotter: A real-time alerting tool to transform teachers' assessment of science inquiry practices (NSF-IIS-1629045). Awarded from the National Science Foundation.

Gobert, J. D., Sao Pedro, M. A., Baker, R. S., Toto, E., & Montalvo, O. (2012). Leveraging educational data mining for real-time performance assessment of scientific inquiry skills within microworlds. *Journal of Educational Data Mining*, *4*(1), 104-143.

Gobert, J. D., Sao Pedro, M., Raziuddin, J., & Baker, R. S. (2013). From log files to assessment metrics: Measuring students' science inquiry skills using educational data mining. *Journal of the Learning Sciences*, *22*(4), 521-563.

Gobert, J., Sao Pedro, M., Toto, E., Montalvo, O., & Baker, R. (2011, April). *Science ASSISTments: Assessing and scaffolding students' inquiry skills in real time.* Paper presented at the annual meeting of the AERA, New Orleans, LA.

Gobert, J. D., Sao Pedro, M.A., Betts, C.G. (2023a). An AI-Based Teacher Dashboard to Support Students' Inquiry: Design Principles, Features, and Technological Specifications. In N. Lederman, D. Zeidler, & J. Lederman (Eds.), Handbook of Research on Science Education, (Vol. 3, pp. 1011-1044). Routledge. https://doi.org/10.4324/9780367855758

Gobert, J.D., Sao Pedro, M.A., Li, H., & Lott, C. (2023b). Intelligent Tutoring systems: a history and an example of an ITS for science. In R.Tierney, F. Rizvi, K. Ercikan, & G. Smith, (Eds.), *International Encyclopaedia of Education* (Vol. 4, pp. 460-470), Elsevier.

Goel, A. K., & Polepeddi, L. (2018). Jill Watson: A virtual teaching assistant for online education. In *Learning Engineering for online education* (pp. 120-143). Routledge

Goodlad, J. I. (1984). *A place called school. Prospects for the future*. McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, NY 10020.

Guan, H., Chen, Q., Han, S., & Zhang, B. (2021). The influence of "artificial intelligence+ human–computer interaction" on teachers' psychological changes in academic management in colleges. *Frontiers in Psychology*, *12*, 730345.

Guilherme, A. (2019). AI and education: the importance of teacher and student relations. *AI and Society*, *34*(1), 47–54.

Guzman, A. L., & Lewis, S. C. (2020). Artificial intelligence and communication: A Human–Machine Communication research agenda. *New Media and Society*, *22*(1), 70–86.

Holmes, W., Bialik, M., & Fadel, C. (2019). Artificial intelligence in education: Promises and Implications for Teaching and Learning. Center for Curriculum Redesign.

Holstein, K., & Aleven, V. (2022). Designing for human–AI complementarity in K-12 education. *AI Magazine*, *43*(2), 239-248.

Holstein, K., Aleven, V., Rummel, N. (2020). A conceptual framework for human–AI hybrid adaptivity in education. In *International Conference on AI in Education* (pp. 240–254).

Holstein, K., McLaren, B. M., & Aleven, V. (2019). Co-designing a real-time classroom orchestration tool to support teacher-AI complementarity. *Grantee Submission*.

Holstein, K., B. M. McLaren, and V. Aleven. (2017). "Intelligent Tutors as Teachers' Aides: Exploring Teacher Needs for Real-time Analytics in Blended Classrooms." In *Proceedings of the LAK Conference*, 257–66.

Holstein, K., B. M. McLaren, and V. Aleven. (2018). "Student Learning Benefits of a Mixed-reality Teacher Awareness Tool in AI- enhanced Classrooms." In *Proceedings of the AIED Conference*, 154–68.

Hsu, H. L., Chen, H. H. J., & Todd, A. G. (2021). Investigating the impact of the Amazon Alexa on the development of L2 listening and speaking skills. *Interactive Learning Environments*, 1–14. https://doi.org/10.1 080/10494820.2021.2016864

Hu, J. (2021). Teaching evaluation system by use of machine learning and artificial intelligence methods. *International Journal of Emerging Technologies in Learning*, *16*(5), 87-101.

Huang, R., & Chen, G. (2021). The role of ethics in AI adoption and integration in education: A systematic review. Computers & Education, 163, 104051.

Humble, N., & Mozelius, P. (2019, October). Teacher-supported AI or AI-supported teachers. In *European Conference on the Impact of AI and Robotics (ECIAIR 2019)* (pp. 157-164).

Ibili, E., Resnyansky, D., & Billinghurst, M. (2019). Applying the technology acceptance model to understand maths teachers' perceptions towards an augmented reality tutoring system. *Education and Information Technologies*, *24*, 2653-2675.

Indira, E. W. M., Hermanto, A., & Pramono, S. E. (2020, June). Improvement of teacher competence in the industrial revolution era 4.0. In *International conference on science and education and technology (ISET 2019)* (pp. 350-352). Atlantis Press.

Jamsandekar, S. S., Kamath, R. S., & Badadare, V. L. (2020). Adaptive Learning System enabled by Machine Learning: An Effective Pedagogical Approach.

Jarrahi, M. H. (2018). Artificial intelligence and the future of work: Human-AI symbiosis in organizational decision making. *Business Horizons*, *61*(4), 577-586.

