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ORIGINAL PAPER

The Promises and Challenges of Artificial Intelligence for Teachers: a Systematic Review of Research

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Abstract

This study provides an overview of research on teachers' use of artificial intelligence (AI) applications and machine learning methods to analyze teachers' data. Our analysis showed that AI offers teachers several opportunities for improved planning (e.g., by defining students' needs and familiarizing teachers with such needs), implementation (e.g., through immediate feedback and teacher intervention), and assessment (e.g., through automated essay scoring) of their teaching. We also found that teachers have various roles in the development of AI technology. These roles include acting as models for training AI algorithms and participating in AI development by checking the accuracy of AI automated assessment systems. Our findings further underlined several challenges in AI implementation in teaching practice, which provide guidelines for developing the field.

Keywords Artificial intelligence in education · Systematic review · Teacher professional development · Technology integration

Introduction

Artificial intelligence (AI) has been penetrating our everyday lives in various ways such as through web search engines, mobile apps, and healthcare systems (Sánchez-Prieto et al., 2020). The swift advancement of AI technologies also has important implications for learning and teaching. In fact, AI-supported instruction is expected to transform education (Zawacki-Richter et al., 2019). Thus, considerable investments have been made to integrate AI into teaching and learning (Cope et al., 2020). A significant challenge in the effective integration of AI into teaching and learning, however, is the profit orientation of most current AI applications in education. AI developers know little about learning sciences and lack pedagogical knowledge for the effective implementation of AI in teaching (Luckin & Cukurova, 2019). Moreover, AI developers often fail to consider the expectations of AI end-users in education, that is, of teachers (Cukurova & Luckin, 2018, Luckin & Cukurova, 2019). Teachers are considered among the most crucial stakeholders in AI-based teaching (Seufert et al., 2020), so their views, experiences, and expectations need to be considered for the successful adoption of AI in schools (Holmes et al., 2019). Specifically, to make AI pedagogically relevant, the advantages that it offers teachers and the challenges that teachers face in AI-based teaching need to be understood better. However, little attention has been paid to AI-based education from the perspective of teachers. Moreover, teachers' skills in the pedagogical use of AI and the roles of teachers in the development of AI have been somehow ignored in literature (Langran et al., 2020; Seufert et al., 2020). To address these research gaps, this study explores the promises and challenges of AI in teaching practice that have been surfaced in research. Since the field of AI-based instruction is still developing, this study can contribute to the development of comprehensive AI-based instruction systems that allow teachers to participate in the design process.

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Educational Use of Artificial Intelligence

There have been several waves of emerging educational technologies over the past few decades, and now, there is artificial intelligence (AI; Bonk & Wiley, 2020). The term *artificial intelligence* was first mentioned in 1956 by John McCarthy (Russel & Norvig, 2010). Baker and Smith (2019) pointed out that AI does not refer to a single technology but is defined as "computers [that] perform cognitive tasks, usually associated with human minds, particularly learning and problem-solving" (p. 10). AI is a general term that refers to diverse analytical methods. These methods can be classified as machine learning, neural networks, and deep learning (Aggarwal, 2018). Machine learning is defined as the capacity of a computer algorithm learning from the data to make decisions without being programmed (Popenici & Kerr, 2017). Although numerous machine learning models exist, the two most used models are supervised and unsupervised learning models (Alloghani et al., 2020). Supervised machine learning algorithms build a model based on the sample data (or training data), while unsupervised machine learning algorithms are created from untagged data (Alenezi & Faisal, 2020). In other words, the unsupervised model performs on its own to explore patterns that were formerly undetected by humans.

AI is used in education in different ways. For instance, AI is integrated into several instructional technologies such as chatbots (Clark, 2020), intelligent tutoring, and automated grading systems (Heffernan & Heffernan, 2014). These AI-based systems offer several opportunities to all stakeholders throughout the learning and instructional process (Chen et al., 2020). Previous research conducted on the educational use of AI presented AI's support for student collaboration and personalization of learning experiences (Luckin et al., 2016), scheduling of learning activities and adaptive feedback on learning processes (Koedinger et al., 2012), reducing teachers' workload in collaborative knowledge construction (Roll & Wylie, 2016), predicting the probability of learners dropping out of school or being admitted into school (Popenici & Kerr, 2017), profiling students' backgrounds (Cohen et al., 2017), monitoring student progress (Gaudioso et al., 2012; Swiecki et al., 2019), and summative assessment such as automated essay scoring (Okada et al., 2019; Vij et al., 2020; Yuan et al., 2020). Despite these opportunities, the educational use of AI is more behind what is expected, unlike in other sectors (e.g., finance and health). To achieve successful AI implementation in education, various stakeholders, specifically, teachers, should participate in AI creation, development, and integration (Langran et al., 2020; Qin et al., 2020).

The Roles of Teachers in AI-based Education

The evolution of education towards digital education does not imply that people will need less teachers in the future (Dillenbourg, 2016). Instead of speculating if AI will replace teachers, understanding the advantages that AI offers teachers and how these advantages can change teachers' roles in the classroom is more reasonable (Hrastinski et al., 2019). Salomon (1996) demonstrated this during the early stages of development of educational technology by pointing out the need to consider how learning occurs through and with computers. As for AI, Holstein et al. (2019) suggested that in the future, AI-based machines can help teachers perform what Dillenbourg (2013) emphasized as their orchestrator role in the learning and teaching process. For AI to be able to truly help teachers in this way, however, it must first learn effective orchestration of learning and teaching from teachers' data. This is because effective teaching depends on teachers' capability to implement appropriate pedagogical methods in their instruction (Tondeur et al., 2020), and their pedagogically meaningful and productive teaching incidents can serve as models for AI-based educational systems (Prieto et al., 2018). That is, the data collected from the learning setting orchestrated by teachers form the foundation of AI-based teaching. For example, the data may help researchers to understand when and how teaching is effectively progressing (Luckin & Cukurova, 2019; Luckin et al., 2016). To prove that the role of teachers in providing the data on features of effective learning is crucial for the development of AI algorithms, we investigated the kind of data collected from teachers and teachers' roles in the creation of AI algorithms.

