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Systematic literature review on opportunities, challenges, and future research recommendations of artificial intelligence in education

Thomas K.F. Chiu [a,*], Qi Xia [b], Xinyan Zhou [b], Ching Sing Chai [b], Miaoting Cheng [c]

[a] Department of Curriculum and Instruction, Centre for Learning Sciences and Technologies, Hong Kong Institute of Asia-Pacific Studies at The Chinese University of Hong Kong, Hong Kong Special Administrative Region

[b] The Department of Curriculum and Instruction Faculty of Education, The Chinese University of Hong Kong, Hong Kong Special Administrative Region

[c] Faculty of Education & Institute of KEEP Collaborative Innovation, Shenzhen University, China

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ABSTRACT

Applications of artificial intelligence in education (AIEd) are emerging and are new to researchers and practitioners alike. Reviews of the relevant literature have not examined how AI technologies have been integrated into each of the four key educational domains of learning, teaching, assessment, and administration. The relationships between the technologies and learning outcomes for students and teachers have also been neglected. This systematic review study aims to understand the opportunities and challenges of AIEd by examining the literature from the last 10 years (2012–2021) using matrix coding and content analysis approaches. The results present the current focus of AIEd research by identifying 13 roles of AI technologies in the key educational domains, 7 learning outcomes of AIEd, and 10 major challenges. The review also provides suggestions for future directions of AIEd research.

1. Introduction

Artificial intelligence (AI) refers to the ability of a digital machine to perform tasks commonly associated with intelligent beings, and its associated technologies are divided into various branches, such as computer vision, speech, machine learning, big data, and natural language processing (Chiu, 2021; Chiu et al., 2022; Xia et al., 2022). Its explosive growth is increasingly transforming the ways people interact, communicate, live, learn, and work (Chiu, 2021; Chiu et al., 2022; Xia et al., 2022; Pedró et al., 2019;). In this study, AI in education (AIEd) refers to the application of AI technologies, such as intelligent tutoring systems, chatbots, robots, and the automated assessment of all modes of digitized artifacts that support and enhance education. AIEd has enormous potential to improve learning, teaching, assessment, and educational administration by offering students more personalized and adaptive learning, fostering teachers' understanding of students' learning process, and providing anywhere anytime machine supported queries and immediate feedback. . AIEd is stimulating an evolution of teaching and learning practices and program development, and it is one of the most important areas for educational research.

The importance of AIEd research and practice is reflected in various national and international initiatives and reports. For example, in 2019, the government of China launched a strategic policy of education modernization to encourage greater integration of intelligent technology into education and more teacher professional development activities related to AI and AIEd (Chiu, 2021; Chiu et al., 2022; Xia et al., 2022). In the United States, resources and grants are being provided to designated institutions and organizations for researching and developing AI-driven personalized learning platforms that have great potential to boost academic performance by deepening students' cognitive engagement and to reduce educational inequalities by assisting underprivileged students (Boninger et al., 2020; Williamson & Eynon, 2020). Jacobs Foundation has awarded CHF 2 million to University of Oulu, Finland, and Radboud University, the Netherlands, to establish a global research center that will prepare young learners for the age of artificial intelligence (AI) - Center for Learning and Living with AI (CELLA). A report from the Organization for Economic Co-operation and Development recommended additional research aimed at translating research findings into educational practice, and for educators to make use of big data and learning analytics to improve teaching and learning (Kuhl et al., 2019). With the continuous advancement of AI technologies and implementation of relevant policies, AIEd has become an important

* Corresponding author.
E-mail addresses: thomas.kf.chiu@gmail.com (T.K.F. Chiu), qxiabo@link.cuhk.edu.hk, Thomas.kf.chiu@gmail.com (Q. Xia), XinyanZ@link.cuhk.edu.hk (X. Zhou), CSChai@cuhk.edu.hk (C.S. Chai), Chengmt1@szu.edu.cn (M. Cheng).

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emerging research area for setting out the future of learning (Holmes et al., 2021), and its effects are felt across the domains of learning, teaching, assessment, and administration (González-Calatayud et al., 2021; Luckin, 2017).

Given AI affordances in enhancing education, the spotlight has been placed on AIEd for educational researchers, policymakers, and practitioners. However, most of the early research was focused on engineering aspects, such as developing new algorithms and enhancing machine learning/deep learning techniques. Compared to other fields of educational technology, such as gamification and blended learning, AIEd research is more scattered and less organized. The impact of AI on education remains unclear (Holmes et al., 2021), and more research is needed to understand whether and how these emerging technologies benefit education. A lack of familiarity with the technologies makes it challenging to introduce or integrate them into schools and universities (Hussin, 2018). Therefore, more review studies are needed to organize the literature, provide an overview of the opportunities and challenges of AIEd, and thereby suggest future research directions.

Accordingly, the number of review papers on this topic has recently increased. For example, Zhai and colleagues (2021) conducted a systematic review focusing on trends in educational AI technologies and tools, and therefore they mainly attended to the engineering aspects. Bozkurt et al. (2021) explored trends in publications on AIEd, including topic areas, geographical distribution, and patterns in textual data. Other review articles have focused on particular disciplines, such as languages, mathematics, and medicine (Karaca et al., 2021), on specific educational activities, such as assessment González-Calatayud et al., 2021, and on certain technologies or applications, such as assistive robots, adaptive learning, or proctoring systems (Nigam et al., 2021; Papadopoulos et al., 2020). However, these review papers focused on a specific key domain (either learning, teaching, assessment, or administration) or an educational outcome. We need a more holistic perspective to analyze the role of AIED (Nigam et al., 2021). To fill these research gaps, this study aims to give an overview study to understand the opportunities and challenges of integrating AIEd in the four key educational domains and two major learning outcomes, with the main goal of engaging researchers, policymakers, teachers, students, and engineers in the pressing dialogue of how the future of AIEd should unfold. This review is guided by the following research questions:

RQ1. How do AI technologies support learning, teaching, assessment, and administration in education, and what are the challenges in their

