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AI technologies for education: Recent research & future directions

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ABSTRACT

From unique educational perspectives, this article reports a comprehensive review of selected empirical studies on artificial intelligence in education (AIEd) published in 1993–2020, as collected in the Web of Sciences database and selected AIEd-specialized journals. A total of 40 empirical studies met all selection criteria, and were fully reviewed using multiple methods, including selected bibliometrics, content analysis and categorical meta-trends analysis. This article reports the current state of AIEd research, highlights selected AIEd technologies and applications, reviews their proven and potential benefits for education, bridges the gaps between AI technological innovations and their educational applications, and generates practical examples and inspirations for both technological experts that create AIEd technologies and educators who spearhead AI innovations in education. It also provides rich discussions on practical implications and future research directions from multiple perspectives. The advancement of AIEd calls for critical initiatives to address AI ethics and privacy concerns, and requires interdisciplinary and transdisciplinary collaborations in large-scaled, longitudinal research and development efforts.

Since Alan Turing first articulated the promising vision of "thinking machines" in 1950, artificial intelligence (AI) research has been advanced in many different fields and generated an increasing body of literature (e.g., Andriessen and Sandberg, 1999; Beck et al., 1996; Burleson & Lewis, 2016; Clancey et al., 1979; Kaplan & Haenlein, 2019; Kurzweil, 1985; Kurzweil & Kapor, 2002; Kurzweil, 2002; Legg & Hutter, 2007; Simmons & Chappell, 1988; Zdenek, 2003). In education, emerging technologies have also been transforming ways of teaching and learning. The AI market in US Education Sector is expected to grow by 48% in 2018–2022 (BusinessWire.com, 2018). With the thrive of AI technology, its applications in education have been increasing, with promising potentials to provide customized learning, to offer dynamic assessments, and to facilitate meaningful interactions in online, mobile or blended learning experiences. More provocatively, in response to the teacher shortage in USA, for example, scholars (Edwards & Cheok, 2018) have proposed to replace some roles of teachers with robots with AI.

The increasing applications of AI in education (AIEd) demand interdisciplinary approaches, while most AI research is carried out only in STEM fields (Zawacki-Richter, Marin, Bond & Gouverneur, 2019). Consistently, a few recent literature reviews have highlighted the lack of educational perspectives in AIEd research (e.g., Chen, Xie, Zou, & Hwang, 2020; Hinojo-Lucena, Aznar-Díaz, Cáceres-Reche, & Romero-Rodríguez, 2019; Zawacki-Richter, Marín, Bond, & Gouverneur, 2019). In addition, researchers have voiced concerns about the absence of educational theories and models, as found in AI-enabled e-learning research published in the past two decades (Tang, Chang, & Hwang, 2021). It is also worth noting that AIEd innovations remain at the early, experimental stage, and there is few collaboration with educational institutions in related interventions such as AI enabled adaptive systems (Kabudi, Pappas, & Olsen, 2021). As a result, there has been a critical gap between what AIEd technologies could do and how they are actually implemented in authentic educational settings (Bates et al., 2020; Kabudi et al., 2021).

As an effort to further advance AI technologies for education, this article intends to help the broader AIEd community, including educators, educational researchers, AI technology creators and other stakeholders to build a deeper understanding in AIEd, including its current state, potentials, challenges and future directions. Specifically, this comprehensive review of related literature aims to achieve the following goals through multiple analysis methods:

- to map the landscape of AIEd research publications in recent decades,

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- to identify AI technologies and their educational applications and benefits, as reported in empirical research,
- to generate practical guidelines, examples, inspirations and other takeaways for both educators and AI technological experts,
- to facilitate communications and collaborations amongst stakeholders with different areas of expertise (e.g., technological skills vs. learning theories and pedagogies),
- to understand AIEd research and development from different perspectives (e.g., technology advancement, teaching and learning, administrations of educational systems, educational research, etc.)
- to shape fruitful collaborations in AIEd research, development, implementation and evaluation.

Thus, with a unique focus on education, this article reports a comprehensive review of eligible empirical studies on AIEd, applying mixed methods, including selected bibliometrics (Okubo, 1997; Thelwall, 2008), a categorical meta-trends analysis (e.g., Hung & Zhang, 2012; Thelwall, 2008) and inductive content analysis (Gao, Luo, & Zhang, 2012; Mogil, Simmonds, & Simmonds, 2009). This study investigates the longitudinal growth of empirical studies on AIEd, generates the macro, as well as micro viewpoints on AIEd research. Through a broad overview on the current state of AIEd research, this review also creates a solid foundation for historical or meta analyses of the increasing body of research literature on AIEd. More importantly, this article provides practical takeaways for varied AIEd stakeholders and identifies new directions for AIEd practice, research, development, implementation and evaluations. From educational perspectives, this study stands out from many other related reviews with the following differences:

(a) the scope, as defined by the research questions and inclusion and exclusion criteria,
(b) the selected mixed methods for varied analyses,
(c) highly focused analyses as related to education, and
(d) the implications and discussions from multiple perspectives.

The following research questions guided the multi-phased search, review and analyses of AIEd research publications in this study:

1. What is the landscape of research publications on AIEd in the Web of Science Database and selected AIEd specialized journals?
2. What are the AIEd Technology applications and their educational benefits, as reported in eligible research publications?
3. What implications does current research have on future research and practice of AIEd?

1. Research methods and process

This multi-phase study critically examines refereed research publications on AI in education. Multi-phase searches and selections were conducted to identify eligible publications for full analyses.