Ji, H., Han, I., & Ko, Y. (2023). A systematic review of conversational AI in language education: focusing on the collaboration with human teachers. *Journal of Research on Technology in Education*, *55*(1), 48-63.

Jonassen, D. H. (1994). Technology as Cognitive Tools: Learners as Designers. *ITForum Pape*, *1*(1), 67–80. https://it.coe.uga.edu/itforum/paper1/paper1.html

Jonassen, D. H., Peck, K. L., & Wilson, B. G. (1999). *Learning with technology: A constructivist perspective*. Upper Saddle River, NJ: Merrill.

Kessler, A., M. Boston, and M. K. Stein. (2019). "Exploring How Teachers Support Students' Mathematical Learning in Computer- directed Learning Environments." *Information and Learning Sciences* 121(1/2): 52–78.

Kim, J., Lee, H., & Cho, Y. H. (2022a). Learning design to support student-AI collaboration: Perspectives of leading teachers for AI in education. *Education and Information Technologies*, 27, 6069–6104. https://doi. org/10.1007/s10639-021-10831-6

Kim, J., Merrill, K., Kun, X., & Sellnow, D. D. (2022b). Embracing AI-based education: Perceived social presence of human teachers and expectations about machine teachers in online education. *Human-Machine Communication*, *4*, 169-184.

Kim, J., Merrill, K., Xu, K., & Sellnow, D. D. (2020). My teacher is a machine: Understanding students' perceptions of AI teaching assistants in online education. *International Journal of Human–Computer Interaction*, *36*(20), 1902-1911.

Kok, J. N., Boers, E. J., Kosters, W. A., Van der Putten, P., & Poel, M. (2009). Artificial intelligence: definition, trends, techniques, and cases. *Artificial intelligence*, *1*, 270-299.

Lee, A. S., Thomas, M., & Baskerville, R. L. (2015). Going back to basics in design science: From the information technology artifact to the information systems artifact. *Information Systems Journal*, *25*(1), 5–21.

Lewis, S. C., Guzman, A. L., & Schmidt, T. R. (2019). Automation, journalism, and human–machine communication: Rethinking roles and relationships of humans and machines in news. *Digital journalism*, *7*(4), 409-427.

Lin, X. F., Chen, L., Chan, K. K., Peng, S., Chen, X., Xie, S., ... & Hu, Q. (2022). Teachers' Perceptions of Teaching Sustainable Artificial Intelligence: A Design Frame Perspective. *Sustainability*, *14*(13), 7811.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. sage.

Lindner, A., & Romeike, R. (2019). Teachers' Perspectives on Artificial Intelligence.

Lincoln, Y. S., & Guba, E. G. (1985). Naturalistic inquiry. Thousand Oak: Sage.

Matayoshi, J., & Cosyn, E. (2018). Identifying Student Learning Patterns with Semi-Supervised Machine Learning Models. In Proceedings of the 26th International Conference on Computers in Education (pp.11-20).

McGraw, K. L., & Harbison, K. (2020). User-centered requirements: the scenario-based engineering process. CRC Press.

Mehmood, A., On, B. W., Lee, I., & Choi, G. S. (2017). Prognosis essay scoring and article relevancy using multi-text features and machine learning. *Symmetry*, *9*(1).

Miles, M. B., & Huberman, A. M. (1984). Qualitative data analysis: A sourcebook of new methods. In *Qualitative data analysis: a sourcebook of new methods* (pp. 263-263).

Miller, W. L., R. S. Baker, M. J. Labrum, K. Petsche, Y. H. Liu, and A. Z. Wagner. 2015. "Automated Detection of Proactive Remediation by Teachers in Reasoning Mind classrooms." In *Proceedings of the LAK Conference*, 290–4.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers college record*, *108*(6), 1017-1054.

Morita, T., Akashiba, S., Nishimoto, C., Takahashi, N., Kukihara, R., Kuwayama, M., & Yamaguchi, T. (2018). A practical teacher–robot collaboration lesson application based on PRINTEPS. The Review of Socionetwork Strategies, 12(1), 97–126.

Moussavi, R., Gobert, J., & Sao Pedro, M. (2016). The effect of scaffolding on the immediate transfer of students' data interpretation skills within science topics. In, *Proceedings of the 12th International Conference of the Learning Science*s. Singapore (pp. 1002-1006).

Mubin, O., Stevens, C. J., Shahid, S., Mahmud, A. A., & Dong, J.J. (2013). A review of the applicability of robots in education. *Technology for Education and Learning*, 1(1).

Nagao, K. (2019). Symbiosis between humans and artificial intelligence. In Artificial Intelligence Accelerates Human Learning (pp. 135–151). Springer.

Nehm, R. H., Ha, M., & Mayfield, E. (2012). Transforming Biology Assessment with Machine Learning: Automated Scoring of Written Evolutionary Explanations. *Journal of Science Education and Technology*, *21*(1), 183–196.

Ng, D. T. K., Leung, J. K. L., Su, J., Ng, R. C. W., & Chu, S. K. W. (2023). Teachers' AI digital competencies and twenty-first century skills in the post-pandemic world. *Educational technology research and development*, *71*(1), 137-161.

Nourbakhsh, I. R. (2013). *Robot futures*. Cambridge, Massachusetts: MIT Press.