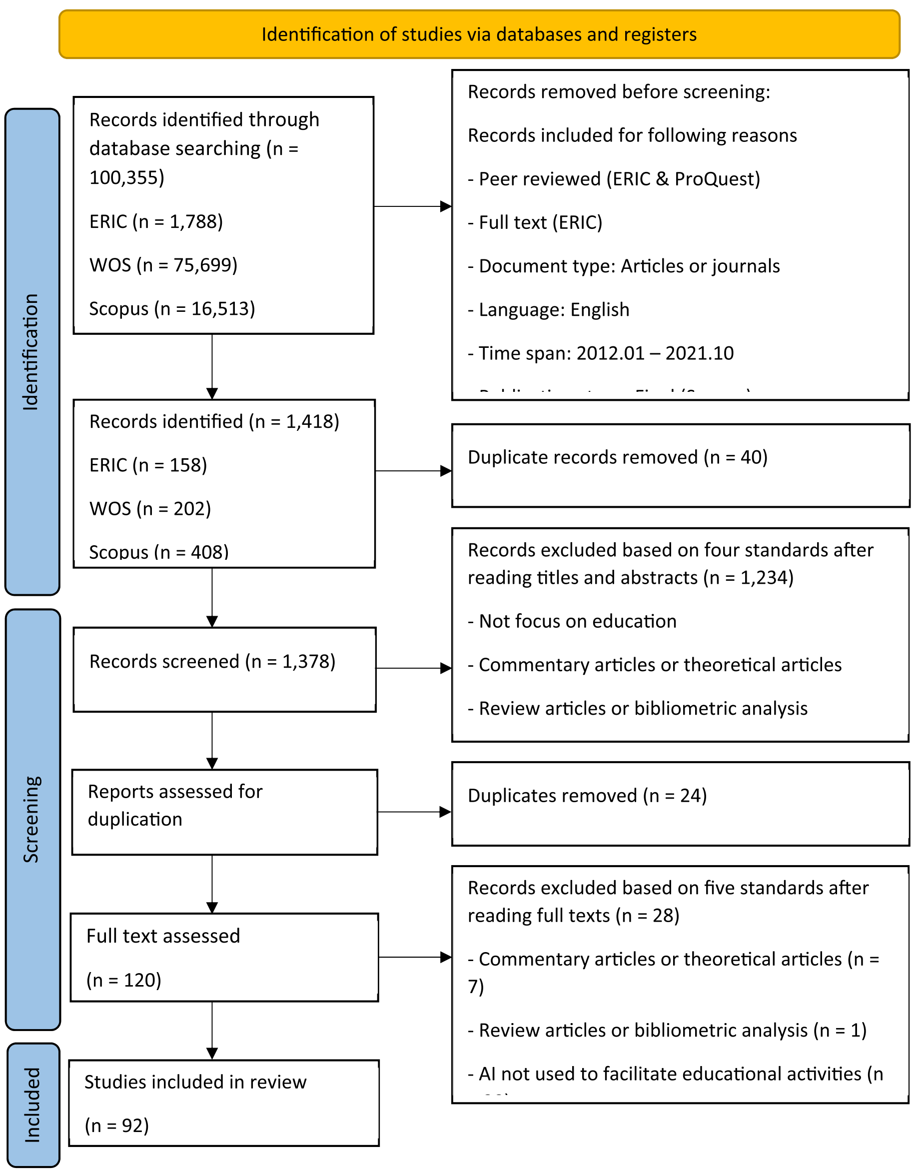

Fig. 1. Flowchart of article selection.

research and development?

RQ2. What student and teacher learning outcomes are fostered by AI technologies?

2. Method

This review adopted the PRISMA Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach (Page et al., 2021) and proceeded in three steps: (i) article selection, (ii) article screening and inclusion, and (iii) data coding, extraction, and analysis.

2.1. Article identification

Only articles relevant to AIEd were selected for this review. To identify relevant published articles, three of the authors collaboratively discussed and developed the criteria depicted in Fig. 1. Based on the previous studies (Nigam et al., 2021), the search query [("AI" OR "artificial intelligence") AND "education"] was used to include papers with these terms in the titles, keywords, or abstracts published from January 1, 2012, to October 24, 2021. The search was executed in ERIC, ProQuest, Scopus, and Web of Science (WOS), and it returned 100,355 initial articles: 1,788 in ERIC, 6,355 in ProQuest, 16,513 in Scopus, and 75,699 in WOS. The investigation covered only peer-reviewed journal article published in English. The inclusion and exclusion criteria varied slightly for each database due to the unique characteristics and functions of the search engines (as shown in Fig. 1). Additionally, the articles selected from ERIC were limited to full-text publications, those from Scopus included those in the final stages of publication, and those from WOS were limited to studies in the area of educational research. After applying the criteria, 1,418 publications were selected for further screening.

2.2. Article screening and inclusion

Screening and inclusion procedures were then used to select articles for the main analysis. First, 40 duplicate articles were eliminated using the duplication detection function of EndNote X9. Two of the authors then examined the titles and abstracts of the articles to identify empirical studies related to AIEd published in journals, thus excluding systematic literature reviews, meta-analyses, conceptual papers, commentaries, editorials, and conference papers. A further 1,234 articles were excluded based on these criteria. When the two authors disagreed on paper identification, another author assessed the paper and made a final decision. The full texts of the remaining articles were then read and 24 duplicates that were not detected by EndNote were removed, leaving 120 articles. A review study, 7 commentaries or theoretical articles, and 20 studies that did not focus on AIEd were also eliminated at this stage. Ultimately, 92 articles were retained, see Table 1 and Fig. 2.

2.3. Coding and analysis

AIEd is often classified into three domains: learning, teaching, and assessment (González-Calatayud et al., 2021 Luckin, 2017). However, educational administration is also a very important domain of AIEd research. Accordingly, this study extends the educational research domains of AI applications to four: learning, teaching, assessment, and administration. We have categorized the reviewed AI according to its role as reported by the authors. For example, if the AI is used to analyze student performance, it would fall into the assessment category. It is important to note that as some AI-based systems were applied across multiple domains, an article may be classified into more than one of these four domains.

Coding categories were established to answer the two research questions by inductive approach (Scott & Howell, 2008). To address the two RQs, two non-corresponding authors were coders, and coded the selected articles independently, they first tried to code 20 articles by extracting and examining AI technologies and their applications in the four key educational domains and learning outcomes of the applications. Then they had a meeting with the corresponding authors to discuss and confirm the coding approaches, domains and outcomes. As explained above, some articles fell into more than one domain. We extract information on AI technologies and outcomes for further analyses. These results in the four domains. As for the results of the learning outcomes, an open coding format was used and then finally summarized according to the student and teacher perspectives. Moreover, to retrieve data related to challenges of using AI in the four domains, we read the manuscript with focus on the sections of discussion and limitation. Three of the authors were involved in the coding. All of the authors discussed the results and made decisions by consensus if the findings were unclear.

3. Results

3.1. The roles of AI in the four key domains and research challenges (RQ1)

Thirteen roles were identified from the selected articles across the four key domains. The contribution of the reviewed studies to each of these domains and the challenges they reveal are described below.

3.1.1. AI in student learning

The application of AI to student learning can be classified into four main roles: (i) assigning tasks based on individual competence, (ii) providing human–machine conversations, (iii) analyzing student work for feedback, and (iv) increasing adaptability and interactivity in digital environments.

- *Assigning tasks based on individual competence*: AI-based environments have been used to personalize tasks for student learning. For example, Hirankerd and Kittisunthonphisarn (2020) built an AI-integrated management system with augmented, virtual, and mixed reality technologies to monitor student learning progress for assigning adaptive tasks; Kong et al. (2021) developed a virtual patient for medical student training; Munawar et al. (2018) created and developed an intelligent virtual laboratory to cater for students' needs by assigning laboratory tasks at an appropriate level; and Yang and Shulruf (2019) used an AI-enhanced skin to provide real-time feedback and adaptive tasks to medical students. However, these studies highlight a lack of supportive learning resources as one of the biggest challenges for fitting tasks to individual competence. As the student learning tasks provided by the intelligent systems were developed in advance, and not dynamically generated, the tasks were not always adequate to meet individual needs (Hirankerd & Kittisunthonphisarn, 2020; Munawar et al., 2018; Yang & Shulruf, 2019). The results of these studies indicate that the personalized learning offered by AI technologies is at an experimental stage in technology and implementation, with a lack of appropriate learning resources presenting the biggest challenge.
- *Providing human–machine conversations*: Most of the studies implemented AI chatbots and interactive books that allowed students to have conversations with machines about their learning. AI techniques emulate the processes of human thought using structures that contain the knowledge and experience of human experts. AI chatbots and books built with these techniques have been applied to language learning to help students develop their communication abilities through ongoing dialogue (Chew & Chua, 2020; Kim et al., 2021; Koc-Januchta et al., 2020; Palasundram et al., 2019; Vazquez-Cano et al., 2021). Students interacted with AI agents using a question-and-answer approach. Most of the students found that this was a useful and enjoyable method of gaining answers to simple questions. Nevertheless, these articles also present some challenges

Table 1
92 selected articles for this review.