1.1. Source databases

With the surge of online publications and open access resources, it is virtually impossible to conduct an exhaustive search even with well-defined criteria. This investigation was carefully designed to focus on research publications collected in one of the most widely used web-based databases, the Web of Science (SCI/SSCI). Web of Science (SCI/SSCI) was chosen as the source database for the following reasons: (1) it collects journals in both Science Citation Index (SCI) and Social Science Citation Index (SSCI); (2) the database is highly selective, including regarded journals in both sciences and social sciences; and (3) it is one of the few comprehensive web-based databases that allow detailed bibliometric analysis (Okubo, 1997).

As newer journals may not be included in Web of Science database, additional search efforts were made to locate more, recent publications on AIEd-specialized journals. The following three specialized journals were selected as additional source databases, *International Journal of Artificial Intelligence in Education*, *International Journal of Learning Analytics and Artificial Intelligence for Education* and *Computers & Education: Artificial Intelligence*.

1.2. Searches and selections

Multiple rounds of searches were conducted on the source database using different combinations of key words and search strategies, such as "AI", "artificial intelligence", and "education". Three rounds of searches on Web of Science yielded a total of 507 articles initially, from which 27 duplicates, one conference paper, and two non-English articles were excluded in the initial screening. In addition, searches were conducted on the three selected journals' websites for research articles published till 2020, using the same search strategies.

1.2.1. Selection criteria and results

In order to achieve the specified research goals, a set of selection criteria were established and applied for inclusion and exclusion. Only English, refereed journal articles reporting empirical, evidence-based studies were selected for further analyses. The following were excluded: (a) non-English publications, (b) conference proceedings or presentations, (c) theoretical or conceptual articles, (d) reports of personal user experiences, (e) articles reporting no data or without enough data, (f) research without human participants, (g) studies not related to education or artificial intelligence, and (h) quantitative studies with less than 20 participants.

In addition, the following criteria were followed strictly in the screening and selection process: 1. Research must focus on AI in educational settings. Published research on AI in the consumer market, engineering, health care systems and other non-educational settings was thus excluded; 2. Research must be data-supported empirical studies. Articles that were solely based on personal opinions or anecdotal experiences were excluded; 3. Research must have investigated educational effects of AI by reporting relevant qualitative or quantitative data. Papers that did not provide any evidence on learning were excluded; 4. Research must have sufficient participants with a large enough sample size. Experimental or quasi experimental studies or survey research with less than 20 participants were thus excluded; 5. Theoretical, conceptual and literature review papers were also excluded for full analyses, but they were carefully read to strengthen our background knowledge and to broaden the theoretical foundation for developing a general understanding of AI in education.

The researchers reviewed all search results together and reached consensus on inclusion or exclusion of each article. After careful screenings and initial analyses, a total of 40 research articles were selected for full analyses, including 34 articles from Web of Science, five from *International Journal of Artificial Intelligence in Education,* and one from *Computers & Education: Artificial Intelligence*. No eligible articles were identified from the *International Journal of Learning Analytics and Artificial Intelligence for Education.*

1.3. Analysis methods

Bibliometrics have been widely applied to evaluate research publications through quantitative analyses to measure varied indicators (e.g., Keshaval & Gowda 2008; Okubo, 1997; Thelwall, 2008). More recently, researchers have also conducted content analysis to address the disparity between quantitative and qualitative approaches in reviewing research publications (e.g., Gao et al., 2012; Hung & Zhang, 2012; Mogil et al., 2009). Thus, in this study, selected bibliometrics (Okubo, 1997), categorical meta-trend analysis (Hung & Zhang, 2012; Thelwall, 2008) and inductive content analysis (Gao et al., 2012; Mogil et al., 2009) were conducted.

The researchers reviewed each eligible article and analyzed them to identify the followings: bibliometrics, setting of the study, participants profile, sample size, country of the study, AI technology applications and effects in education, and implications on AIEd. The researchers collaboratively developed a coding system for this review. Major codes included bibliometrics of the publication (e.g., year of publication, name of the journal, etc.), countries where studies were carried out, educational setting of the study, (e.g., K-12 or higher education), subject area in which a particular AI technology was implemented and researched (e.g., engineering, psychology, etc.), participants profile (e.g., grade level, age, demographics, etc.), number of participants, specific AI technology applications and their educational benefits as reported in the study. Both researchers discussed on the coding, categorization and themes emerged in the process and resolved any disagreements through discussions to build shared understandings. The collaborative approach throughout multiple analyses ensured a high reliability and trustworthiness of the review.

2. Results

2.1. The landscape of AIEd research publications

Bibliometric analyses (e.g. Keshaval & Gowda 2008; Okubo, 1997; Thelwall, 2008), categorical meta-trend analysis (Hung & Zhang, 2012; Thelwall, 2008) and inductive content analysis were conducted on all eligible research articles. The following summarizes the AIEd research analyzed in this study.

2.1 Prolific countries. Artificial intelligence in education (AIEd) research has been conducted in many countries around the world. The 40 articles reported AIEd research studies in 16 countries (See Table 1). USA was so far the most prolific, with nine articles meeting all criteria applied in this study, and noticeably seven of them were conducted in K-12. Followed was China with seven AIEd articles. Two of them were conducted in Hong Kong Special Administrative Region in the early 2000s (i.e., Cheung, Hui, Zhang, & Yiu, 2003; Xu & Wang, 2006), and two took place in Taiwan (Hwang, Sung, Chang, & Huang, 2020; Shih, Chang, Chen, Chen, & Liang, 2012), including one study in 2012, a few years before the global research community caught up with the surge of AIEd publications in 2015. More recently, scholars in mainland China also conducted large-scaled AIEd research in 2017 (Xie, Zheng, Zhang, & Qu, 2017) and 2018 (Wei, Yang, Chen, & Hu, 2018).