Olson, S. (1976). Ideas and data: Process and practice of social research. Homewood, IL: The Dorsey Press.

O'Neill, T., McNeese, N., Barron, A., & Schelble, B. (2020). Human–Autonomy Teaming: A Review and Analysis of the Empirical Literature. *Human Factors*.

Ouyang, F., & Jiao, P. (2021). Artificial intelligence in education: The three paradigms. *Computers and Education: Artificial Intelligence*, *2*, 100020.

Pai, K. C., Kuo, B. C., Liao, C. H., & Liu, Y. M. (2021). An application of Chinese dialogue-based intelligent tutoring system in remedial instruction for mathematics learning. *Educational Psychology, 41*(2), 137–152.

Paquette, L., Baker, R. S., Sao Pedro, M. A., Gobert, J. D., Rossi, L., Nakama, A., & Kauffman-Rogoff, Z. (2014, June). Sensor-free affect detection for a simulation-based science inquiry learning environment. In *International conference on intelligent tutoring systems* (pp. 1-10). Springer, Cham.

Parker, C. E., Stylinski, C. D., Bonney, C. R., DeLisi, J., Wong, J., & Doty, C. (2019). Measuring quality technology integration in science classrooms. *Journal of Science Education and Technology*, *28*, 567-578.

Pedhazur, E. J., & Schmelkin, L. P. (1991). *Measurement, design, and analysis: An integrated approach.* Hillsdale, N.J.: Lawrence Erlbaum Associates.

Peng, H., & Zhu, Z. (2019). An analysis of personalized adaptive learning strategies based on human-computer collaborative decision support. *Audio Visual Edu Research, 02*, 1–8.

Prahani, B. K., Rizki, I. A., Jatmiko, B., Suprapto, N., & Amelia, T. (2022). Artificial Intelligence in Education Research During the Last Ten Years: A Review and Bibliometric Study. *International Journal of Emerging Technologies in Learning*, *17*(8).

Rogers, Y., & Paay, J. (2014). Reimagining Human-Computer Interaction in the Age of Pervasive Computing. In J. Simonsen & C. Stappers (Eds.), The Encyclopedia of Human-Computer Interaction (2nd Ed.). Aarhus, Denmark: The Interaction Design Foundation.

Roschelle, J., Dimitriadis, Y., & Hoppe, U. (2013). Classroom Orchestration: Synthesis. *Computers & Education*, 69, 523–526.

Roschelle, J., Lester, J., & Fusco, J. (2020). *AI and the future of learning: Expert panel report*. Digital Promise.

Russell, S. J. (2010). *Artificial intelligence a modern approach*. Pearson Education, Inc.

Schuetz, S. W., & Venkatesh, V. (2020). The Rise of Human Machines: How Cognitive Computing Systems Challenge Assumptions of User-System Interaction. *Journal of the AIS*, *21*(2), 460–482.

Schofield, J. W., Eurich-Fulcer, R., & Britt, C. L. (1994). Teachers, computer tutors, and teaching: The artificially intelligent tutor as an agent for classroom change. *American Educational Research Journal*, *31*(3), 579-607.

Serholt, S., Barendregt, W., Vasalou, A., Alves-Oliveira, P., Jones, A., Petisca, S., & Paiva, A. (2017). The case of classroom robots: teachers' deliberations on the ethical tensions. *Ai & Society*, *32*, 613-631.

Serholt, S., Barendregt, W., Leite, I., Hastie, H., ... & Castellano, G. (2014, August). Teachers' views on the use of empathic robotic tutors in the classroom. In *23rd IEEE International Symposium on Robot and Human Interactive Communication* (pp. 955-960). IEEE.

Seufert, S., Guggemos, J., & Sailer, M. (2020). Technology-related knowledge, skills, and attitudes of pre-and in-service teachers: The current situation and emerging trends. *Computers in Human Behavior*, *115*, 106552. https://doi.org/10.1016/j.chb.2020.106552

Sharkey, A. J. (2016). Should we welcome robot teachers? *Ethics and Information Technology*, *18*(4), 283-297.

Spector, J. M., & Ma, S. (2019). Inquiry and critical thinking skills for the next generation: from AI back to human intelligence. *Smart Learning Environments*, *6*(1), 1-11.

Spikol, D., Ruffaldi, E., Dabisias, G., & Cukurova, M. (2018). Supervised machine learning in multimodal learning analytics for estimating success in project-based learning. *Journal of Computer Assisted Learning*, *34*(4), 366–377.

Strich, F., Mayer, A. S., & Fiedler, M. (2021). What do i do in a world of AI? Investigating the impact of substitutive decision-making AI systems on employees' professional role identity. *Journal of the Association for Information Systems*, *22*(2), 304–324.

Topal, A., Eren, C., & Geçer, A. (2021). Chatbot application in a 5th-grade science course. *Education and Information Technologies*, *26*(5), 6241-6265.

Taylor, R. P. (1980). The computer in the school: Tutor, tool, tutee. In *Contemporary Issues in Technology and Teacher Education* (Vol. 3, Issue 2).

Van Ewijk, G., Smakman, M., & Konijn, E. A. (2020). Teachers' perspectives on social robots in education: An exploratory case study. *Proceedings of the Interaction Design and Children Conference, IDC 2020*, 273–280.