ID	Author	Year	Domain	Region of corresponding author	Educational level of Participants	AI technology	AI_based Tools	Outcomes of students	Outcomes of teachers
1	Ãebi & Karal	2017	assessment	Turkey	higher education	fuzzy analytic hierarchy process	Assessment System	academic performance	working efficiencyteaching competence
2	Akmese et al.	2021	assessment	Turkey	higher education	Random Forest algorithm	Prediction Model	academic performance	N/A
3	Aldeman et al.	2021	teaching	Brazil	higher education	J48 algorithm	teaching system: SmartPathK	motivation and engagement	working efficiencyteaching competence
4	Aldosari	2020	opinion	Kingdom of Saudi Arabia	higher education	N/A	N/A	non-cognitive aspects	attitude toward AIEd
5	Alghamdi et al.	2020	assessment	Kingdom of Saudi Arabia	N/A	Fuzzy logic	Assessment System	N/A	working efficiency
6	Attwood et al.	2020	opinion	USA	Secondory education	N/A	N/A	N/A	attitude toward AIEdworking efficiency
7	Banerjee et al.	2021	opinion	UK	higher education	N/A	N/A	non-cognitive aspects	N/A
8	Bellod et al.	2021	administration	Spain	secondary education	Self-organizing Artificial Neural Networks	Analysis method of stress and academic-sports commitment	academic performance	N/A
9	Bennane	2013	teaching	Morocco	higher education and K-12	reinforcement learning; Bayesian network	pedagogic learning agent	academic performance	teaching competence
10	Bimbrahw et al.	2012	teaching	Canada	Primary education	N/A	autonomously assist equipment	academic performance	working efficiency
11	Bonneton-Botte et al.	2020	learning	France	Pre-school education	N/A	Kaligo – Handwriting and spelling App https://www.kaligo-apps.com	motivation and engagement	N/A
12	Cao et al.	2021	opinion	Mainland China	higher education	N/A	N/A	N/A	attitude toward AIEd
13	Chew & Chua	2020	learning	Malaysia	higher education	Sound Recognition, NLP	Robotic Chinese language tutor	21st century skills	N/A
14	Chiu et al,	2021	learning	Hong Kong	Secondary education	N/A	Robotic car	motivation and engagement	N/A
15	Costa-Mendes et al.	2021	assessment	Portugal	secondary education	random forest, support vector machine, artificial neural network and Extreme Gradient Boosting (XGBoost)	Prediction System	academic performance	N/A
16	Crowe et al.	2017	teaching	USA	N/A	NLP	Intelligent tutoring system	motivation and engagement	working efficiencyteaching competence
17	Cukurova et al.	2019	teaching	UK	higher education and K12	audio analysis algorithms	expert tutor	21st century skills	teaching competence
18	Cukurova et al.	2020	opinion	UK	higher education	N/A	N/A	N/A	attitude toward AIEd
19	Fu et al.	2020	assessment	Mainland China	Higher education	speech recognition	automatic scoring-empowereddigital learning tools	academic performance	N/A
20	Garg & Sharma	2020	opinion	India	primary and secondary education	N/A	N/A	motivation and engagement	N/A
21	Gunawan et al.	2021	learning	Indonesia	higher education	N/A	learning web based-AI	motivation and engagement	attitude toward AIEdworking efficiencyteaching competence
22	Gupta & Bhaskar	2020	opinion	Oman	higher education	N/A	N/A	N/A	attitude toward AIEd
23	H. I. Haseski	2019	opinion	Turkey	higher education	N/A	N/A	non-cognitive aspects	N/A
24	Hill et al.	2015	learning	USA	higher education	N/A	Chatbot		N/A

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Table 1 (*continued*)

ID	Author	Year	Domain	Region of corresponding author	Educational level of Participants	AI technology	AI_based Tools	Outcomes of students	Outcomes of teachers
								motivation and engagement	
25	Hirankerd & Kittisunthonphisarn	2020	administration	Thailand	higher education	AR robotic arms; speech recognition and machine vision	management system	academic performance	N/A
26	Holstein et al.	2019	assessment	USA	primary and secondary education	N/A	Lumilo, a wearable, real-time learning analytics tool	academic performance	N/A
27	Hsieh et al.	2020	teaching	Taiwan	Secondary education	Convolutional Neural Network, CNN; Face recognition technology	Teaching Robots	motivation and engagement 21st century skills	working efficiencyteaching competence
28	Hu, J. J.	2021	assessment	Mainland China	N/A	weighted naive Bayes (WNB) algorithm	Assessment System	N/A	N/A
29	Huang et al.	2021	teaching	Mainland China	N/A	N/A	N/A	academic performance 21st century skills	working efficiency
30	Huang	2018	teaching	Taiwan	higher education	N/A	teaching system	21st century skills	teaching competence
31	Ilić et al.	2021	opinion	Serbia	higher education	N/A	N/A	non-cognitive aspects	N/A
32	Jaiswal & Arun	2021	opinion	India	Adult education (Experts and managers in edutech company)	N/A	N/A	N/A	attitude toward AIEd
33	Jarke & Macgilchrist, 2021	2021	assessment	Germany	higher education	N/A	Prediction System	N/A	N/A
34	Kadhim & Hassan	2020	assessment	Iraq	N/A	Recurrent Neural Networks (RNN)	Prediction System	N/A	N/A
35	Karaca et al.	2021	opinion	Turkey	higher education	N/A	N/A	non-cognitive aspects	N/A
36	Khan et al.	2021	assessment	Malaysia	higher education	Artificial Neural Networks (ANN), Naive Bayes, k-Nearest Neighbors (k-NN), Support Vector Machines, and Decision Trees.	Prediction System	motivation and engagement	N/A
37	Khan & Alotaibi	2020	administration	Kingdom of Saudi Arabia	higher education	Face recognition	User Authentication System	N/A	N/A
38	Kickmeier-Rust & Holzinger	2019	learning	Austria	higher education	Ant Colony Optimization (ACO)	serious game	motivation and engagement	N/A
39	Kim et al.	2021	learning	Korea	higher education	N/A	Chatbot	academic performance	N/A
40	Koc-Januchta et al.	2020	learning	Sweden	higher education	knowledge representation, algorithmic methods, and NLP	AI book	motivation and engagement	N/A
41	Kong et al.	2021	learning	Singapore	higher education	NLP	virtual patient simulator: conversation that can enhance specific skill acquisition	21st century skills	teaching competence
42	Kuleto et al.	2021	opinion	Romania	higher education	N/A	N/A	non-cognitive aspects	N/A
43	Kumar & Boulanger	2020	assessment	Canada	secondary education	Deep Learning	Assessment System	N/A	teaching competence
44	Lampos et al.	2021	teaching	UK	primary education	machine learning techniques; logistic regression and random forests	Teaching system	motivation and engagement	N/A
45	Li & Su	2020	assessment	Hong Kong	primary education		Assessment System	academic performance	teaching competence

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Table 1 (*continued*)