Turkey and Spain tied as the third most prolific countries, each with five AIEd studies, and they were all in the recent years. Interestingly to note, while UK had the first AIEd study (Kelly, Sleeman, & Gilhooly, 1993) in 1993, that was also the only one from UK. Other countries contributing to the increasing body of AIEd research included Australia, Brazil, Canada, France, Greece, Japan, Korea, Pakistan, Slovenia, Sweden, UAE and UK. Remarkably, the Global South is well represented in AIEd research publications. In addition, there was one multinational study that took place in United Arab Emirates and Spain (Rapanta & Walton, 2016). One AIEd study was executed at a high school in Europe, but it did not specify which country (Moridis & Economides, 2009).

2.2. Educational settings

The reviewed articles reported various empirical studies in both K-12 (n = 17) and higher education systems (n = 21). Articles did not specify the educational settings in which they were carried out were not included in Table 2.

2.3. Subject areas

AI was implemented and examined in a wide variety of subject areas, such as science, medicine, arts, sports, engineering, mathematics, technologies, foreign language, business, history and more (See

Table 1
A summary of countries and participants of AIEd research.

Country/ Place of Study	n	Article	Participants
Australia	1	Ijaz, Bogdanovych, and Trescak (2017)	60 undergraduate students
Brazil	1	Santos and Notargiacomo (2018)	21 volunteers
Canada	1	[a]. Xiao and Hu (2019)	203 primary school ESL students (177 high-achieving and 36 low-achieving students)
China	7	1. [a]. Wei et al. (2018)	169 undergraduate students in School of International Studies majoring in English
		2. [b]. Xie et al. (2017)	7341 students in engineering, medical science, and business science
		3. Zheng, Zhang, Xu, Peng, and Wu (2018)	20 elementary students
		4. [b]. Cheung et al. (2003) (Hong Kong)	40 university students for initial evaluation; & 1300 students for full scale evaluation
		5. [a]. Xu and Wang (2006) (Hong Kong)	228 online undergraduate students taking the "Introduction to the Oracle Database" course
		6. Shih et al. (2012) (Taiwan)	49 sixth grade students from a school with lower socioeconomic status compared to other schools in the region
		7. [a]. Hwang et al. (2020) (Taiwan)	162 5th graders (53 (26 male, 27 female) in the experimental group, 53 (26 male, 27 female) and 56 (26 male, 30 female) in the other two groups
Europe (country not specified)	1	[a]. Moridis and Economides (2009)	153 high school students
France	1	Loup-Escande et al. (2017)	76 participants learning calligraphy
Greece	2	1. Samarakou, Fylladitakis, Fruh, Hatziapostolou, & Gelengenis (2015)	60 postgraduate students pursuing a master's degree on Energy Technology
		2. Samarakou, Tsaganou, and Papadakis (2018)	28 undergraduate students studying Informatics (16 from third grade, 12 from second grade)
Japan	1	[a]. Fryer, Ainley, Thompson, Gibson, and Sherlock (2017)	122 first and second-year university students
Pakistan	1	[a]. Munawar, Toor, Aslam, and Hamid (2018)	161 postgraduate and undergraduate students
Slovenia	1	[b]. Flogie and Abersek (2015)	4473 students in 7th-9th grades in total: (4373 in the control group and 100 in the experimental group) & 20 teachers in the qualitative research
Spain	5	1. Griol, Molina, and Callejas (2014)	56 undergraduate students in computer science
		2. [a]. Leony, Munoz-Merino, Pardo, & Kloos (2013)	334 s-year undergraduate engineering students in a programming course
		3. [a]. Mas-Sanso and Manresa-Yee (2016)	160 undergraduate engineering students
		4. [a]. Montalvo, Palomo, and de la Orden (2018)	138 undergraduate students in Business Administration program
		5. [a]. Rapanta and Walton (2016) (UAE & Spain)	205 university students – 112 were undergraduates in Dubai, UAE and 93 were undergraduates in Barcelona, Spain

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Table 1 (*continued*)

Country/ Place of Study	n	Article	Participants
Sweden	2	1. [a]. Tarning, Silvervarg, Gulz, & Haake (2019)	166 students – ages 10-11
		2. Gulz, Londos, and Haake (2020)	36 children – ages 4–6 years old from three different preschools
Turkey	5	1. [a]. Arpaci (2019)	308 undergraduate students in IT classes
		2. [a]. Bahçeci and Gürol (2016)	162 undergraduate software engineering students
		3. [a]. Köse and Arslan (2016)	110 undergraduate students in computer technologies
		4. [a]. Köse (2017)	453 university students
		5. [a]. Peker, Guruler, Sen, and Istanbullu (2017)	300 9th grade students
UAE	1	[a]. Rapanta and Walton (2016) (UAE & Portugal)	205 university students – 112 were undergraduates in Dubai, UAE and 93 were undergraduates in Barcelona, Spain
UK	1	Kelly et al. (1993)	38 first year undergraduate psychology students
USA	9	1. [a]. Chin et al. (2010)	First study: 28 and 30 students in 6th grade; Second study: 104 Fifth Grade students
		2. [a]. Chin, Dohmen, and Schwartz (2013)	153 fourth-grade students in a small public school
		3. Gonzalez, Hollister, DeMara, Leigh, Lanman, Lee, Parker, Walls, Parker, Wong, Barham, & Wilder (2017)	Middle school students who visited the museum; Responses to survey questions vary: 48 responses to Q11, and 56 responses to Q12
		4. [a]. McCarthy, Likens, Johnson, Guerrero, and McNamara (2018)	234 high school students and recent high school graduates
		5. [a]. McLaren, DeLeeuw, & Mayer (2011)	132 urban high school students in five chemistry classes
		6.Keshav, Salisbury, Vahabzadeh, and Sahin (2017)	21 adults and children with autism
		7. [a]. Atilola et al. (2014)	Freshmen engineering students: Spring 2011 semester n = 64, Fall 2011 semester: Honors section n = 36 & Regular section n = 86, Fall 2012 semester n = 49
		8. [a]. Walkington & Bernacki (2019)	106 high school students
		9. [a]. Matsuda, Weng, and Wall (2020)	208 6th, 7th and 8th grade students