To effectively integrate AI-based education in schools, teachers must be empowered to implement such integration by endowing them with the requisite knowledge, skills, and attitudes (Häkkinen et al., 2017; Kirschner, 2015; Seufert et al., 2020). However, teachers' AI-related skills have not yet been sufficiently defined because the potential of AI in education has not yet been fully exploited (Luckin et al., 2016). To explore teachers' AI-related knowledge, skills, and attitudes, their engagement with AI-based systems within their teaching setting has to be investigated in detail (Dillenbourg, 2016; Seufert et al., 2020). Therefore, in this study, we reviewed empirical research on how teachers interacted with AI-based systems and how they participated in the development of AI-based education systems. We believe that our synthesis of empirical research on the topic will contribute to the identification of AI-related teaching skills and the effective implementation of AI-based education in schools with the support of teachers.

This study explored the perspective and roles of teachers in AI-based research through a systematic review of

the latest research on the topic. Our specific research questions (RQs) are as follows:

RQ1—What was the distribution over time of the studies that examined teachers' AI use?
RQ2—What data were collected from teachers in the studies on AI-based education?
RQ3—What were the roles of teachers in AI-based research?
RQ4—What advantages did AI offer teachers?
RQ5—What challenges did teachers face when using AI for education?
RQ6—Which AI methods were utilized in AI-based research that teachers participated in?

Table 1 below lists these RQs with their corresponding rationales.

Methods

Manuscript Search and Selection Criteria

In reviews of research, several methods are used to select the studies that will be reviewed. Studies published in important journals of a given domain are selected from databases such as ProQuest (Heitink et al., 2016), Education Resources Information Center (ERIC), and the Social Science Citation Index (SSCI) (Akçayır & Akçayır, 2017; Kucuk et al., 2013). For this review, we selected English-language scientific studies on teachers' AI use that were published in journals from the Web of Science (WoS) database within the last 20 years until 14 September 2020. We used this method because the field tags (e.g., the topic and research area) of the studies were easy to access from the WoS database (Luor et al., 2008). We used the following search string: "artificial intelligence," "deep learning," "reinforcement learning," "supervised learning," "unsupervised learning," "neural network," "ANN," "natural language processing," "fuzzy logic," "decision trees," "ensemble," "Bayesian," "clustering," and "regularization." To narrow our search, we used "teacher," "teacher education," "teacher professional development," "K-12," "middle school*," "high school*," "elementary school*," and "kindergarten*." We selected the search strings based on the main concepts of AI in education in past studies and literature reviews (Baran, 2014; Zawacki-Richter et al., 2019). Figure 1 presents our study search procedure.

In our first search, we found 751 studies. Next, we checked them to see if they met our inclusion and exclusion criteria. Our inclusion criteria were as follows: (a) empirical studies on AI in pre-service and in-service teacher education and on in-service teachers' use of AI; (b) studies on AI applications and algorithms (e.g., personal tutors, automated scoring, personal assistant; decision trees, and artificial neural networks) for teaching or analyzing teachers' data; and (c) studies on data collected from in-service K-12 teachers or pre-service teachers. We excluded editorials, reviews, and studies conducted at the higher education level. After we applied the criteria, 44 articles remained suitable for inclusion in this study.

Data Coding and Analysis

The publication year of the articles was noted to determine the distribution of the studies over time (RQ1). For

Table 1 Themes and rationales of research questions

Theme of research questions (RQs)	Rationale
The distribution of the studies (RQ1)	The education sector is behind other sectors (e.g., finance and health) in the use of artificial intelligence (AI) (Clark, 2020). To more insightfully compare educational AI use with AI use in other sectors, it is important to understand the trend of research on teachers' use of AI
The data collected from teachers (RQ2)	Teachers' pedagogically meaningful and productive teaching moments serve as models for educational AI-based interventions (Luckin & Cukurova, 2019). The data modality from these moments is crucial for training AI algorithms
The role of teachers in AI-based research (RQ3)	For successful integration of AI into education, teachers' AI views, experiences, and expectations need to be explored (Holmes et al., 2019). However, AI developers generally ignore the expectations of teachers (Cukurova & Luckin, 2018). Understanding the roles of teachers in effective AI implementation can yield insights into further AI-based interventions and research
The advantages that AI offers teachers (RQ4) The challenges that teachers face when using AI (RQ5)	Considering the advantages that AI offers teachers and the challenges that teachers face during AI-based teaching may be important for promoting teachers' adoption of AI (Holmes et al., 2019). Specifically, more information is needed to understand the advantages and challenges of teachers' AI use
AI methods in AI-based research with teachers (RQ6)	Revealing teachers' commonly used AI approaches can shed light on AI developers who are far from educational science