Van Pinxteren, M. M., Wetzels, R. W., Rüger, J., Pluymaekers, M., & Wetzels, M. (2019). Trust in humanoid robots: implications for services marketing. *Journal of Services Marketing*.

Wang, Y. (2021). When artificial intelligence meets educational leaders' data-informed decision-making: A cau- tionary tale. *Studies in Educational Evaluation*, 69, 100872.

Wang, Y., Liu, C., & Tu, Y. F. (2021). Factors affecting the adoption of AI-based applications in higher education. *Educational Technology & Society*, *24*(3), 116-129.

Wang, S., & Vásquez, C. (2020). Artificial Intelligence in Education: Promises and Implications for Teaching and Learning. In M. Khosrow-Pour, D.B.A. (Ed.), Encyclopedia of Information Science and Technology (5th ed.). IGI Global.

Westlund, J. K., Lee, J. J., Plummer, L., et al. (2016). Tega: A social robot. *The Eleventh ACE/IEEE International Conference on Human Robot Interaction*, *2016*, 561–561.

Wilson, S. M., & Schwarz, N. (2019). Toward ethical review of algorithms in education. Educational Researcher, 48(1), 38-48.

Wong, E.M.L. & Li, S.C. (2008). Framing ICT implementation in a context of educational change: a multilevel analysis. *School effectiveness & school improvement*, 19(1), 99-120.

Xu, W., Dainoff, M. J., Ge, L., & Gao, Z. (2023). Transitioning to human interaction with AI systems: New challenges and opportunities for HCI professionals to enable human-centered AI. *International Journal of Human–Computer Interaction*, *39*(3), 494-518.

Yin, R. K. (2014). *Case study research: Design and methods*. Thousand Oaks, CA: Sage.

Zeng, Y., Zhao, Y., Bai, J., & Xu, B. (2018). Toward Robot Self-Consciousness (II): Brain-Inspired Robot Bodily Self Model for Self-Recognition. *Cognitive Computation*, *10*(2), 307–320.

Zhai, X., He, P., & Krajcik, J. (2022). Applying machine learning to automatically assess scientific models. *Journal of Research in Science Teaching*, *59*(10), 1765-1794.

Zhai, X., & Jackson, D. F. (2021). A pedagogical framework for mobile learning in science education. *International encyclopedia of education*.

Zhai, X., Yin, Y., Pellegrino, J. W., Haudek, K. C., & Shi, L. (2020). Applying machine learning in science assessment: a systematic review. In *Studies in Science Education* (Vol. 56, Issue 1, pp. 111–151). Routledge.

Zhao S (2006) Humanoid social robots as a medium of communication. *New Media & Society* 8(3): 401–419.

CHAPTER 5

CONCLUSION

As intelligent machines continue to advance and have a greater social presence in various aspects of society, it is important to examine the evolving relationship between humans and machines, (Bian et al., 2020; Wang & Cheng, 2019), which now includes social and emotional interactions (Bickmore & Picard, 2005). In educational contexts, various AI technologies were integrated in teaching and learning, and the concept of the complementary or hybrid of machine intelligence and human intelligence was examined. This dissertation study contributes to this area of research by exploring the relationship between teachers and AI in an educational context, specifically in terms of how they collaborate to facilitate student learning. The study provides a theoretical framework for understanding the teacher-AI partnership in pedagogy and offers empirical evidence of in-service teachers' perceptions and experiences with AI integration in classrooms.

To unpack the pedagogical roles and characteristics of AI in teachers' instructional practices, Chapter 2 of the dissertation discussed the need to systematically review the literature on AI in various teaching practices to address how AI could impact teachers' pedagogical practices in science classrooms and beyond and proposed a three-dimensional analytical framework to guide the literature analysis. Based on analyzing AI in education studies in the past decade, this study revealed five distinctive pedagogical roles that AI can play in transforming and enhancing teaching practices, including (1) participating in instruction, (2) monitoring student progress, (3) innovating assessment practices, (4) providing teacher pedagogical recommendations, and (5) driving teachers' effective pedagogical decision-making and action-taking. Finally, the unique characteristics of AI in supporting teaching, such as its interactivity with humans, automaticity, and autonomy were extracted based on features of various pedagogical roles of AI. The review highlights research gaps and future directions to conceptualize and examine AI's roles from the teachers' pedagogy perspective.

To conceptualize the novel teacher-AI relationships in AI-integrated classrooms, Chapter 3 of the dissertation first reviewed the integration of AI into teachers' instructional practice and the corresponding challenges. I then articulated the emerging research in human-machine relationships across various fields and the demands for conceptualizing teacher-AI relationships in educational contexts. From the theoretical perspectives of actor-network theory, social presence, and distributed cognition, an integrated conceptual framework was proposed to leverage the goals of teachers' collaboration with AI in education. The conceptual framework first includes a three-dimensional teacher-AI pedagogical partnership (TAIPP) model, consisting of (1) two social agents (i.e., teacher, artificial social agent), (2) independence and interdependence, and (3) partnering agency. The conceptual framework also includes the critical impacts of TAIPP on teachers in four areas. Finally, the potential implications in teachers' changed mindsets, the effective AI-integrated collaborative instructional design, and the future research foci were proposed.