Note.
[a] study with a sample size larger than 100 but smaller than 1000.

[b] study with a sample size larger than 1000.

Table 2
AIEd research articles by setting.

Educational Setting	n	Articles
Higher education	21	1. Arpaci (2019) 2. Atilola et al. (2014) 3. Bahçeci and Gürol (2016) 4. Cheung et al. (2003) 5. Dias, Hadjileontiadou, Hadjileontiadis, and Diniz (2015) 6. Fryer et al. (2017) 7. Griol et al. (2014) 8. Ijaz et al. (2017) 9. Kelly et al. (1993) 10. Köse and Arslan (2016) 11. Köse (2017) 12. Leony, Munoz-Merino, Pardo, & Kloos (2013) 13. Mas-Sanso and Manresa-Yee (2016) 14. Montalvo et al. (2018) 15. Munawar et al. (2018) 16. Rapanta and Walton (2016) 17. Samarakou, Fylladitakis, Fruh, Hatziapostolou, & Gelengenis (2015) 18. Samarakou et al. (2018) 19. Wei et al. (2018) 20. Xie et al. (2017) 21. Xu and Wang (2006)
K-12 education	17	1. Chin et al. (2013) 2. Chin et al. (2010) 3. Flogie and Abersek (2015) 4. Gonzalez, Hollister, DeMara, Leigh, Lanman, Lee, Parker, Walls, Parker, Wong, Barham, & Wilder (2017) 5. Gulz et al. (2020) 6. Keshav et al. (2017) 7. Matsuda et al. (2020) 8. McCarthy, Likens, Johnson, Guerrero, & McNamara (2018) 9. McLaren, DeLeeuw, & Mayer (2011) 10. Moridis and Economides (2009) 11. Peker et al. (2017) 12. Shih et al. (2012) 13. Tarning, Silvervarg, Gulz, & Haake (2019) 14. Walkington & Bernacki (2019) 15. Xiao and Hu (2019) 16. Zheng et al. (2018) 17. Hwang et al. (2020)

Table 3). The largest number of AIEd research studies (n = 14) were in engineering, computer science, information technology (IT), or informatics, followed by mathematics (n = 8), foreign language (n = 4), science (n = 3), and business (n = 3). In total, 25 of the 40 research studies were conducted in STEM fields. Three studies investigated AIEd in multiple disciplines (i.e., Cheung et al., 2003; Dias et al., 2015; Xie et al., 2017). Articles did not specify the subject areas addressed in the study were not in Table 3.

2.4. Collaborations in AIEd research

Most of the AIEd research articles were outcomes of collaborative work with two or more authors. Among the 40 research articles reviewed in this study, only two empirical studies were single authored (Arpaci, 2019; Köse, 2017). Collaborative research on AIEd involved not only multiple authors but also multiple disciplines (e.g., Cheung et al., 2003; Dias et al., 2015; Xie et al., 2017), and sometimes in multiple countries (e.g., Rapanta & Walton, 2016) as well.

2.5. Participants and sample sizes

The sample sizes of the AIED research varied greatly, ranging from 20 (Zheng, Zhang Xu, Peng, & Wu, 2018) to 7341 (Xie et al., 2017), as noted in Table 1. Most of the studies had a sample size of 100–500 (n = 24), and three studies had sample sizes larger than 1000 (i.e., Dias et al., 2015, Flogie & Abersek, 2015; Xie et al., 2017).

Participants profiles also varied by study. AIEd research involved participants from K-12 schools or higher education institutions (see Table 2), from different countries (see Table 1), in distinct academic programs or courses (Table 3), and of various social economic states (Table 1). Participants in a study were from different grade levels (e.g., Chin et al., 2010; Flogie & Abersek, 2015; Samarakou et al., 2018), from multiple disciplines (e.g., Cheung et al., 2003; Dias et al., 2015; Xie et al., 2017), in different countries (e.g., Rapanta & Walton, 2016), included both adults and children (e.g., Keshav et al., 2017), or involved both faculty and students (e.g., Cheung et al., 2003).

Student diversity was also examined in some AIEd research studies.

Table 3
A Summary of subject areas addressed in AIEd research articles.