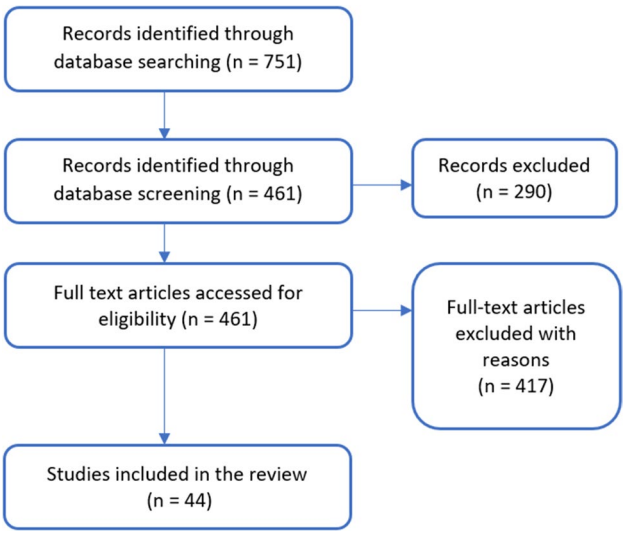

Fig. 1 Flow chart for the selection of articles

RQ2, the following categories and category numbers were assigned to the data collected from teachers in previous AI-based research: self-report (1), video (2), interview (3), observation (4), feedback/discourse (5), grading (6), eye tracking (7), audiovisual/accelerometry (8), and log file (9). We qualitatively analyzed the content of the 44 articles to determine the advantages and challenges of AI for teachers (RQ4 and RQ5, respectively) and teachers' roles in AI-based instruction as found in research (RQ3). We coded the studies not with the preliminary or template coding scheme, which would have unnecessarily limited them by fitting them into a pre-determined coding scheme (Şimşek & Yıldırım, 2011), but with the open coding process (Akçayır & Akçayır, 2017; Williamson, 2015), which followed these steps: (1) Familiarize with the whole set of articles; (2) Choose a document randomly, consider its primary meaning, and write down your thought on such meaning on the margin of the document; (3) List all your thoughts on the subject, combine similar thoughts, create three columns for key, unique, and leftover thoughts, and put each thought in the appropriate column; (4) Code the text; (5) Find the most illustrative phrases for your thoughts and turn them into categories; (6) Decide on an abbreviation for each category and alphabetize these abbreviations; (7) Incorporate the final codes and perform the initial analysis; and (8) Recode the studies if needed. To classify the AI methods (RQ6), we used previous literature reviews of AI use in diverse areas such as higher education, medicine, and business (Borges et al., 2020; Contreras & Vehi, 2018). We performed the investigator triangulation method to ensure the reliability of the coding process (Denzin, 2017). Accordingly, the first author coded the articles separately and then shared the codes with the second author. We negotiated disagreements by checking the code list and the relevant studies, and we updated and renamed some categories. Finally, we recoded the studies using the final code list.

Results and Discussion

Distribution of the Studies

(RQ1—What was the distribution over time of the studies that examined teachers' AI use?)

Our analysis indicated that the first study on teachers' AI use was published in 2004. Of the 44 studies we reviewed, 22 were published in 2018 and the following years. It has been forecasted that the usage of educational AI applications will increase (Qin et al., 2020; Zawacki-Richter et al., 2019). Such increase is implied in our finding that the publication of studies on AI-based teaching increased after 2017. Figure 2 presents the research trend on AI and teachers.

Figure 2 further indicates that research on teachers' AI use in education intensified in the last four years. This implies that AI-based instruction by teachers is most likely to become more common in the near future. Supporting this, our review of literature on the topics "AI" and "education" showed that studies published between 2015 and 2019 accounted for 70% of all the studies from Web of Science and Google Scholar since 2010 (Chen et al., 2020). The availability of AI technologies and of educational software companies to create AI-based applications is increasing rapidly all over the world (Renz & Hilbig, 2020). Accordingly, it seems likely that teachers' use of AI in the teaching process will grow and more studies will be conducted on this topic.

On the other hand, there are still fewer studies on AI use in education than in other areas such as medicine and business (Borges et al., 2020; Luckin & Cukurova, 2019). The educational technology (EdTech) market is growing much more slowly than other markets with respect to the dynamics of digital transformation. One of the reasons for this is the resistance of decision-makers such as educators, teachers, and traditional textbook publishers to the use of AI (EdTechXGlobal Report, 2016). Considering this resistance, it can be argued that more AI research is needed to show the pedagogical uses of AI in instructional processes and to speed up the uptake of AI technologies in education.

Data Types Collected from Teachers

(RQ2—What data were collected from teachers in the studies on AI-based education?)

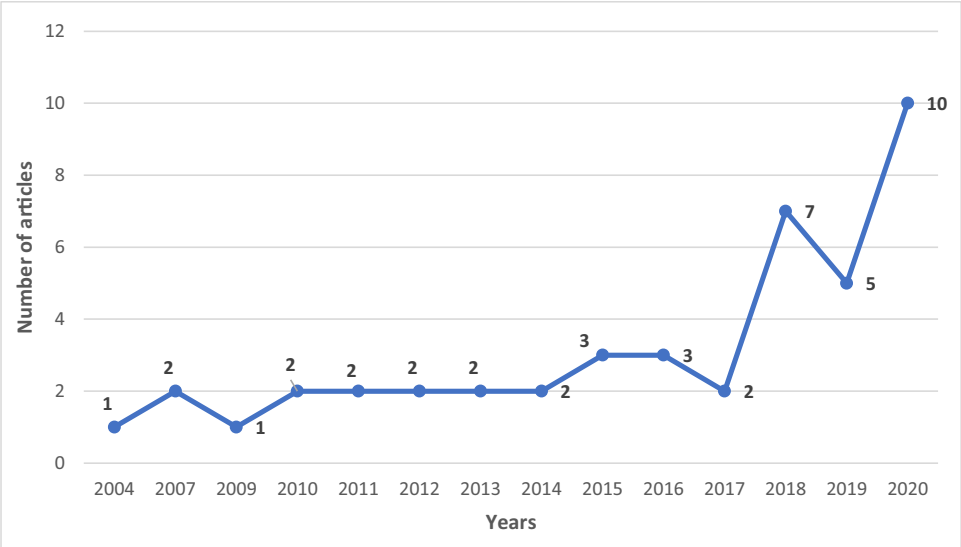

Fig. 2 Number of articles published by year

Self-reported data were the most common data collected from teachers in the AI-based education studies. The researchers collected self-reported data to predict teacher-related variables such as engagement, performance, and teaching quality. In these studies, machine learning algorithms were used instead of conventional regression analysis to reveal nonlinear relationships between variables of teaching practice. For instance, Wang et al. (2020) collected data from 165 early childhood teachers to better understand indicators of quality teacher–child interaction. Similarly, in Yoo and Rho (2020), teachers' self-reported job satisfaction was predicted by a machine learning technique. In some AI studies, teacher grades of student assignments or essays were used to train AI algorithms. For example, Yuan et al. (2020), in developing an automated scoring approach, needed expert teachers' grades to validate their AI-based scoring system. A notable finding from our review is that self-reported grades accounted for nearly 44% of all data obtained from teachers (Fig. 3).