ID	Author	Year	Domain	Region of corresponding author	Educational level of Participants	AI technology	AI_based Tools	Outcomes of students	Outcomes of teachers
						entropy weight method and grey clustering analysis			
46	Li	2021	administration	Mainland China	Higher education	N/A	management platform	N/A	N/A
47	Liu & Wu	2019	assessment	Mainland China	secondary education	Facial and Speech Emotion Recognition	Assessment System	N/A	N/A
48	Luckin & Cukurova	2019	learning	UK	higher education	facial recognition	commercial AI platform	motivation and engagement	N/A
49	Luo	2018	teaching	Mainland China	higher education	AI language Prolog	teaching system	academic performance 21st century skills	working efficiencyteaching competence
50	Ma & Slater	2015	assessment	USA	higher education	N/A	Assessment System	academic performance	N/A
51	Malik et al.	2021	opinion	India	higher education	N/A	N/A	N/A	attitude toward AIEd
52	McCarthy et al.	2016	teaching	USA	N/A	N/A	Braille Tutor (adaptive teaching system)	21st century skills	teaching competence
53	Mokmin	2020	teaching	Malaysia	higher education	case-based reasoning (CBR) algorithm	AI-based mobile application	motivation and engagement 21st century skills	teaching competence
54	Munawar et al.	2018	learning	Pakistan	higher education	N/A	Intelligent tutoring system	motivation and engagement	N/A
55	Nabiyev et al.	2013	administration	Turkey	secondary education	forward chaining and backward chaining	Expert System	academic performance 21st century skills	N/A
56	Page & Gehlbach	2017	administration	USA	higher education	convolutional neural networks	intelligent virtual assistant for freshman	academic performance	working efficiency
57	Palasundram et al.	2019	learning	Malaysia	higher education and K12	Recurrent Neural Network (RNN)	Chatbot	motivation and engagement	N/A
58	Parapadakis	2020	assessment	UK	higher education	N/A	Prediction System	N/A	N/A
59	Porter & Grippa	2020	assessment	USA	higher education	N/A	Assessment System	21st century skills	N/A
60	Qin et al.	2020	opinion	Mainland China	primary education	N/A	N/A	non-cognitive aspects	N/A
61	Rapanta & Walton	2016	assessment	Portugal	higher education	N/A	Assessment System	N/A	N/A
62	Renz & Hilbig	2020	opinion	Germany	higher education	N/A	N/A	N/A	attitude toward AIEd
63	RodrÃguez et al.	2021	opinion	Spain	higher education	N/A	N/A	motivation and engagement	N/A
64	Rodriguez-Barrios et al.	2021	assessment	Mexico	primary education	Bayesian Approach	Bayesian Approach to Analyze Reading Comprehension	academic performance	teaching competence
65	Ruiperez-Valiente et al.	2019	assessment	Spain	higher education and K12	random forest algorithm	Assessment System	academic performance	attitude toward AIEd
66	Salas-Pilco	2020	learning	Mainland China	primary education	N/A	WeDo robotic kits	21st century skills	N/A
67	Samarakou et al.	2015	teaching	Greece	higher education	N/A	Assessment System	motivation and engagement 21st century skills	working efficiency
68	Sharma et al.	2019	administration	Norway	higher education	Support Vector Machines (SVM), Neural Networks, decision trees	N/A	N/A	attitude toward AIEd
69	Shih et al., 2021	2021	learning	Taiwan					

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Table 1 (*continued*)

ID	Author	Year	Domain	Region of corresponding author	Educational level of Participants	AI technology	AI_based Tools	Outcomes of students	Outcomes of teachers
					higher education	convolutional neural network (CNN)	motor-controlled car kit	motivation and engagement	attitude toward AIEd
70	Soong et al.	2020	teaching	Canada	higher education	AI algorithm	software package	motivation and engagement	teaching competence
71	Standen et al.	2020	teaching	UK	N/A	facial expressions; Convolutional Neural Network (CNN);, support-vector machine	adaptive learning system	motivation and engagement	teaching competence
72	Sun	2021	teaching	Mainland China	higher education	fuzzy theory	N/A	21st century skills	working efficiencyteaching competence
73	Tang & Hai	2021	assessment	USA	N/A	analytic hierarchy process (AHP)	Assessment System	N/A	N/A
74	Terzi	2020	opinion	Turkey	primary and secondary education	N/A	N/A	non-cognitive aspects	attitude toward AIEdworking efficiency
75	Topal et al.	2021	teaching	Turkey	primary education	N/A	Chatbot	motivation and engagement 21st century skills	working efficiency
76	Tsai et al.	2020	administration	Taiwan	higher education	Multi-layer Perceptron (MLP)	prediction model	N/A	N/A
77	Vahabzadeh et al.	2018	learning	USA	primary education	The technology behind the Empowered Brain is based on innovations in software, engineering, and artificial intelligence afforded through relationships with X (formerly Google X, Mountain View, CA, USA), Affectiva (Boston, MA, USA), and Amazon (Seattle, WA, USA).	Empowered Brain: smartglasses and apps	3.21st century skills	N/A
78	Vazquez-Cano et al.	2021	learning	Spain	higher education	natural language processing, decision tree techniques	Chatbot	21st century skills	working efficiency
79	Villegas-Ch et al.	2020	learning	Mexico	higher education	natural language processing (NLP) natural language understanding (NLU)	Chatbot	academic performance	N/A
80	Villegas-Ch et al.	2021	administration	Mexico	higher education	N/A	Academic Activities Recommendation System	academic performance	N/A
81	Wang et al.	2020	opinion	Mainland China	higher education	N/A	N/A	N/A	attitude toward AIEdworking efficiencyteaching competence
82	Wang & Zheng	2020	assessment	Mainland China	higher education	analytic hierarchy process (AHP); fuzzy interval number, grey system theory	Assessment System	motivation and engagement 21st century skills	N/A
83	Wang & Wang	2019	opinion	Taiwan	higher education	N/A	N/A	N/A	attitude toward AIEd
84	Weragama & Reye	2014	teaching	Australia	higher education	N/A	Intelligent tutoring system	academic performance	teaching competence
85	Westera et al.	2020	learning	The Netherlands	N/A	NLP, facial recognition, fuzzy algorithm.	Intelligent tutoring systems, Serious Games	motivation and engagement	N/A
86	Wood et al., 2021	2021	opinion	USA	higher education	N/A	N/A	non-cognitive aspects	N/A

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Table 1 (*continued*)

ID	Author	Year	Domain	Region of corresponding author	Educational level of Participants	AI technology	AI_based Tools	Outcomes of students	Outcomes of teachers
87	Yang, Huan, & Yang, 2020	2020	teaching	Mainland China	higher education	lightweight non-aligned convolutional neural network model; deep learning; semantic analysis, image recognition, optical character recognition,big data and data analysis technologies; natural language processing, speech recognition, image recognition and data mining,	Intelligent management cloud platform	21st century skills	working efficiency teaching competence
88	Yang, Oh, & Wang, 2020	2020	teaching	Mainland China	primary education	Voice Interactive Artificial Intelligence	Voice Interactive Robot	academic performance	working efficiency
89	Yang & Shulruf	2019	learning	Taiwan	higher education	N/A	artificial skin that was connected to an AI recording & analysis system	motivation and engagement	N/A
90	Yu	2021	assessment	Mainland China	higher education	random forest (RF); decision tree	Prediction Model	N/A	N/A
91	Zhang, J. J.	2021	teaching	Mainland China	N/A	random selection algorithm and backtracking heuristics algorithm	teaching system	motivation and engagement	working efficiencyteaching competence
92	Zhang, L.	2021	assessment	Mainland China	higher education	Machine Learning Framework	Assessment System	N/A	N/A

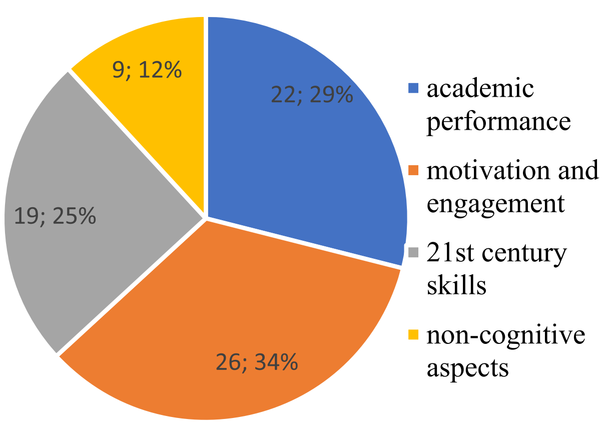

Fig. 2. Student learning outcomes.

involved in these conversations, and suggest that findings on how conversations with AI machines affect the student experience were limited. Accordingly, when and how to use chatbots for fostering learning and engaging students remains unclear (Chew & Chua, 2020; Palasundram et al., 2019).