Next, engagement and experiences of in-service teachers' AI integration were examined in Chapter 4. A qualitative case study was employed by interviewing six science teachers and observing their AI-integrated classroom practices to understand their use and interaction with various features of the AI system, as well as their perceptions and experiences of incorporating

AI to aid their instructional practices. In terms of teachers' use and engagement with AI, the data revealed that when AI guides students' independent inquiry, it is a participant in teachers' pedagogy to provide varied teacher support and teachers provide additional support to AI. The findings revealed teachers' two different perceptions of the roles of AI: a supportive tool and a partner. The integration of AI into teachers' instructional practices resulted in four emerging classroom interaction changes: individualized, data-driven and targeted, shifts in teachers' roles, and persisting challenges. The findings indicated AI transforming technology's roles from a merely supportive tool to a collaborative partner, suggesting for teachers' changed mindset and appropriate professional learning related to AI integration. Table 5.1 illustrates the alignment of ideas of the conceptual framework and the empirical study.

Table 5.1. The theoretical perspectives and empirical findings on the roles of AI and its impact on the teacher-AI relationship

Literature Review (Chapter 2)	Theoretical Perspective (Chapter 3)	Empirical Findings (Chapter 4)
Five pedagogical roles: 1. AI assists teachers' instructional activities 2. AI supports teachers in tracking student progress 3. AI innovates teachers' classroom assessment practice 4. AI recommends appropriate pedagogical approaches to teachers 5. AI drives teachers' effective pedagogical decision-making and action-taking	Three-dimensional teacher-AI pedagogical partnership model Dimension 1: two social agents in the teacher-AI relationship Dimension 2: the independence and interdependence between social agents Dimension 3: partnering agency between social agents	Teachers' engagement with AI Mutual support: 1. AI offers teachers substantial supports 2. Teachers actively support the work of AI Teachers' perception of AI's roles 1. perceiving AI as a supportive tool 2. perceiving AI as a partner.
Three characteristics: 1. AI-teacher interactivity	The impact of partnership on teachers	The shifts in classroom interactions

2. Automaticity 3. Autonomous	1. Pedagogy 2. Cognition 3. Affection 4. Classroom interactions	1. Individualized and immediate instruction and feedback 2. Data-driven and targeted approach 3. Shifts in teachers' roles 4. Persisting challenges in AI-integrated classrooms

Implications of the Dissertation Research

The various pedagogical roles of AI identified through the systematic review in Chapter 2 highlighted the distinctive advantages of AI in supporting and transforming pedagogy, which, in turn, informed our reflection on the emerging relationship between AI and humans (i.e., the teacher) in educational contexts. The conceptualized teacher-AI relationship in Chapter 3 described the interdependent and independent relationship in pedagogy between two social agents (i.e., teacher, AI) who share agency and responsibilities for achieving common pedagogical goals. This novel relationship was conceived to have significant impacts on teachers' pedagogy, emotion, and cognition, as well as the changes in classroom interactions. Empirical findings presented in Chapter 4 provided strong support for the conceptualization of the teacher-AI pedagogical partnership. The findings suggested that teachers and AI mutually depend on each other to provide additional support to the other party for fulfilling their respective responsibilities while being independent in guiding and facilitating students' learning. This collaborative relationship positively promotes some teachers' perceptions of the AI partner and results in changes in classroom interactions.

The overall discussions in the three chapters have led to several key ideas about the integration of AI in classrooms. Zhao (2006) advocated for greater attention to be paid to the social implications of human-like technologies such as AI, given its potential to take on roles like those of teachers in classrooms. As AI, a radical and disruptive innovation (Bughin et al., 2018), increasingly disrupts traditional pedagogical paradigms, it is imperative that teachers adopt a changed mindset regarding the perfect ways to integrate AI into their pedagogy. To effectively integrate AI, our findings implied that teachers should differentiate AI from traditional technologies and recognize its pedagogical potential in teaching. Additionally, teachers need to develop pedagogical strategies that incorporate AI into the existing curriculum to achieve desired pedagogical goals. This requires training in AI knowledge and integration, support in the development of appropriate pedagogical strategies, and opportunities for meaningful reflection on AI integration practice. By developing collaborative pedagogy with AI that reflects responsibility toward the public good, both in-service and pre-service teachers can gain valuable knowledge and experience. This will help to create a more effective and efficient partnership between teachers and AI in the classroom. Overall, it is essential that teachers embrace the integration of AI in pedagogy, recognizing its potential benefits while navigating the unique challenges it presents.

Recommendations for Future Research and Limitations

The findings of the dissertation research indicate that AI is increasingly becoming a new agent in teachers' instructional practices, which suggests a novel teacher-AI pedagogical partnership that collaboratively facilitates students' learning. The study has reported various findings, but there are implications that could be addressed through future research in this emerging area.