In 11 of the studies that we reviewed, teachers provided more than one type of data. The data were mostly collected during or after teachers' instruction. Our review findings highlight the crucial role of teachers in the instructional process (e.g., Huang et al., 2010; Lu, 2019; McCarthy et al., 2016; Pelham et al., 2020). For example, Schwarz et al. (2018) presented an online learning environment that uses machine learning to inform teachers about learners' critical moments in collaborative learning by sending the teachers

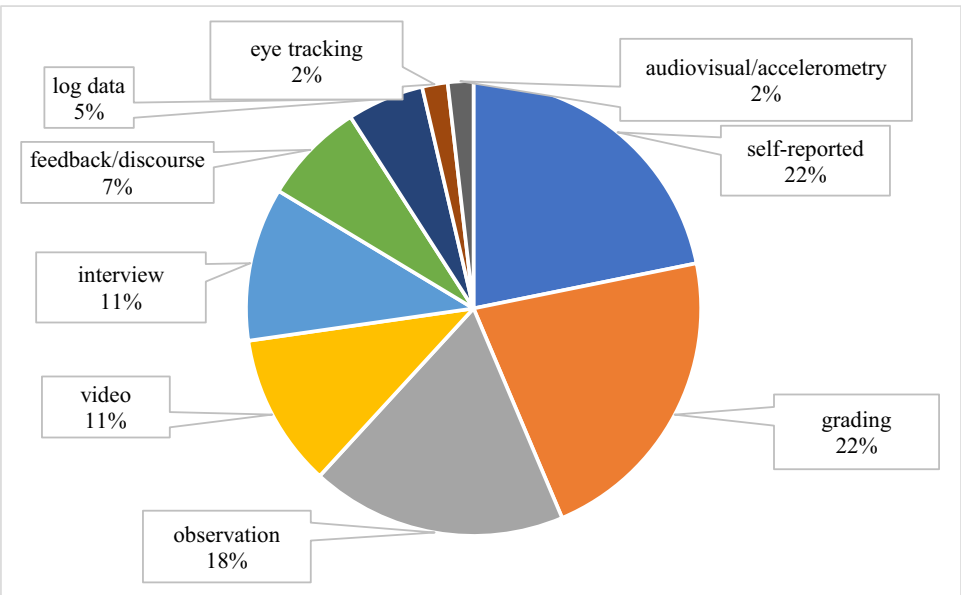

Fig. 3 Data types

warnings. In their study, they observed how the teacher guided several groups at different times in a mathematics classroom. In addition to observations, they collected interview data from the teachers about the effectiveness of the online environment. Our review indicates that there is a significant gap in physiological data collection in AI studies with teachers. Only one of the studies we reviewed collected physiological data, that is, data on eye tracking and audio-visual/accelerometry data from sensors worn by the teachers (Prieto et al., 2018). In fact, physiological data can be considered relevant and useful for providing process-oriented, objective metrics regarding the critical moments that impact the quality of teaching or learning in an educational activity (Järvelä et al., 2021).

The Roles of Teachers in AI-based Research

(RQ3—What were the roles of teachers in AI-based research?)

Our findings from our open-coding analysis indicate that teachers have seven roles in AI research. These roles and their descriptions are shown in Table 2. As seen from the table, teachers participated in AI research as models to train AI algorithms. This role was found to be the most common role of teachers in AI-based instruction ($f=18$). This finding underlines the pivotal role of teachers in the development of AI-based education systems. For instance, Kelly et al. (2018) conducted a study to train AI algorithms to automatically detect teachers' authentic questions in real-life classrooms. During the training of the AI algorithms, the teachers' effective authentic questions were fed to the AI system as features. Following the AI training, the researchers tested AI in a different classroom and found that AI successfully identified authentic questions.

Another role that teachers were observed to have in AI research was providing big data to AI systems to enable them to forecast teachers' professional development. In this line of research, teachers mostly provided data to AI systems for the latter's prediction of different variables of the professional development of teachers such as their job satisfaction, performance, and engagement. For example, in one study, 10,642 teachers answered a survey (Buddhtha et al., 2019). Then, using AI, predictors of teacher engagement were determined. Similar to other areas, big data have played an important role in education, and teachers are considered among the most important sources of big data (Ruiz-Palmero et al., 2020). Our findings imply that AI can effectively inform teachers of their professional development.

This study also found that teachers involved in AI research provided input information on students' characteristics for the AI-based implementation. For example, Nikiforos et al. (2020) investigated automatic detection of learners' aggressive behavior in a virtual learning community. The AI system utilized teacher observations of students' behavioral characteristics to predict the students who were more likely to bully others in the online community. Our review further revealed that teachers have taken on the role of grading assignments and essays to test the accuracy of AI algorithms in grading student performance. In such studies, the accuracy rate of the AI-based assessment was determined with the help of experienced teacher assessments

Table 2 Teachers' roles in educational AI research

Role of teachers	Description	f	Sample research
Being models for AI training	Teachers acted as sources of data from an effective teaching process or moment	18	Su et al. (2014); Kelly et al. (2018)
Feeding AI systems with data on their professional development	Teachers participated in research for more accurate prediction of teacher-related variables (e.g., teaching quality and teacher performance and engagement)	9	Alzahrani et al. (2020); Yoo and Rho (2020)
Feeding AI algorithms with student information and behaviors	Teachers provided information on students' characteristics for the AI implementation (or intervention)	8	Bonneton-Botté et al. (2020); Nikiforos et al. (2020)
Checking the accuracy of assessments	Teachers graded assignments and essays to test the accuracy of AI grading algorithms	5	Yuan et al. (2020)
Determining the assessment criteria	Teachers defined the criteria for AI-based assessment	4	Huang et al. (2010)
Providing pedagogical guidance for the selection of materials	Teachers provided pedagogical guidance for the selection of materials for AI-based implementation (intervention)	3	Dalvean and Enkhbayar (2018); Fitzgerald et al. (2015)
Providing feedback on technical issues	Teachers gave feedback and raised their views on technical issues (e.g., on AI design or usability) in AI-based education	1	Burstein et al. (2004)

(Bonneton-Botté et al., 2020; Gaudioso et al., 2012; McCarthy et al., 2016; Yuan et al., 2020).