- *Analyzing student work for feedback*: Another common use of AI has been to give students timely guidance and feedback by analyzing their work and learning process (Fu et al., 2020; Porter & Grippa, 2020). For example, Bonneton-Botte et al. (2020) used an AI application for notebooks to recognize and acquire kindergarten students' handwriting and then analyze its spatiotemporal characteristics (i.e., the shape, order, and direction of the segments). The application gave feedback to the students at the end of each writing session. Vahabzadeh et al. (2018) used AI-enabled smart glasses to improve the attention of autistic students by monitoring their socially aware emotions and behavior. In most cases, however, the feedback given by these systems was pre-prepared and did not meet the needs of every student. Teachers and students would prefer a more user-friendly and effective system that provides meaningful advice over the mechanical repetition of feedback (Holstein et al., 2019). This is a significant challenge for future research.
- *Increasing adaptability and interactivity in digital environments*: AI technologies have been implemented to capture student learning data and facilitate interactions for more adaptive digital environments. For instance, Samarakou et al. (2015) developed an advanced e-learning enviroment for engineering students. Kickmeier-Rust and Holzinger (2019) designed and developed a combinatorial optimization algorithm (the MAXMIN ant system) that was useful and effective in adaptive games. Westera et al. (2020) used techniques, such as facial emotion recognition, automatic difficulty adaptation, and stealth assessment, to profile students and applied techniques, such as non-verbal bodily motion and lip-synchronized speech, to develop non-playing characters. The student profiles and characters enhanced the adaptability and interactivity of learning. However, these studies focusing on the development and application of AI-supported digital environments did not address how they affect the student learning experience and outcomes. Overall, research in this area is at an exploratory stage and has as its biggest challenge the lack of an appropriate evaluation approach.

3.1.2. AI in teaching

The three roles that have been assigned to AI in teaching are (i) providing adaptive teaching strategies, (ii) enhancing teachers' ability to teach, and (iii) supporting teacher professional development.

- *Providing adaptive teaching strategies*: Intelligent tutoring systems aim to recommend teaching content and tasks that are appropriate for teaching needs (Aldeman et al., 2021; Bellod et al., 2021; McCarthy et al., 2016; Weragama & Reye, 2014). For example, Luo (2018) and Standen et al. (2020) adopted AI systems using multimodal sensor data to identify students' affective statuses and help teachers determine the optimal presentation of content, teaching methods, and communication strategies. Lampos et al. (2021) used an AI classifier to recommend effective communication strategies for teachers to teach autistic students by analyzing student responses and attributes. In the study of Crowe et al. (2017), teachers adjusted their teaching strategies based on the instant feedback provided by an academic writing software package on individual and whole class processing of learning material. However, our analysis revealed two major challenges in this area. First, there is a lack of practical testing of these intelligent systems. Some researchers noted that their studies were limited by an insufficient number of participants and the short duration of the experiment (Aldeman et al., 2021; Standen et al., 2020; Weragama & Reye, 2014). Second, the lack of any criteria for evaluating the effectiveness of these systems (Weragama & Reye, 2014) hinders the objectivity of evaluation and the beneficial development of the related technologies.
- *Enhancing teachers' ability to teach:* The combination of computer assisted instruction and AI technologies has been applied to helping teachers manage their classroom teaching (D. Yang, Oh, & Wang, 2020; Jaiswal & Arun, 2021; Nabiyev et al., 2013; Wang & Zheng, 2020; Zhang, 2021). AI technologies have been used to support teaching in different subject classrooms (e.g., physical and language education) by efficiently uploading, assigning, and distributing learning materials and assignments and by speaking out text-based problems. These applications have greatly improved the efficiency of classroom management for teachers (Gupta & Bhaskar, 2020; Huang et al., 2021; Jarke & Macgilchrist, 2021; Rapanta & Walton, 2016). However, most teachers lack an understanding of how the technologies operate. Without a grasp of the mechanism of task assignment and teaching strategy recommendations, teachers have reported feeling that their control was diminished and that they were working with a black box. The resulting decline in self-efficacy may discourage teachers from using AI to support their classroom teaching.
- *Supporting teachers' professional development:* AI technologies have been applied not only to support teaching but also to support the professional development of teachers (Gunawan et al., 2021; Lampos et al., 2021). In these studies, teachers were given suggestions and comments on their teaching by AI agents that analyzed real-time data in classrooms, such as behavior and questioning skills, and teachers' responses to diagnostic tests of their pedagogical content knowledge. Teaching evaluation models have also been built from teaching data (Hu, 2021; Li & Su, 2020). The objectivity of AI evaluators means that teachers are less offended by criticism and encouraged to reflect on their teaching practices. However, only one of the articles under review had teacher's professional development as its primary research goal, which indicates that applications of AI in teacher professional development activities are in their infancy (Gunawan et al., 2021). The development of AI for this purpose also faces some challenges. Especially, the limited number of pre-designed suggestions and comments may not be suitable for experienced teachers.

3.1.3. AI in assessment

Two main roles have been assigned to AI in assessment: (i) providing automatic marking and (ii) predicting students' performance.

- *Providing automatic marking*: Our analysis showed that the use of AI to enhance and automate assessment resulted in more effective grading (Äebi & Karal, 2017; Alghamdi et al., 2020; Fu et al., 2020; Kumar & Boulanger, 2020; Ma & Slater; 2015). AI-enhanced grading systems for language writing and speaking and mathematics provided more accurate, fast, and secure grading in tests and examinations than teachers. The systems were also able to return immediate marks for formative feedback in online learning. However, most of the automatic grading and marking was homogenous and applied to just a few disciplines and domains, such as language learning, which indicates that this application of AI is at an early development stage. Migrating the technology to authentic educational environments would present huge challenges (Ma & Slater, 2015; Sun, 2021). Additionally, there are insufficient criteria for assessing the validity of the grading systems in different contexts (Hu, 2021; Äebi & Karal, 2017).
- *Predicting students' performance:* AI technologies appear to have assisted in predicting student performance, particularly in online education (Akmese et al., 2021; Costa-Mendes et al., 2021; Yu, 2021). They have shown a capacity to predict students' performance in online courses by assessing the extent and quality of their participation in learning activities, such as discussion forums. This functionality is very important for distance education and MOOCs due to the absence of teachers. However, selecting data for prediction is challenging. Costa-Mendes et al. (2021) argued that the student data used for classic statistics may not fit AI predictive models. For example, the existing data on family income support, scholarship assistance, and county socio-economic status were unable to represent socio-economic variables for AI models. In other words, selecting appropriate data for student performance predictive models remains challenging as the data are not the same as those used in traditional educational research.