Subject Area(s)	n	Articles
Engineering/computer science/IT/Informatics	14	1. Arpaci (2019) 2. Atilola et al. (2014) 3. Bahçeci and Gürol (2016) 4. Griol et al. (2014) 5. Köse and Arslan (2016) 6. Köse (2017) 7. Leony, Munoz-Merino, Pardo, & Kloos (2013) 8. Mas-Sanso and Manresa-Yee (2016) 9. Moridis and Economides (2009) 10. Munawar et al. (2018) 11. Samarakou, Fylladitakis, Fruh, Hatziapostolou, & Gelengenis (2015) 12. Samarakou et al. (2018) 13. Xie et al. (2017) 14. Xu and Wang (2006)
Mathematics	8	1. Gulz, Londos, & Haake (2020) 2. Kelly et al. (1993) 3. Matsuda et al. (2020) 4. Shih et al. (2012) 5. Tarning, Silvervarg, Gulz, & Haake (2019) 6. Walkington & Bernacki (2019) 7. Hwang et al. (2020) 8. Xie et al. (2017)
Foreign Language/ESL	4	1. Fryer et al. (2017) 2. Wei et al. (2018) 3. Xiao and Hu (2019) 4. Zheng et al. (2018)
Sciences	3	1. Chin et al. (2013) 2. Chin et al. (2010) 3. McLaren, DeLeeuw, & Mayer (2011)
Business/economics	3	1. Montalvo et al. (2018) 2. Rapanta and Walton (2016) 3. Xie et al. (2017)
Calligraphy	1	Loup-Escande et al. (2017)
History	1	Ijaz et al. (2017)
Health Assessment	1	Xie et al. (2017)
Reading	1	McCarthy, Likens, Johnson, Guerrero, & McNamara (2018)
Multiple disciplines	3	1. Dias et al. (2015) 2. Xie et al. (2017) 3. Cheung et al., 2003

For instance, in a recent study in Canada (Xiao & Hu, 2019), researchers analyzed possible differences between high achieving and low achieving students. In an earlier study in Taiwan, Shih and colleagues (Shih et al., 2012) studied sixth graders from a school with lower socioeconomic status, in comparison to other schools in the same region. Also, in some research, both teachers and students were studied. For example, in a study in Slovenia, the researchers examined the effects of a trans-disciplinary cognitive neuro-educational model on the attitudes of both students and teachers toward school (Flogie & Abersek, 2015). In sum, AIEd research was conducted with participants representing diverse populations in different countries, in various educational settings and in an array of subject areas.

3. AIEd technology applications & educational benefits

AI technology brings virtually unlimited possibilities to education. The 40 articles investigated a wide variety of AI applications in education, including the following types of learning technology:

•Chatbot (Fryer et al., 2017);

•Expert systems (Dias et al., 2015; Hwang et al., 2020);

•Intelligent tutors or agents (Cheung et al., 2003; Chin et al., 2010; Chin et al., 2013; Cung, Xu, Eichhorn, & Warschauer, 2019; Gulz et al., 2020; Köse & Arslan, 2016; Matsuda et al., 2020; McCarthy et al., 2018; McLaren, DeLeeuw, & Mayer, 2011; Tärning, Silvervarg, Gulz, & Haake, 2019);

•Machine learning (Arpaci, 2019; Wei, et a., 2018);

•Personalized learning systems or environments (PLS/E) (Bahçeci & Gürol, 2016; Griol et al., 2014; Köse, 2017; Montalvo et al., 2018; Samarakou et al., 2018; Santos & Notargiacomo, 2018; Xu & Wang, 2006; Walkington & Bernacki, 2019);

•Visualizations (Keshav et al., 2017; Leony, Munoz-Merino, Pardo, & Kloos, 2013; Lou-Escande, Frenoy, Poplimont, Thouvenin Gapenne, & Megalakaki, 2017)

3.1. Chatbot

Only one study focused solely on chatbot in education and it was not directly linked to learning outcomes. Through a twelve-week experiment, researchers tested the effects of chatbot partners, compared to human partners, on students' course interest in foreign language classes with 122 students (Fryer et al., 2017). The study found that students' interests dropped after one week with chatbot, and the Structural Equation Modelling indicated that task interest predicted future course interest in human partner conditions, while under Chatbot partner conditions it did not. While researchers attributed the decrease in interest to a novelty effect (Fryer et al.), it calls for more empirical studies to examine effects of chatbot in education.

3.2. Expert system

AIEd research suggested that dynamic, holistic expert systems can help with pedagogical planning and fully unleash the potentials of learning management systems (LMS) for teaching and learning (Dias et al., 2015). For example, Dias and colleagues researched on the quality of interactions in a blended learning environment with 1037 students and 75 professors in an LMS through multiple courses in an academic year (Dias et al., 2015). Their study proved that the structural characteristics of an expert system can model how LMS users interact with it (Dias et al., 2015), and thus to facilitate and improve the teaching and learning experiences on the LMS. In a recent study (Hwang et al., 2020), researchers investigated the effects of a fussy expert system on elementary students' math learning outcomes in Taiwan. In this study, students in the experimental group outperformed those in the other two groups in mathematics learning achievement. In addition, the adaptive learning model with affective and cognitive performance analysis was found effective in reducing math anxiety amongst the fifth graders in Taiwan (Hwang et al., 2020).

3.3. Intelligent tutors or agents

Intelligent tutors or agents provide customized, timely, and appropriate materials, guidance, and feedback to learners. With great potentials, research indicates mixed implications regarding its effects on learning. For example, a few studies examined the effects of Teachable Agent (TA) (Chin et al, 2010, 2013; Matsuda et al., 2020; Tärning et al., 2019). Research indicated that TA promoted learning for elementary students in different grades (Chin et al, 2010, 2013; Matsuda et al., 2020) and prepared students to learn new science content from their regular lessons, even when they were not using the AI software (Chin et al., 2010). More recently, researchers in Sweden (Gulz et al., 2020) studied preschoolers' understanding of a TA-based math game as reflected in their gaze behaviors. The study indicated that young children perceived the TA as an independent entity, and researchers thus suggested that TA was promising in facilitating metacognitive scaffolding (Gulz et al., 2020). In another study, researchers examined the effects of metacognitive scaffolding by teaching a TA on 7th & 8th graders' learning outcomes (Matsuda et al., 2020). They found that students' ability to solve problems increased with the three TA interventions, but there was no difference amongst the three different conditions (Matsuda et al., 2020). Research also suggested that TA with a similar level of self-efficacy with target students may help improve learners' performance in math (Tärning et al., 2019). McCarthy and colleagues (2018) found that metacognitive prompts provided by an intelligent tutoring system did not improve student performance, but practice and actionable feedback were essential in the intelligent tutoring system for improving reading comprehension. In another study, McLaren and colleagues (McLaren et al., 2011) found that for students with low prior knowledge, a polite web-based tutor led to more learning as compared to the regular web-based tutor.