In some AI-based education studies, teachers determined the criteria for some components of AI-based systems and assessments. For example, Huang et al. (2010) investigated the effect of the learning assistance tool *ICT Literacy*. The tool used machine learning. In their study, experienced teachers guided the AI system by defining the criteria for effective and timely feedback. In some studies, teachers also provided pedagogical guidance on the selection of materials for AI-based implementation. For example, Fitzgerald et al. (2015) utilized AI to present learning content with varying degrees of text complexity to early-grade students. They attempted to explore early-grade text complexity features. Text complexity in the AI system was determined based on teachers' pedagogical guidance. Furthermore, teachers commented on the usability and design of AI-based technologies (Burstein et al., 2004). Finally, our results revealed a notable absence of pre-service teachers as participants in AI use studies. That is, there were no studies in which pre-service teachers actively participated or interacted with AI technologies.

Advantages of AI for Teachers

(RQ4—What advantages did AI offer teachers?)

We found several advantages of AI from our review of selected empirical studies on teachers' AI use. The open coding revealed three categories of AI advantages: planning, implementation, and assessment (see Table 3).

Planning

The advantages of AI related to planning involved receiving information on students' backgrounds and assisting teachers in deciding on the learning content during lesson planning. In a study, an AI system provided teachers background information on students' risk factors for delinquency, such as aggression (Pelham et al., 2020). In terms of teacher assistance in planning learning content, Dalvean and Enkhbayar (2018) used machine learning to classify the readability of English fiction texts. The results of their study suggested that the classification can help English teachers to plan the course contents considering the readability features (Table 4).

Implementation

According to our review (see Table 3), the most prominent advantage of AI was stated as timely monitoring of learning processes ($f=12$). For example, Su et al. (2014) developed a sensor-based learning concentration detection system using AI in a classroom environment. The system allowed teachers to monitor the degree of students' concentration on lesson activities. Such AI-based monitoring can help teachers to provide immediate feedback (Burstein et al., 2004; Huang et al., 2010, 2011) and quickly perform the necessary interventions (Nikiforos et al., 2020; Schwarz et al., 2018). For instance, teachers were able to discover critical moments in group learning and provide adaptive interventions for all the groups (Schwarz et al., 2018). Hence, AI systems can decrease the teaching burden on teachers by providing them feedback and assisting them with planning interventions and with student monitoring. In several studies, these contributions to teachers were particularly emphasized (Lu, 2019; Ma et al., 2020). Therefore, we assume that reduced teaching load may be another significant advantage of AI systems in education. For example, researchers reported that teachers benefitted from an AI-based peer tutor recommender system and saved time for other activities (Ma et al., 2020).

Our findings further revealed that AI can enable teachers to select or adapt the optimum learning activity based on AI feedback. For example, in Bonneton-Botté et al. (2020), teachers decided to implement exercises such as writing letters and numbers for students with a low graphomotor level based on the feedback they received from AI. According to our synthesis, AI can also make the teaching process more interesting for teachers. Teachers reported that AI-tutors facilitated enjoyable teaching experiences for them by breaking the monotony in the classroom (McCarthy et al., 2016). We also found out that AI algorithms can increase opportunities for teacher-student interaction by capturing and analyzing data from productive moments (Lamb & Premo, 2015) and tracking student progress (Farhan et al., 2018).

Assessment

According to our review, AI helps teachers in exam automation and essay scoring and in decision-making on student performance. It has been found that an automated essay scoring system can not only significantly advance the effectiveness of essay scoring but also make scoring more objective (Yuan et al., 2020). Therefore, researchers are interested in the use of AI affordances to investigate automated systems. An important utility of AI-based applications in the context of assessment is to detect plagiarism in student essays (Dawson et al., 2020). Several existing AI-based systems (e.g., Turnitin) allow teachers to check the authenticity of essays submitted by students in graduate courses (Alharbi & Al-Hoorie, 2020). This can be considered an important utility of AI in student assessment. We coded seven studies on the advantage of exam automation and essay scoring. Six of these studies investigated the scoring of student-related outcomes (Annabestani et al., 2020; Huang et al., 2010; Tepperman et al., 2010; Yuan et al., 2020; Vij et al., 2020; Yang, 2012), and one study used AI-based systems