To expand upon this research, future studies could focus on exploring the teacher-AI relationship in different educational contexts, such as higher education or different subjects to identify collaborative environments and patterns of AI integration. Since the empirical evidence of the dissertation was collected from middle school science teachers and an intelligent tutoring system, further research in this line can add to the overarching ideas and knowledge of teachers' AI integration and strengthen the proposed teacher-AI pedagogical partnership. Moreover, studies examining the differences in AI integration between teachers with different professional backgrounds or pedagogical beliefs can explain their diverse pedagogical approaches and experiences in integrating AI. As emerging themes and ideas of teachers' relationship with AI continue to be identified through research, the meaning and components of the teacher-AI pedagogical partnership in classrooms will become more grounded. Thus, it is recommended that future research in this area continues to explore and identify the underlying aspects of the teacher-AI pedagogical partnership, enabling teachers to develop meaningful and effective pedagogical strategies that incorporate AI with existing curricula for better student learning outcomes. Additionally, investigating how the teacher-AI partnership impacts student learning outcomes and engagement could provide valuable insights into the effectiveness of this collaborative approach. Finally, examining the ethical considerations and potential biases that may arise in the teacher-AI partnership could inform best practices for integrating AI in education while promoting equity and fairness

This dissertation study has made efforts to underscore the emerging relationship between teachers and AI and its critical impact on classroom paradigms. While this adds value to the existing literature that highlights the importance of the human-machine relationship in the era of

AI, further empirical studies are needed to validate the meaning and components of the teacher-AI relationships. For instance, increasing the number of participants to develop a validated survey that quantitatively assesses and measures the components of the teacher-AI relationship may be meaningful to better represent the relationship. Such a tool can also be used to assess classroom relationships in the era of AI more accurately. Additionally, investigating teachers' integration of different types of AI systems in diverse educational contexts can generate comprehensive knowledge of teachers' engagement and perceptions of using AI in the classrooms. To promote teachers' AI integration competence and acceptance, professional development programs that prepare teachers' AI-related technological pedagogical knowledge can be meaningful and demanding These programs can help develop novel relationships with AI, thereby contributing to the evolving paradigm of the human-machine relationship in education.

References

Bian, F., Ren, D., Li, R., Liang, P., Wang, K., & Zhao, L. (2020). An extended DMP framework for robot learning and improving variable stiffness manipulation. *Assembly Automation*, *40*(1), 85-94.

Bickmore, W., & Picard, R. W. 2005. Establishing and maintaining long-term human-computer relationships. *ACM Transactions on Computer-Human Interaction* 12(2):293– 327.

Bughin, J., Hazan, E., Ramaswamy, S., Chui, M., Allas, T., Dahlström, P., Henke, N., & Kostka, V. (2018). Artificial Intelligence: The Next Digital Frontier? McKinsey Global Institute.

Wang, X., & Cheng, Y. (2019). Lane departure avoidance by man-machine cooperative control based on EPS and ESP systems. *Journal of Mechanical Science and Technology*, *33*, 2929-2940.

Zhao S (2006) Humanoid social robots as a medium of communication. *New Media & Society* 8(3): 401–419.

Appendices

Appendix A. Summary of the human and AI interaction and relationship research

Reference	Research context	AI technology	Human and AI Interaction	Research focus	Outcomes	Theories
Pentina et al. (2023)	Personal life	chatbot	Human-chatbot relationship	Anthropomorphism, Authenticity with attachment, Social Interaction	Human and Chatbot develops relationships	Computers are Social Actors; Perceived Social Presence; Parasocial Interaction; Social Penetration
Textor et al. (2022)	Organization	Autonomous AI	Human-AI teams	AI trust	AI ethnics impact human's trust on AI	-
Skjuve et al. (2021)	Personal life	chatbot	Human-chatbot companion	Trust, relationship development	Three stages relationship development	Social exchange theory; self-disclosure; Social Penetration Theory
Fang et al. (2020)	Education	AI robot assistant	Human-machine collaborative teaching	Student personalized learning	The design outcomes of teacher-AI collaborative teaching	-
Ciechanowski et al. (2019)	Personal life	Chatbot	Human and chatbot collaboration	User affective responses to chatbot: fear, psychophysiological reactions	Attitude towards collaborating with chatbot	Theory of planned behavior, social presence,
Lewis et al. (2019)	Journalism	Automation	Human-Machine communication	Communication	Machine-consumer relationship	-

					Machine-Journalist relationship	
Van Pinxteren et al. (2019)	Service marketing	Robot	Interaction partner	Consumers' perceived anthropomorphism, comfort	Trust, enjoyment, intention to use	Comfort theory, uncertainty reduction theory
Wang et al. (2019)	Company	AutoAI	Human-AI collaboration	Perceived benefit, perceived danger, AI trust	AutoAI collaborate with data scientists	-
Desideri et al. (2018)	Mental Health care	Social robot	Interact with humanoid robot	User's emotional processes of robot	Affective states, physiological arousal, and valence	Computers are social actors
Jarrahi (2018)	Organization	AI systems	Human-AI symbiosis and collaboration	Decision-making	Human and AI complementary.	-
Seo et al. (2018)	Workplace	Robot	Human-robot collaboration, team	Relationship building	Human verbal and non-verbal behaviors for relationship building	-
Van Doorn et al. (2017)	Consumer service marketing	Robot	Human-robot collaborate to provide service	Automated social presence, psychological ownership	Positive and negative service and customer outcome	-
Fridin & Belokopytov (2014)	Education	Social robot	Human and robot interaction	User's acceptance	Perceived sociability, enjoyment, adaptability	Unified Theory of Acceptance

Appendix B. AI Classroom Observation Sheet (AI-COS)