3.1.4. AI in administration

The three main roles assigned to AI in administration are (i) improving the performance of management platforms, (ii) providing convenient and personalized services, and (iii) supporting educational decision-making with evidence.

- *Improving the performance of management platforms*: Our results indicate that AI has significantly enhanced the performance of management platforms (Kadhim & Hassan, 2020; Khan & Alotaibi, 2020; Li, 2021; Ruiperez-Valiente et al., 2019; Tang & Hai, 2021; Villegas-Ch et al., 2021). These platforms were made more secure through the addition of a facial authentication function for examinations and portal management (Khan & Alotaibi, 2020; Li, 2020; Liu & Wu, 2019), and were made more effective for administrators by assigning AI-enabled routines to such tasks as scheduling courses and managing personnel data (Li, 2020). Nevertheless, because most AIEd research has concerned learning and teaching (Khan & Alotaibi, 2020; Villegas-Ch et al., 2021), this management role is seen as an auxiliary function for AI, tending to be more homogeneous and lacking in interactive mechanisms.
- *Providing convenient and personalized services*: AI technologies have been used to offer personalized academic and non-academic recommendations, thereby improving the work efficiency and quality of staff (Crowe et al., 2017). For example, activity recommendation systems can recommend the type of activities most appropriate for individual students based on an evaluation of their academic performance (Page & Gehlbach, 2017; Villegas-Ch et al., 2021). This indicates that AI technologies can replace staff in some administrative tasks. However, these studies had a common shortcoming in the limited accuracy of the user models. Intelligent recommendations are based on the premise that systems can build user models, but the

studies adopted data including age, gender, and behaviors (Li, 2021; Page & Gehlbach, 2017; Villegas-Ch et al., 2021). This indicates that there are similar challenges to those of predicting student performance, with existing data not always a good fit for AI predictive models.

- *Supporting educational decision-making with evidence*: AI technologies have provided educational administrators and management teams with evidence to support their decision-making. With access to big data, AI agents can predict the probability of students discontinuing their courses, identify the factors affecting student academic performance, and assist students with course selection (Cukurova et al., 2019; Tsai et al., 2020; Villegas-Ch et al., 2021). AI can thereby provide information for administrative decision-making and academic advising. However, applications in this area face similar challenges to the other roles assigned to AI (i.e., selecting appropriate data for predictive models).

3.2. Student and teacher learning outcomes in AIEd research (RQ2)

From the reviewed AIEd research, four categories of student learning outcomes and three categories of teacher learning outcomes were identified. The student outcomes can be classified into motivation and engagement, academic performance, 21st century skills, and non-cognitive aspects (see Fig. 3).

3.2.1. Student learning outcomes

Sixty-eight articles reported 76 times on the impact of AI on students or on students' attitudes towards AI. Motivation and engagement accounted for 34% of the student learning outcomes examined in the reviewed literature. Most of these were studies of the use of AI robots to motivate student engagement in various disciplines, including physical education, computer science, and mathematics, and across different educational settings, such as K–12 and higher education (Chiu, 2021; Chiu et al., 2022; Xia et al., 2022; Ilić et al., 2021; Kuleto et al., 2021; Yang, Oh, & Wang, 2020). Human–robot interactions helped low-achieving students feel more confident and useful and less embarrassed. Moreover, the results suggest that automatic scoring systems based on image and speech recognition technologies foster engagement in language learning (Fu et al., 2020; Ma & Slater, 2015). Students perceived those scores were more objective and received more direct and immediate feedback, which encouraged active learning. Overall, these studies show that the major outcome of applying AI to student learning is motivation and engagement.

Twenty-nine percent of the articles investigated the effects of AI on student academic performance as a learning outcome. Most of the studies reveal significant increases in academic performance with the support of AI technologies (e.g., Khan et al., 2021; Kim et al., 2021; Weragama & Reye, 2014), and the two studies indicating no significant change in performance nonetheless reported that students' learning interest and confidence were increased (Topal et al., 2021; Yang & Shulruf, 2019). The studies that examined the effects of AI on performance found that AI not only enhanced mainstream student performance but also that of students with special needs (Bimbrahw et al., 2012; Garg & Sharma, 2020). For example, McCarthy et al. (2016) designed an AI braille tutor to support the learning of students with visual impairments and found that the students responded significantly faster and more accurately when their teachers made use of the AI tutor. However, some of the studies suggest that not all students benefit from AI technologies, with motivated and/or high achieving students being the main or only beneficiaries. Among kindergarten students, for example, only those with intermediate handwriting skills performed better with AI learning, and not those with beginner-level skills (Bonneton-Botte et al., 2020). Among university students, only the more motivated held meaningful conversations with chatbots (Hill et al., 2015; Malik et al., 2021; Villegas-Ch et al., 2020). In learning visual arts, students with lower grades found an intelligent tutoring system fun but those with higher grades found it boring (Nabiyev et al., 2013). In general, the studies support the notion that AI can improve student performance, with the proviso that its effect depends on the roles of teachers in teaching and learning. In addition, AI technologies not only support learning in classrooms but can also prevent serious student disengagement. They have been used to predict student learning state, help program officers or teachers provide timely academic advice, and effectively reduce student dropout rates (Tsai et al., 2020; Villegas-Ch et al., 2021).

The third major learning outcome, examined by 25% of the reviewed studies, is 21st century skills, including online collaboration, creativity, and self-regulated skills. Real-time feedback platforms supported by AI have been demonstrated to produce sustainable growth in online collaborative skills (Porter & Grippa, 2020), creativity (Huang, 2018), problem-solving skills (Mokmin, 2020; Nabiyev et al., 2013), communication skills (Hill et al., 2015), and self-directed learning capacity (RodrÃguez et al., 2021; Soong et al., 2020; Yang, Oh, & Wang, 2020) among university students. These platforms promote direct and personalized feedback and stimulating problems that inspire students to think more deeply, and they offer step-by-step guidance and timely assistance that encourages students to identify and learn from their logical mistakes (i.e., self-reflection) for better self-directed learning.

Non-cognitive learning outcomes were examined in 12% of the reviewed studies. In most cases, students reported a more positive attitude and greater confidence in learning from the use of AI. For example, robots enhanced student confidence in learning (Hsieh et al., 2020), resulting in more positive awareness and attitude toward self-directed, collaborative, and social learning (Huang, 2018). In language learning, AI chatbots and tutors not only enhanced students' confidence but also reduced their learning anxiety (Kim et al., 2021; Yang & Shulruf, 2019). However, some students were found to develop stronger AI anxiety after using the technologies for learning; in particular, they worried about their future employment opportunities because of the rapid development of AI technologies (Terzi, 2020; Wang & Wang, 2019; Wood et al., 2021).

3.2.2. Teacher outcomes

Forty-three articles reported 57 times on the impact of AI on teachers or on teachers' attitudes towards AI. As shown in Fig. 3, the teacher outcomes can be classified into working efficiency, teaching competence, and attitude toward AIEd. Thirty percent of the studies reported that AI technologies improved teacher working efficiency. AI technologies have been used to automate and simplify trivial and routine tasks, which eases teachers' workloads. Specifically, AI has been applied to (i) online classroom management, including course enrollment and student attendance (Aldeman et al., 2021), (ii) intelligent learning resources organization, including student check-in and task assignment (e.g.,

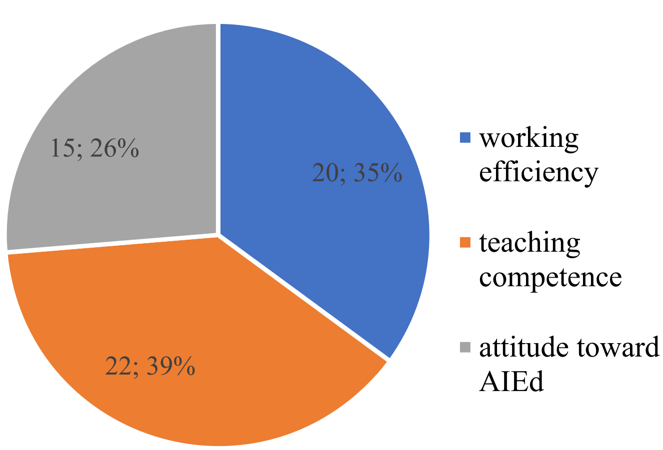

Fig. 3. Teacher outcomes.