3.4. Machine learning

Despite the wide applications of machine learning, a small number of research studies met all criteria for full analyses in this study. This important AI technology was effective in assessing the changes of learning styles in ESL/EFL in multiple grades (Wei et al., 2018). In another study, machine learning algorithms were used to predict undergraduate students' attitudes toward educational applications of cloud-based mobile computing services by their information management behaviors with 74% accuracy (Arpaci, 2019).

3.5. Personalized learning systems or environments (PLS/E)

Personalized learning systems or environments (PLS/E) were found effective in facilitating interactions (Xu & Wang, 2006) and improving e-learning experiences (Cheung et al., 2003; Köse, 2017; Köse & Arslan, 2016; Xu & Wang, 2006). Turkish researchers, Köse and Arslan (2016) studied the effects of PLS, with 110 undergraduate students through two semesters in computer programming courses. They found the PLS system helped learners to achieve desirable learning outcomes and reportedly improved their learning experiences as well. In another study, Köse (2017) also found that personalized mobile learning, via AI and Augmented Reality (AR), improved learning experiences as well as learning outcomes in open computer education. A study with over 1300 participants in Hong Kong investigated an AI-enhanced e-learning system called SmartTutor (Cheung et al., 2003). And, it was found that customized learning materials and resources were well received and both students and faculty confirmed that they were helpful in the teaching/learning process (Cheung et al., 2003). A study with high school students in USA (Walkington & Bernacki, 2019) found that connecting math to students' personal interests that were not school-related would increase learning in an intelligent tutoring system, and thus highly customized personalization could promote learning and thus may lead to student success.

3.6. Visualizations and virtual learning environments (VLE)

Together with the surge of virtual reality (VR) technologies, research has started exploring the potential benefits of visualizations and VLE with AI in education. Evidently, students enjoyed the learning experience in VLE and reported that it facilitated learning and collaborations (Griol et al., 2014). Similarly, teachers also noted that students were better engaged in learning (Griol, Molina, & Callejas). A technology combining both AI and virtual reality (VR) was found effective in improving the learning experience and engaging the young generation of learners in Australia (Ijaz et al., 2017). Undergraduate students learning with AI and VR also performed better in comprehensions as measured in this study (Ijaz et al., 2017). A study on a smart glass system also confirmed that AI technology with visualizations helped both children and adults with autism, by serving as a social communication aid (Keshav et al., 2017). However, supplementary visual feedback in a mixed reality (MR) environment led to a cognitive load for participants when learning calligraphy, yet without effect on user experience (Loup-Escande et al., 2017). The inconsistent research results call for improvements in this type of AI technology and demand more research on AI visualizations and VLE.

4. Discussions

4.1. AI in education: technologies & benefits

As early as 1991, Garito has stressed that AI is changing the traditional role of a teacher (Garito, 1991). Lately, more scholars point out that AI empowers educators with better ways to teaching and learning (Cope, Kalantzis, & Searsmith, 2020). With scalable applications, AI is transforming educational practices with profound impacts across the world, including the Global South and in emergent forms of education like MOOCs, blended learning, flipped classrooms and more (e.g., Al Braiki, Harous, Zaki, & Alnajjar, 2020; Reynolds, Reeves, Bonk, & Zhang, 2020; Roschelle, Lester, & Fusco, 2020; Zhang, Bonk, Reeves, & Reynolds, 2020).

A recent review (Zawacki-Richter et al., 2019) summarizes an array of AIEd applications for varied purposes, such as learner profiling, performance prediction, assessment, evaluation, personalization, adaptive learning and more. Evidently, AI systems can analyze student input and provide corrective feedback instantly (Mirzaeian, Kohzadi, & Azizmohammadi, 2016; Roschelle, Lester, & Fusco, 2020), generate automatic scoring and formative assessments (Zhu, Liu, & Lee, 2020), and help students with revisions during in the learning process (Lee et al., 2019). Intelligent tutoring systems can help identify learners' strengths and gaps in their current knowledge base (Zawacki-Richter, Marin, Bond, & Gouverneur, 2019). More importantly, intelligent feedback systems can also measure how people learn, in addition to what is learned (Cutumisu, Chin, & Schwartz, 2019). Machine learning for example, can predict at-risk or marginal college students (Chui, Fung, Lytras, & Lam, 2020) as well as gifted students (Hodges & Mohan, 2019) with high accuracy, which then empowers educators to intervene accordingly for student successes.

AIEd advancement calls for more empirical studies with a particular focus on AI technologies in real teaching and learning settings (Kabudi et al., 2021), serving educational needs and purposes. As researchers point out in a recent literature review, there has been a severe discrepancy between the potentials of AIEd and their actual implementations in education (Kabudi et al., 2021). To illustrate how AI technologies are currently leveraged for various teaching and learning purposes, Fig. 1 highlights some practical examples of AIEd applications from the research articles reviewed in this study. It may also serve as a snapshot of the current practice of AIEd with educational aspirations, which in turn may also stimulate more research on AIEd.