1. Classroom information
Teacher name:
Grade level
Student number
Course title
Observation date and time
2. Classroom observation interval sheet

AI classroom observation (Interval Sheet #)	
Interval Codes	Interval Description
Time period	Time started: Time finished:
Activities Observed	
Classroom social organization	
Teacher presence	
Student presence	
	The Inq-ITS features/functions used by teachers
	A detailed description of how Inq-ITS functions support teachers a. Cognitive: (e.g., track student progress, personalized scaffolding, automatic scoring)
AI presence	b. emotional:(e.g., change of emotion, emotional mode through facial expression, verbal, body language)
	c. Interactions: student, teacher, and AI
	User’s perspective of AI

Appendix C. Pre-interview guide: teachers practice in regular classrooms

Please identify one of the representative science lessons you taught last semester and walk me through how you taught that lesson; it could be one class or a series of classes.

- specific instructional methods (pedagogical approaches).
- Students' experience (learning and engagement) with the lesson from the teachers' perspective
- Your challenge in teaching
- Teachers' role and responsibility during the lesson
- The technology used to support teacher teaching
- The features/role of technology
- Technology addressing the teaching challenges.
- Technology integration challenges
- Additional thoughts

Appendix D. Post-interview guide: teachers' practices and experiences in AI-integrated classrooms

Teachers' practice with Inq-ITS

- Teacher report summary: When did you use it, and what type of information did you typically look for?
- Real-time teacher alert: how did you use it? To what extent do you rely on teacher alert to help students?
- Teacher inquiry practice support (TIPS): how did you use it? Did it help you develop new teaching strategies or approaches?
- Rex, how did your student use it? What is your view of Rex?
- Inq-ITS as Assessment tool: How did you typically do the formative assessment? How did Inq-ITS impact the way of doing formative assessments? Change? Benefit?

Teachers' experience of using Inq-ITS

- Please describe a specific instance where Inq-ITS helped you identify a student need or issue that you may not have noticed otherwise.
- Please describe any areas where Inq-ITS provides more support to you than you expected.
- How has Inq-ITS reduced your workload and cognitive load in classroom teaching?
- How has Inq-ITS in general impacted your teaching practice and approach?

Teachers' feelings of Inq-ITS and AI in general

- How does using Inq-ITS impact your confidence and comfort level in the classroom?
- Do you feel more supported and empowered as a teacher, or does it create additional stress or uncertainty?
- How has your feeling changed during your journey of using Inq-ITS?
- Please use one word, phrase, or sentence to describe your overall feeling of using Inq-ITS and other AI technology in classrooms.
- What would you say to teachers hesitant to adopt AI technology like Inq-ITS in their teaching based on your experiences?
- Are there any challenges or frustrations you have experienced while using Inq-ITS in your teaching? How have you addressed these challenges?

Classroom interaction

- Compared to your help to students in general classrooms
- How do you identify students who need help when using Inq-ITS?
- How does Inq-ITS impact your interaction with students? Please provide examples to illustrate your viewpoint (time length, number of students, focus/direction of teacher help, quality of teacher help?)
- How have your role and responsibilities as a teacher shifted, if at all, with using Inq-ITS?

- Compared to previously used technology,
- Please describe the role that Inq-ITS played from your perspective. And examples.
- What is the most promising aspect of Inq-ITS that will lead to your continued use in the future?

Appendix E. Data Analysis Process

This section presents the data analysis process for Chapter 4, *Exploring Teachers' Pedagogical Practices and Experiences of Integrating Artificial Intelligence into Teaching: a Qualitative Case Study*. The following procedures were taken to find emerging themes across the six interviews and classroom observations. The interview transcripts and classroom observation notes in Word documents were first used by the first author (the interviewer and primary classroom observer) to review and highlight the quotations that align with the research questions. The highlighted quotations were initially coded to generate the initial meaning of the data. See below for an example of initial coding.

	Interview Transcript	Initial codes
Interviewer	Could you describe your use and interaction with the feature of real-time teacher alerts	
Participant	I liked most I like real-time alerts, because it would tell me, you know, which kid needed what and when, and a lot of times, the kids would just sit there and shy before they ask a question. And I think it helps me know which kids need my help faster than they know that they even need help	• Like real-time teacher alerts • Real-time teacher alerts help teacher know the most struggling student faster
Interviewer	Does real-time teacher alerts influence the way you approach to student for help? And how?	
Participant	And where it automatically tells you which kids, that's nice. I guess it's the real time analytics. But if you click on it towards the time to when they pop up when they need help, and it'll pop up. Like, if there's a kid super struggling, it'll like be like, like a box, you have to exit click the X, because it'll take over your home screen and say, you	• Real-time teacher alerts help teacher identify students' challenges

	know, Susie needs help on hypothesis. So you're like, Okay, go straight to her because she's really struggling	● Teachers proactively approach to student
Interviewer	Would you please describe an area where InqITS provide you the most important support than you expected in your teaching practice	
Participant	I think definitely in those teacher tips, when, even if the kid doesn't need as much scaffolding, you can automatically click to the last one. So, you know, okay, this is what we're trying to get the kids to do. And it would help me kind of guide the question. if they didn't need as much support, but I may, I knew because of the tips where it wanted them to be. I was able to help guide them there. Easier. For sure. I think the teacher TIPS is The best	● TIPS helps teachers to guide student learning ● Teacher TIPS is the best feature

The first author initially reviewed and coded the data from the first participant using line-by-line coding. The initial codes were shared and reviewed with the third author to enhance the trustworthiness of the findings. After, all data was transferred over to Dedoose for the first author to conduct initial coding with all participants' data and find themes of the identified codes.