Table 3 Advantages of AI use for teachers

Inductive categories	Advantages of AI *subcategories*	Description	f	Sample research
Planning	Provision of information on student backgrounds	Teachers can get information from the AI system about their students' background	4	Pelham et al. (2020)
	Decision-making on learning content	Teachers can use AI to decide on the suitability of their learning content to their students' proficiency and needs	2	Fitzgerald et al. (2015)
	Planning of activities	AI may be helpful for teachers during their planning of course activities	1	Dalvean and Enkhbayar (2018)
Implementation	Timely monitoring	Teachers can monitor their students using AI	12	Swiecki et al. (2019)
	Reducing teacher workload	AI can reduce teacher workload	8	Vij et al. (2020)
	Giving immediate feedback	AI enables teachers to give immediate feedback	7	Huang et al. (2011)
	Selecting/adapting the optimum learning activity based on AI feedback	AI can help teachers to decide on which exercises are most appropriate for their students based on their students' characteristics	5	Bonneton-Botté et al. (2020)
	Facilitating timely intervention	AI can facilitate teachers' timely intervention for better learning	4	Schwarz et al. (2018)
	Tracking student progress	Teachers can track student progress using AI	4	Farhan et al. (2018)
	Making the teaching process more interesting	Utilizing AI-based applications or AI-based teaching makes instruction more interesting for teachers	2	Lu (2019)
	Increasing interaction	AI has the potential to promote teacher-student interaction	1	Lamb and Premo (2015)
Assessment	Better prediction/ assessment of teacher performance/outcomes	Important insights for teacher development can be more accurately revealed by AI (machine learning algorithms) than by linear regression	14	Kelly et al. (2018)
	Automated assessment and evaluation	AI helps teachers to automate exams, essay scoring, and decision-making	7	Kersting et al. (2014)
	Provision of feedback on the effectiveness of instructional practice	AI can show teachers how effectively they teach	5	Prieto et al. (2018)
	Assistance in making clinical decisions	AI can allow teachers to support clinical decisions (e.g., on autism spectrum disorder)	2	Cohen et al. (2017)

to score teachers' open-ended responses, to assess usable mathematics teaching knowledge (Kersting et al., 2014). We suggest that more studies be conducted on automatic scoring of teacher-related variables such as technological and pedagogical knowledge. Considering that classroom video analysis (CVA) assessment is capable of scoring and assessing teacher knowledge (Kersting et al., 2014), CVA can be used in both in-service and pre-service teacher education, particularly on micro-teaching methods. For example, natural language processing methods (Bywater et al., 2019) can utilize existing CVA scoring schemes to detect teachers' verbal communication patterns in conveying instructional content to students. Furthermore, machine vision methods (Ozdemir & Tekin, 2016) can be applied to teachers' video recordings to observe the patterns in their body posture. Such methods may provide valuable feedback to novice teachers on developing their teaching skills.

AI could also help provide teachers feedback on the effectiveness of their instructional practice (Farhan et al., 2018; Lamb & Premo, 2015). Teachers' pedagogically meaningful teaching aspects can be modeled automatically using multiple data sources and AI (Dillenbourg, 2016; Prieto et al., 2018). Through these models, teachers can improve their instructional practices. Besides, the pedagogically effective models can train AI algorithms to make them more sophisticated.

Also, AI technologies were used to better predict or assess teacher performance or outcomes. Researchers predicted pre-service or in-service teachers' professional development outcomes such as course achievement using machine

Table 4 Challenges in AI use by teachers

Challenge in AI use	Description	f	Sample research
Limited reliability of AI algorithms	AI algorithms are not reliable enough to provide useful information to teachers	6	Schwarz et al. (2018)
Limited technical capacity of AI	AI may not be capable of processing specific features (e.g., graphics or images and text)	3	Ma et al. (2020)
Limited technical infrastructure in schools for AI	Technical infrastructure in schools are limited for AI-based teaching	2	Ozdemir and Tekin (2016)
Inapplicability of the AI system to multiple settings	An AI system cannot operate in multiple learning settings	2	Nikiforos et al. (2020)
Inefficiency of AI for assessment and evaluation	AI cannot properly evaluate text structure and content logic and coherence	2	Lu (2019)
Lack of technological knowledge of teachers on AI use	Teachers may not have the technological knowledge needed for AI-based teaching	1	Chiu and Chai (2020)
Lack of interest of teachers in AI	Teachers may perceive AI as uninteresting and unenjoyable for teaching	1	McCarthy et al. (2016)
Slow AI feedback	AI feedback may take longer than expected	1	McCarthy et al. (2016)
Limited AI adaptive feedback	AI may not provide comprehensive adaptive and personalized feedback	1	Burstein et al. (2004)

learning algorithms, which are beneficial in revealing complex and nonlinear relationships. While seven studies collected data from in-service teachers, two studies obtained data from pre-service teachers (Akgün & Demir, 2018; Demir, 2015).

In addition, Cohen et al. (2017) conducted a study on a sample with autism spectrum disorder and another sample without. The results revealed that a machine learning tool can provide accurate and informative data for diagnosing autism spectrum disorder. In the study of Cohen et al., teachers commented on the accuracy of the tool.

Figure 4 illustrates the role of teachers in AI research and the advantages of AI for teachers. This gives us ideas about AI expectations from teachers and AI opportunities for teachers.