With educational goals and objectives in mind, the examples in Fig. 1 showcase how students and educators may benefit from AI-enhanced learning systems or experiences.

4.2. Practical implications for AIEd

With a wide range of technologies, features and functions, the advancement of AI brings exciting opportunities to education. To realize its full potential for education, it is critical to bridge the gaps between AI technological innovations and its educational applications. Fig. 2 summarizes some of the most widely applied AIEd technologies and their proven or potential benefits for education. For learners, AIEd may facilitate varied interactions, increase learner engagement, generate adaptive learning materials, offer meta-cognitive prompts, provide enriched learning environments, and improve learning outcomes. For educators and administrators, AIEd may provide predictive models, identify gifted or at-risk students, monitor the learning progress, create personalized learning materials, assessments and feedback, and analyze scaled data instantly for evaluation or administrative purposes. AI-enhanced learning environments may improve the LMS for both instructors and students through expert systems, generate visual feedback, and enrich the learning experience with visualization and immersive technologies.

With highlighted practical takeaways, Fig. 2 can serve in multiple

Practical AIEd Application Examples

Use of teachable agents help 5th and 6th grade students learn new science topics as they get to teach the agent by creating concept maps and the agent guides their learning through its AI power (Chin, Dohmen, Cheng, Oppezzo, Chase, & Schwartz, 2010).

Potential use of teaching agents for scaffolding and individualized feedback to improve learning process of preschoolers (Gulz, Londos, & Haake, 2020).

AI supported avatars in a virtual historical city to help students interact in the intended context– students showed better comprehension (quantitative) and they also reflected they had positive learning experiences (qualitative) (Ijaz, Bogdanovych, & Trescak, 2017).

Use of intelligent system that is aware of learner's emotions with the aim to provide teachers with the knowledge about their learners learning intentions, causes, and the relationship between their emotions and learning in the higher education context (Leony, Munoz-Merino, Pardo, & Kloos, 2013).

Use of a complimentary teaching tool to include more relevant real-life insights to increase student motivation of finance students (Montalvo, Palomo, & de la Orden, 2018).

Use of AI supported web-based career guidance system offering vocational insights to support 9th graders' career decisions (Peker, Guruler, Sen, & Istanbullu, 2017).

Use of an open learning system supported by AI to predict students' text comprehension and learning styles to generate profiles of learners to support their learning in higher education (Samarakou, Tsaganou, & Papadakis, 2018).

Use of machine learning as an artificial intelligence technique, ESL students' learning styles were predicted in the higher education setting (Wei, Yang, Chen, & Hu, 2018).

Prediction of high achieving and low achieving students in ESL education through an AI algorithm based on reading materials, classroom organization, reading strategies, in-class reading activities and post-reading activities (Xiao & Hu, 2019).

Predicting the active video-viewing time in massive open online courses (Xie, Zheng, Zhang, & Qu, 2017).

Personalization with intelligent tutor to increase the effectiveness of learning in a virtual learning environment in the higher education setting (Xu & Wang, 2006).

Use of emotion and cognition aware mobile app to promote mobile English learning for elementary students. If the app detects student is distracted or tired, the next content provides music or animation clip to help student become more interested (Zheng, Zhang, Xu, Peng, & Wu (2018).

Fig. 1. Practical Examples of AIEd applications.

ways to guide both technological experts that create AI technologies for education as well as educators and educational researchers, who spearhead AI innovations in educational systems through practice, evaluation and research. AI technology inventers, for instance may note its educational benefits and collaborate with educators to leverage AI technologies with specific goals to improve learning and teaching on a large scale. Likewise, educators, or educational institutions, may identify appropriate AI technologies from the figure for varied educational needs or goals, without being overwhelmed by the technical details.

Also highlighted in Fig. 2 are some key challenges in promoting AIEd, such as costs & scalability, ethics & privacy, the lack of actionable guidelines for educators, and limited AI expertise among educators. The figure may further facilitate meaningful communications amongst stakeholders with different areas of expertise (e.g., technological skills vs. learning theories and pedagogies), from different perspectives (e.g., technology advancement, teaching and learning, administrations of educational systems, educational research, etc.) and thus lead to fruitful collaborations in AIEd research, development, implementation and evaluation.

Recent research has found that students' task engagement and performance increased when AI-supported systems also attended to their affective status in addition to cognitive aspects (Hwang et al., 2020). The study demonstrates the potential of AI in addressing learners' affective or emotional needs, which in turn may improve learning. It also suggests the need for more inclusive designs of AIEd technologies to address students' varied needs and preferences.

Recent reviews on AIEd related research have consistently emphasized the lack of educational perspectives in AIEd research, development or implementations (Chen et al., 2020; Hinojo-Lucena et al., 2019; Kabudi et al., 2021; Tang et al., 2021, ; Zawacki-Richter et al., 2019). Thus, to further advance AI technologies for education, perhaps the most important initiative is to invite educators and educational researchers to fully participate in the technological innovation process, to proactively seek input from the educational communities, and to integrate