Bennane, 2013; D. Yang, Oh, & Wang, 2020; Zhang, 2021), (iii) the automatic marking of multiple choice questions and simple reading and writing tasks (Fu et al., 2020; Ma & Slater, 2015; Rodriguez-Barrios et al., 2021; Ãebi & Karal, 2017), and (iv) advisory and/or question-and-answer facilities for answering simple queries by students and translating teachers' responses (Chew & Chua, 2020; Kim et al., 2021; Vazquez-Cano et al., 2021). These AI technologies can save teachers many hours of time spent on simple and routine tasks. The use of AI technologies to support online teaching was particularly beneficial during the COVID-19 pandemic. The urgent transition from face-to-face to online teaching increased teachers' workload in terms of preparing and managing online courses and placed a lot of stress on teachers, which reduced their well-being. An AI system for automatically recommending academic activities to students was found to have increased teachers' working efficiency (Villegas-Ch et al., 2021). Overall, it appears that AI technologies can play a very effective role in undertaking simple tasks for teachers and thus increasing their productivity.

In 20% of the reviewed studies, AI technologies were found to have improved teaching competence by inspiring teachers and encouraging self-reflection. Some intelligent learning platforms have been tasked with recommending adaptive teaching content and teaching methods to teachers and students (Aldeman et al., 2021; McCarthy et al., 2016; Weragama & Reye, 2014). These recommendations can inspire teachers by giving them more ideas to consider, including opportunities to comment on and criticize the ideas and content generated by the platform if they disagreed with its recommendations. The process creates space for teachers to reflect on their own practices and thus improve their teaching. The platforms can thereby indirectly improve teacher teaching competence by recommending different ideas and approaches.

Most of the reviewed studies reported that teachers had expressed positive attitudes toward the use of AI technologies to support teaching, learning, and administration (e.g., Aldosari, 2020; Haseski, 2019; Nabiyev et al., 2013). Teachers generally acknowledged that the technologies had improved their work efficiency and teaching competence, as outlined above. They found teaching with these advanced and emerging technologies fun and interesting and were curious to learn more about the technologies and their pedagogies (Gunawan et al., 2021; Wood et al., 2021). However, some teachers described the technologies as difficult to control, lacked an understanding of how the technologies operated, and were concerned about ethical issues, such as bias and breaches of privacy (Aldosari, 2020; Haseski, 2019; Kahn & Winters, 2021; Wood et al., 2021). Further concerns were expressed that there might be unknown risks of harm to teachers and students associated with AIEd (Haseski, 2019). Some teachers complained that the intelligent systems performed poorly; for example, as the content provided by AI agents was limited to a single format, it failed to cater to the need for diverse teaching methods (Holstein et al., 2019; Kahn & Winters, 2021; Nabiyev et al., 2013). Some teachers were also concerned that the AI systems failed to explain the reasons and mechanism behind the assignment of different tasks to students (Holstein et al., 2019). This

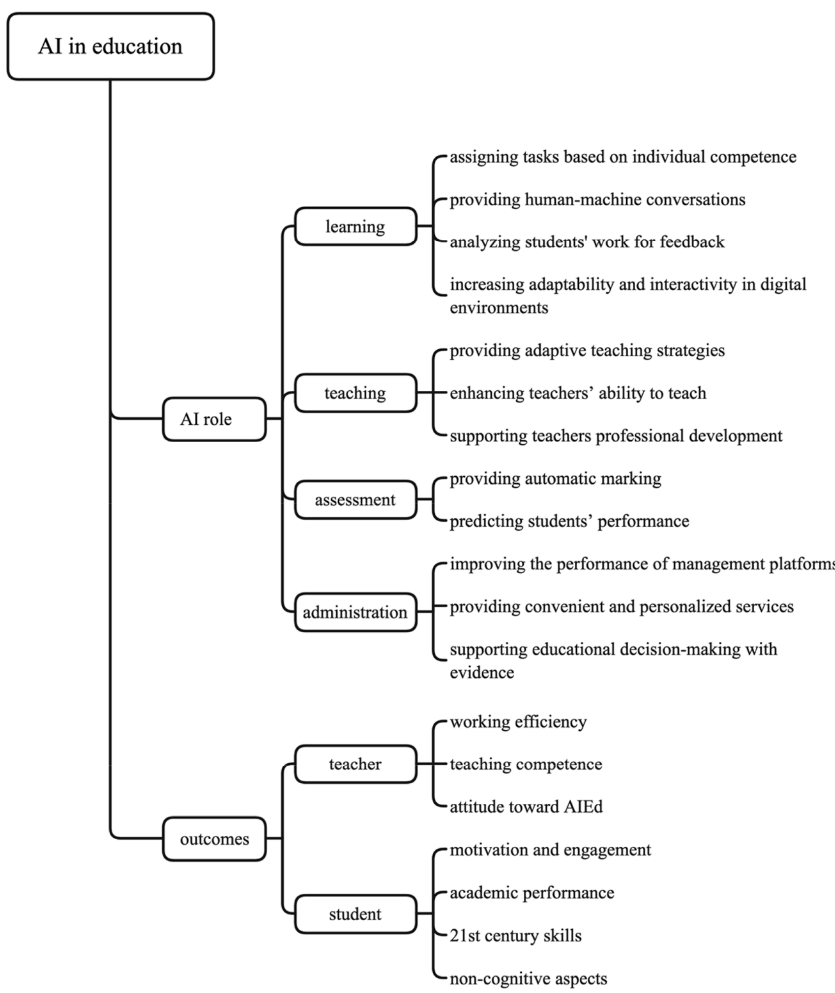

Fig. 4. The roles and outcomes of AI applications in education.

led teachers to feel frustrated and disappointed with the technology. Our analysis indicates that teachers had more doubts and negative feelings toward AI than students did.

4. Discussion

4.1. Summary of the opportunities for AIEd and future research directions

As shown in Fig. 4, the recent AIEd literature has examined AI agents playing 13 roles across the four key educational domains of learning, teaching, assessment, and administration, and it has examined seven learning outcomes for students and teachers.

4.1.1. Four key educational domains

- *Learning*: The technologies have been applied to (i) assigning tasks based on individual competence, (ii) providing human–machine conversations, (iii) analyzing students' work for feedback, and (iv) increasing adaptability and interactivity in digital environments.
- *Teaching*: AIEd has been applied to (v) providing adaptive teaching strategies, (vi) enhancing teachers' ability to teach, and (vii) supporting teachers' professional development.
- *Assessment*: The technologies have been applied to support teachers' work on assessment by (viii) providing automatic marking and (ix) predicting students' performance.
- *Administration*: AIEd has been used for (x) improving the performance of management platforms, (xi) providing convenient and personalized services (non-academic and academic), and (xii) supporting educational decision-making with evidence.