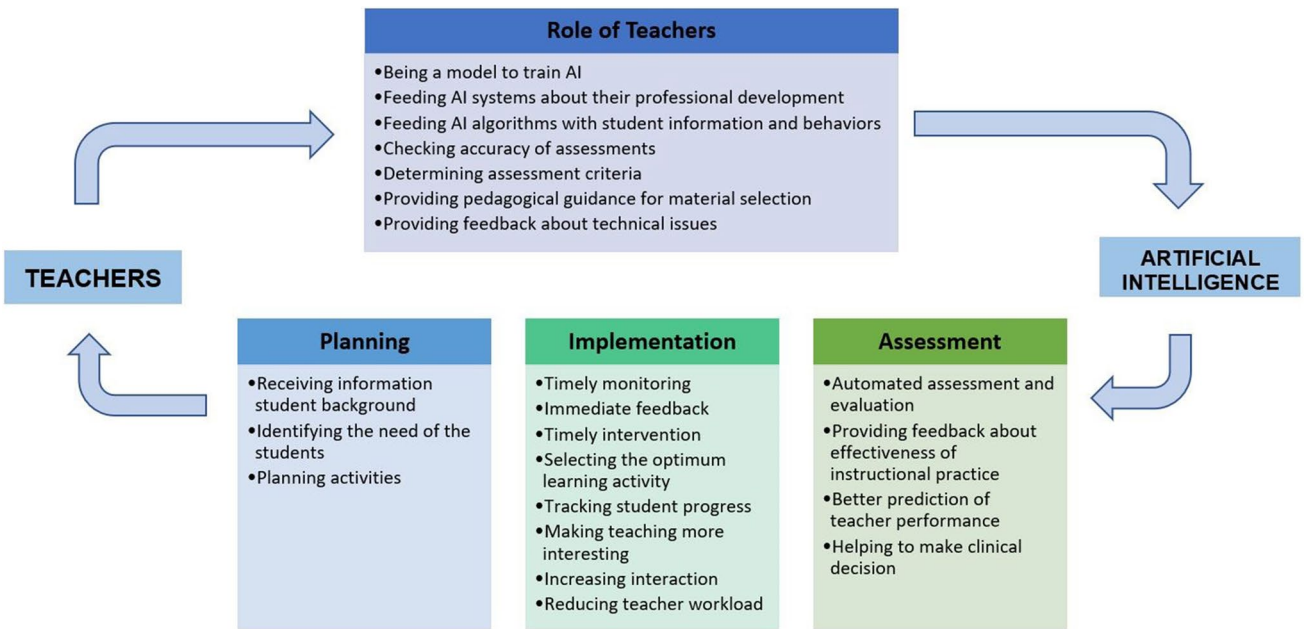

Fig. 4 Advantages of AI and teacher roles in AI research

Challenges in AI Use by Teachers

(RQ5—What challenges did teachers face when using AI for education?)

The challenges in teachers' use of AI are summarized in Table 3. One of the most observed challenges is the limited technical capacity of AI. For example, AI may not be efficient for scoring graphics or figures and text. Fitzgerald et al. (2015) reported that an AI-based system failed to assess the complexity of texts when they included images. The limited reliability of the AI algorithm was found to be another considerable challenge. Therefore, automated writing evaluation technologies that use AI algorithms have to be improved to provide trustworthy evaluations for teachers (Qian et al., 2020). Inefficiency of AI systems in assessment and evaluation is related more to validity than to reliability. AI-based scoring may sometimes improperly evaluate performance (Lu, 2019). Our review further indicated that AI systems may be too context-dependent such that using them in varying educational settings can be challenging. For example, an AI algorithm designed to detect specific behavior in a specific online learning environment cannot work in different languages (Nikiforos et al., 2020). In other words, this limitation can stem from cultural differences.

The lack of technological knowledge of teachers (Chiu & Chai, 2020) and the lack of technical infrastructure in schools (McCarthy et al., 2016) are two other challenges in integrating AI into education. It has also been reported that AI-based feedback is sometimes slow. This can lead to teacher boredom in using AI (McCarthy et al., 2016). Although adaptive and personalized feedback is important for teachers to reduce their workload, AI systems are not always capable of giving different kinds of feedback based on students' needs (Burstein et al., 2004). Therefore, AI systems currently fall short of meeting the needs of teachers for effective feedback (Fig. 5).

AI Methods in Research

(RQ6—Which AI methods were utilized in AI-based research that teachers participated in?)

We coded AI methods in the studies, following previous reviews (Borges et al., 2020; Contreras & Vehi, 2018; Saa et al., 2019). Artificial neural networks (ANN) appeared to have been the most used ($f = 16$) AI method in the education studies involving teachers. ANN is a machine learning method that is widely used in business, economics, engineering, and higher education (Musso et al., 2013). According to our review, ANN also processes common data sourced from teachers. For example, Alzahrani and his colleagues (Alzahrani et al., 2020) investigated the relationship between thermal comfort and teacher performance. Through ANN analysis, they analyzed the data related to teachers' productivity and the classroom temperature. Decision trees, another machine learning algorithm, were frequently utilized in our reviewed studies. For instance, Gaudioso et al. (2012) used decision tree algorithms on data to support teachers in detecting moments in which students were having problems in an adaptive educational system. Similar to our findings, a review of predictive machine learning methods for university students' academic performance found that the decision tree algorithm was the most commonly used (Saa et al., 2019).

In our review, we also investigated the subject domains of teachers' AI-based instruction. The studies with teachers from various domains accounted for 16% of all research (see Fig. 6). These studies generally had a larger sample size