Examples of Dedoose raw data

- Interaction with features of Inq-ITS

Quotations:

1.2. with the more serious alert helping me pick the kind of critical kids who really needed my focus who and whom Rex wasn't helping enough, and who needed that teacher intervention…
2.3. it would tell me, you know, which kid needed what and when,…
3.4. it was telling me what they were messing up on. So they asked me as it came when I stood by them, they were like so what do I need to know…
5.2. this is what we're trying to get the kids to do. And it would help me kind of guide the question.

- The perceived roles of Inq-ITS

Quotations:

2.6. it's nice to kind of feel like I have a second person to be like, Oh, they're not doing that. Right, you might want to go check on them
4.5. He is definitely like a teacher's assistant. He's able to watch every student at the same time. 1.5. Like another teacher, Assistant classroom…
3.5. collaborator in that it's, it's preparing materials for me and giving me giving the kids feedback and then allowing me the space to also give feedback in my own way
6.7. It is like having a person to help you

- The classroom interactions

Quotations:

1.10. it is more than what we would do normally. Because there's no way that I can meet with all of my children, specifically about whatever they're struggling with, that's impossible. But this makes it to where it can
2.9. With him (Rex) as if I were able to watch students type every word and give feedback every time like, I think his feedback is great. And it's what I would want to give each student at the individual level)…
3.8. And you have a list of what you know, however, you're going to go which order you're going to go in…

The first author shared all initial codes and themes with the second and third authors for peer debriefing again. All authors discussed the in-depth meaning of the data and themes. After in-depth review and discussion of the initial codes and themes that emerged through this process, overarching themes were identified. See below for an example of initial coding and overarching themes.

	Interview Transcript	Initial codes	Category	Theme
Interviewer	Could you describe your use and interaction with the feature of real-time teacher alerts			
Participant	I liked most I like real-time alerts, because it would tell me, you know, which kid needed what and when, and a lot of times, the kids would just	• Like real-time teacher alerts • Real-time teacher alerts	• Like real-time teacher alerts	• Inq-ITS provides substantial

	sit there and shy before they ask a question. And I think it helps me know which kids need my help faster than they know that they even need help	help teacher know the most struggling student faster	● Identify struggling students	support to teachers
Interviewer	Does real-time teacher alerts influence the way you approach to student for help? And how?			
Participant	And where it automatically tells you which kids, that's nice. I guess it's the real time analytics. But if you click on it towards the time to when they pop up when they need help, and it'll pop up. Like, if there's a kid super struggling, it'll like be like, like a box, you have to exit click the X, because it'll take over your home screen and say, you know, Susie needs help on hypothesis. So you're like, Okay, go straight to her because she's really struggling	● Real-time teacher alerts help teacher identify students' challenges ● Teachers proactively approach to individual student to provide help	● Identify struggling students ● Targeted scaffolding from teacher	● Inq-ITS provides substantial support to teachers ● Targeted pedagogical approach
Interviewer	Would you please describe an area where Inq-ITS provide you the most important support than you expected in your teaching practice			
Participant	I think definitely in those teacher tips, when, even if the kid doesn't need as much scaffolding, you can automatically click to the last one. So, you know, okay, this is what we're trying to get the kids to do. And	● TIPS helps teachers to guide student learning ● Teacher TIPS is the best feature	● TIPS provides pedagogical suggestions	● Inq-ITS provides substantial support to teachers

	it would help me kind of guide the question. if they didn't need as much support, but I may, I knew because of the tips where it wanted them to be. I was able to help guide them there. Easier. For sure. I think the teacher TIPS is The best			

Appendix F. The Codes and Excerpts Frequency of the emerging Themes and Categories

Themes	Categories	# of Initial Codes	# of Coded Excerpts
AI provides substantial support to teachers	The teacher alerts support teachers in identifying student challenges in real-time	3	20
	The teacher reports provide teachers information on student progress	4	16
	Teacher inquiry practice support provides teachers with expert advice	4	10
Teachers support the work of A	Teachers preparing students with sufficient prior knowledge prior to using Inq-ITS	2	5
	Teachers facilitate Inq-ITS during its guidance of students' independent learning	4	15
	Teachers step in to help when Inq-ITS is insufficient in guiding students' learning	3	11
AI is perceived as a facilitating tool	--	1	4
AI is perceived as an interactive collaborator	Collaborative partner	2	8
	Consultant	2	6
Individualized and immediate instruction and scaffolding	Individual student follows the guidance and help from Inq-ITS to conduct independent scientific inquiry	4	14
	Teacher assesses students on individual level and provides immediate feedback	5	19
Data-driven and targeted pedagogical approach	Data-driven pedagogy	3	9
	Targeted scaffolding	3	12
Shifts in teachers' role	Teachers focused more on actual teaching and less on classroom management	3	21
	Teachers become students' final source of assistance	2	5
	Teachers conduct more data analytics work	1	4