4.1.2. Two major educational outcomes

- *Student learning*: Among students, the effects of AIEd have been tested on the outcomes of (i) motivation and engagement, (ii) academic performance, (iii) 21st century skills, and (iv) non-cognitive aspects.
- *Teacher practice and learning*: Among teachers, the effects of AIEd have been tested on the outcomes of (v) working efficiency, (vi) teaching competence, and (vii) attitude toward AIEd.

These roles and outcomes represent the current research focus in the field and can inform practitioners on how to approach the application of AI to teaching and learning as well as inform administrators on when and how they should look to support their work using AI technologies. The multiple roles and outcomes associated with AIEd suggest that research should be interdisciplinary and engage scholars from outside of the education field (Cukurova et al., 2020).

4.2. Challenges of AIEd and future research directions

In this section, 10 major challenges to AIEd that emerged from this review are summarized. These challenges can serve to guide further research in the field.

- *Lack of relevant learning resources for personalized/adaptive learning:* Teachers have reported that the teaching methods and learning resources recommended by personalized/adaptive learning platforms are overly homogeneous. AI agents make recommendations of learning objects, which are any reusable standardized digital educational resources that can be readily reused and adapted to fit a learning objective in a variety of contexts (Cao et al., 2021). Further research is needed to investigate how learning objects are to be used in personalized and adaptive learning and how better learning objects can be designed for this purpose.
- *Selecting appropriate data for AI predictive models:* The well-structured student data used in existing traditional predictive models (linear regressions) are not always appropriate for the emerging AI technologies. An effective AI predictive model requires a more detailed set of structured and less-structured student data, which raises important privacy issues. With AIEd often targeting young learners, how to balance the effectiveness of AI technologies with ethical restraints is crucial. Further research is needed into what types of data should be used in AI models, with careful consideration of ethical issues (Sharma et al., 2019).
- *Lack of connection between the AI technologies and their use in teaching*: Emerging AI technologies look to offer instructional assistance (e.g., via chatbots and robots) and to provide teachers with rich information supporting their pedagogical decision-making (e.g., learning analytics; Kim et al., 2022). However, this review indicates that teachers may not have a sufficient understanding of the technologies to apply them effectively. Teachers are sometimes unable to interpret the information provided by learning analytics, lack an understanding of the affordances of AI technologies for education, and can be uncertain on the pedagogical implications of using AI for teaching students. To take a simple example, are chatbots to be used for student discussion before or after a teaching session? Accordingly, future research should investigate the roles of teachers in AI-supported pedagogies.
- *Lack of interdisciplinary AI technologies for learning*: As learning is complicated, AI technologies developed for a particular discipline may not be effective for all student learning. Although AI comprises a variety of sub-fields, such as natural language processing, computer vision, and neural networks (Chiu, 2021; Chiu et al., 2022; Xia et al., 2022), the AI techniques used in education tend to be simple and single purpose. The development of AI technologies is relatively lagging in the field of education (Bates et al., 2020; Nicolae & Nicolae, 2018). Teachers generally use off-the-shelf technologies for learning and teaching, which may not be the most suitable for their purposes. Therefore, researchers should look to develop interdisciplinary tools with the use of more advanced AI technologies.
- *Worsening educational inequity by widening the digital divide among students*: Most of the reviewed AIEd studies highlighted that AI technologies could motivate student engagement and foster 21st century skills. However, the benefits often accrued mostly to the most competent and motivated students. There are two plausible explanations for this finding: (i) AI technologies are not well designed and developed for student learning and (ii) teachers lack pedagogical knowledge for applying the technologies. Students who needed greater support may have been demotivated by the use of AI technologies because they found it difficult to communicate with the AI agents and found the recommended learning resources inappropriate. Introducing or integrating AIEd may thus contribute to widening the digital divide and worsening educational inequity. Future research should focus on (i) proposing a new pedagogical framework for AI learning and teaching and (ii) using a learning sciences approach to the design and development of algorithms for personalized learning (Luckin & Cukurova, 2019).
- *Insufficient knowledge of AI technologies among teachers*: Most teachers lack an understanding of how AI technologies work (e.g., the principles or algorithms for recommending resources), and they have therefore been teaching with a black box. As a result, they are unable to answer student questions related to AIEd (e.g., why the AI platforms recommended particular learning resources) and cannot fully utilize the technologies for learning, teaching, and assessment. The need for teachers to have knowledge of AI and its application to pedagogy should therefore be considered in future research.
- *Negative attitudes toward AI among students and teachers*: Some students and teachers have reported feeling anxious and less confident when learning with AI. Students can become worried about their future, as AI technologies may make their preferred careers redundant. Meanwhile, teachers' lack of knowledge of the systems can lead to weak self-efficacy (Wang et al., 2020). These uncertainties can generate negative attitudes toward AIEd, which affects behavioral

intentions to use AI to support learning and teaching (Attwood et al., 2020; Qin et al., 2020). More studies are needed of AIEd for students outside of the engineering context, including K–12 and art students, and of teachers' professional development on AI topics (Chiu, 2021; Chiu et al., 2022; Xia et al., 2022; Chai et al., 2022).

- *Lack of AIEd research on socio-emotional aspects*: Most studies of AIEd have been devoted to cognitive outcomes and adaptive learning, with few having examined socio-emotional outcomes (Salas-Pilco, 2020). Risks and maladaptive outcomes of AIEd have been reported (Banerjee et al., 2021; Haseski, 2019; Kahn & Winters, 2021; Parapadakis, 2020; Wood et al., 2021), and students and teachers are aware of the ethical concerns surrounding AIEd. Ethical issues have been carefully discussed in researching the applications of AI in law, engineering, and social science, but not in education. More research into the ethical issues related to AIEd is therefore needed.
- *Lack of education perspectives in AIEd research*: This review hopes to capture more of the educational research perspective on AIEd. However, most AIEd researchers have a strong engineering background and therefore tend to focus on technological design and development and to take an engineering approach to AIEd research. This approach fails to capture the perspectives of educational researchers and teachers. As AI is an interdisciplinary domain, future studies should investigate new research methods for interdisciplinary studies of AIEd that can actively engage teachers, students, and educational researchers (Holstein et al., 2019).
- *Ineffective evaluation methods of AIEd*: The most commonly used evaluation methods may not be effective for AIEd research. Most of the reviewed studies used existing methods to evaluate emerging technologies that are novel in their use of big data (e.g., huge numbers of students) and poorly structured data (Renz & Hilbig, 2020). Teachers and students have reported feeling confused or discouraged with the AI-enabled systems that engineering-focused studies evaluate as the most effective. Accordingly, the study of AIEd needs to devise new methods for evaluating the success of AI systems.

5. Conclusions and limitations

Ninety-two articles published on AIEd between 2012 and 2021 in ERIC, ProQuest, Scopus, and WOS were reviewed to provide new insights into and evidence for AIEd research and practice. Although the results of this study are preliminary, they provide a comprehensive overview of the integration of AI in education across the four key educational domains and with consideration of various outcomes.

Although the review provides information on some valuable trends and suggests potential research directions in AIEd for researchers and practitioners, three limitations need to be considered. First, different search strings would have produced different results (e.g., ["AI" AND "AIEd"]), which means that some articles identified only by AIEd might have been excluded. Second, some grey literature publications not indexed by academic databases might have offered a complementary viewpoint but were not considered in this study. Third, some of the reviewed studies discussed the application of AI-based tools in general without mentioning specific AI technologies, so the results pertaining to the roles of AI in this review may lack sufficient detail.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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