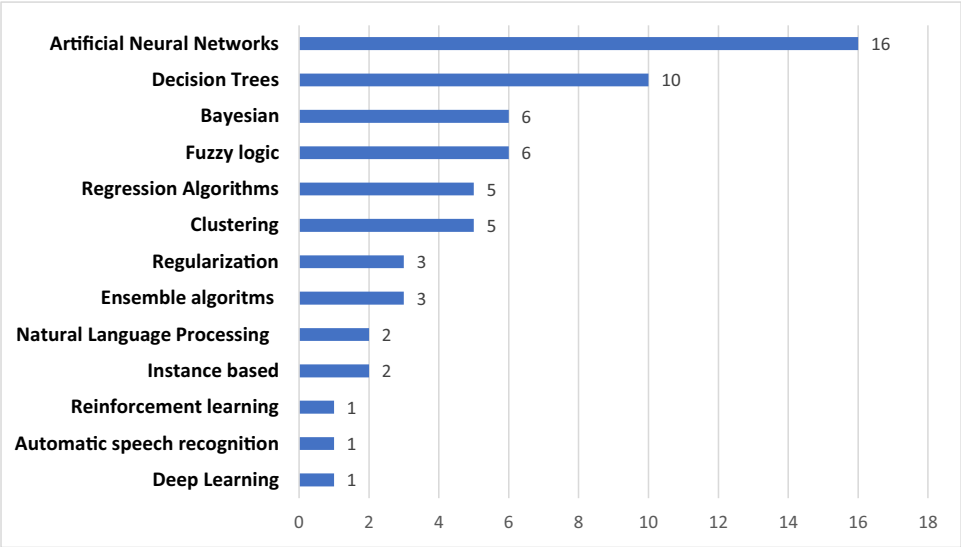

Fig. 5 AI methods in the reviewed studies

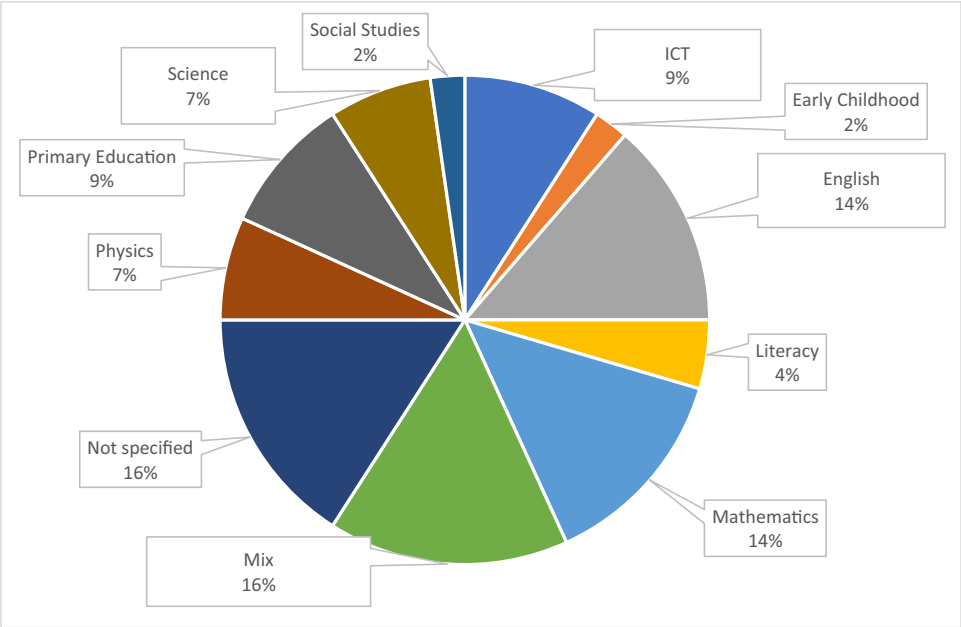

Fig. 6 Distribution of studies by subject domain

than the studies with teachers from a single domain (e.g., Buddhtha et al., 2019). Primary education and the English language appeared to be the domains where teachers use AI the most. Studies on automated essay scoring and adaptive feedback were conducted in English language courses. We found that 46% of all the studies we reviewed were performed in fields related to science, technology, engineering, and mathematics (STEM), and a much smaller percentage of studies were performed in the social science and early childhood fields together. These might have been because teachers in STEM fields are more accustomed to technology use (Chai et al., 2020).

Conclusions and Future Research

Due to the growing interest in AI use, the number of studies on teachers' use of AI has been increasing in the last few years, and more studies are needed to know more about teachers' AI use. As AI continues to become popular in education, undoubtedly more research will focus on AI use in teachers' instruction. Our synthesis of relevant studies shows that there has been little interest in investigating AI in pre-service teacher education. Hence, we recommend more empirical studies on pre-service teachers' AI use. Developing AI awareness and skills among pre-service teachers may facilitate better adoption of AI-based teaching in future classrooms. As Valtonen et al. (2021) have shown, teachers' and students' use of emerging technologies can make a major contribution to the development of 21st-century practices in schools.

Another gap we found in our review is the limited variety of methods and data channels used in AI-based systems. It seems that AI-based systems in education do not exploit the potential of multimodal data. Most of the AI applications that teachers use utilize only self-reported and/or observation data, while different data modalities can create more opportunities to understand teaching and learning processes (Järvelä & Bannert, 2021). Enriching AI systems with other data types (e.g., physiological data) may give a better understanding of different layers of teaching and learning, and thus, help teachers to plan effective learning interventions, provide timely feedback and conduct more accurate assessments of students' cognitive and emotional states during the instruction. Utilizing multimodal data can help to model more efficient and effective AI systems for education. Thus, we conclude that further work is necessary to improve the capabilities of AI systems with multimodal data.

Our review revealed that teachers have limited involvement in the development of AI-based education systems. Although in some studies, experienced teachers were recruited to train AI algorithms, further efforts are needed to involve a wider population of teachers in developing AI systems. Such involvement should go beyond training AI algorithms and involve teachers in the crucial decision-making processes on how (not) to develop AI systems for better teaching. For their part, AI developers and software companies should consider involving teachers in the development process to a greater extent.

This study showed that AI has been reported as generally beneficial to teachers' instruction. Teachers can take advantage of AI in their planning, implementation, and assessment work. AI assists them in identifying their students' needs so

that they can determine the most suitable learning content and activities for their students. During the activities, such as a collaborative task, with the help of AI, teachers can monitor their students in a timely manner and give them immediate feedback (e.g., Swiecki et al., 2019). After the instruction, AI-based automated scoring systems can help teachers with assessment (e.g., Kersting et al., 2014). These advantages mainly reduce teachers' workload and help them to focus their attention on critical issues such as timely intervention and assessment (Vij et al., 2020). However, many of the studies reviewed were conducted to predict outcome variables (e.g., performance, engagement, and job satisfaction) through machine learning algorithms (Yoo & Rho, 2020). More studies are needed to enable AI systems to provide information and feedback on how the learning processes temporally unfold during teachers' instruction. Then, teachers will be able to interact with actual AI systems to better understand possible opportunities.

This study revealed several limitations and challenges of AI for teachers' use such as its limited reliability, technical capacity, and applicability in multiple settings. Future empirical research is necessary to address the challenges reported in this study. We conclude that developing AI systems that are technically and pedagogically capable of contributing to quality education in diverse learning settings is yet to be achieved. To achieve this objective, multidisciplinary collaboration between multiple stakeholders (e.g., AI developers, pedagogical experts, teachers, and students) is crucial. We hope that this review will serve as a springboard for such collaboration.

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Declarations

Human and Animal Rights There were no human participants and/or animals.

Informed Consent This study is a literature review; therefore, no informed consent was needed.

Conflict of Interest There are no potential conflicts of interest.

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