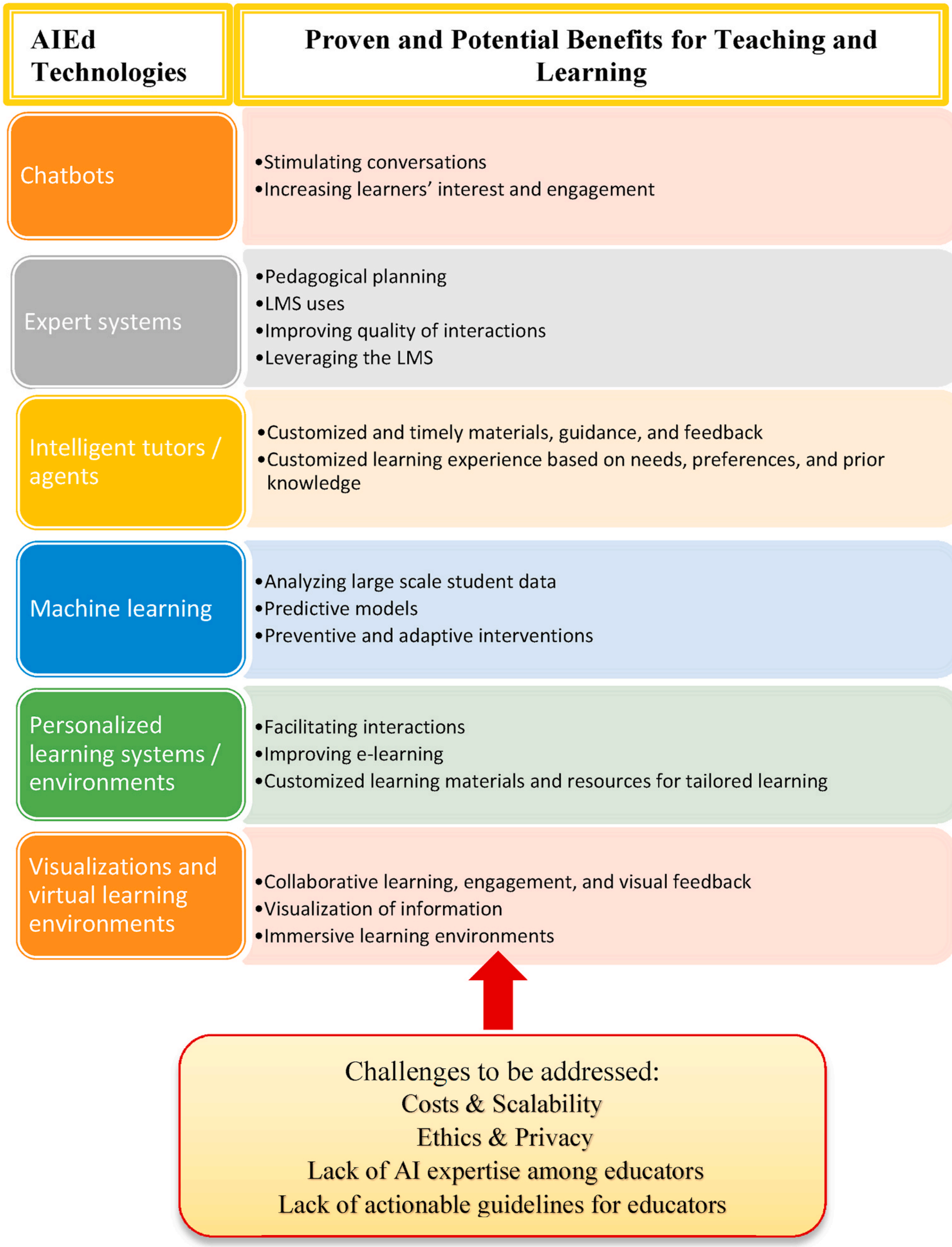

Fig. 2. Proven and potential educational benefits of AI technologies.

theoretical, conceptual, practical and empirical support from educational literature.

4.3. Directions for future research on AIEd

The booming of AI technology in 2016 highlighted with tech companies bringing AI home and the famous AlphaGo with an overwhelming win over a professional world champion in the Go game (Deepmind.com, n. d.). AIEd research has yet to catch up with the rapid advancement of AI technology to provide evidence-based guidelines and support for AI applications in education. Despite the advancement of AIEd technologies, there is still a lack of educational perspectives in AIEd research, as recent literature reviews have stressed (e.g., Chen et al., 2020; Hinojo-Lucena et al., 2019; Zawacki-Richter et al., 2019). Interdisciplinary research with educators and educational researchers will more likely result in feasible practical guidelines and good examples for fellow educators. In addition, to reach the full potentials of AI in education, collaborative research focusing on AI technology applications that may result in direct or indirect effects on learning outcomes in real educational settings is particularly vital.

Research also needs to scale up to examine AIEd on the institutional, regional and national levels, and for longer time durations. In addition, emerging methods like educational data mining, text mining, learning analytics, data visualizations are also imperative to advance AIEd research. In particular, emerging educational research methods, such as educational design research (EDR) (McKenney & Reeves, 2018), is highly recommended for research on innovative technologies like AIEd, because it empowers educators to incorporate their research inquiries as part of the technology development and implementation cycle in authentic settings. EDR can be particularly powerful when educators participate during the stages of AI technology creation, development or evaluations for educational purposes.

Amongst the range of AIEd technologies, some have been studied more frequently than others. For example, a lot of research focused on intelligent tutors or personalized learning systems/environments, while only a very limited number of research publications examined the effect of chatbot or machine learning in education, as found in this review. Thus, future research should cover more AIEd technologies, especially those have not received much attention in research.

As emerging technologies such as VR, AR or MR being integrated with AI for various learning supports (e.g., Köse, 2017; Ijaz et al., 2017; Loup-Escande et al., 2017), it is also vital to conduct research through interdisciplinary and transdisciplinary collaborations as researchers have suggested (Zhang & Aslan, 2020) for successful AIEd development, implementation and research.

4.4. AIEd ethics & privacy

As educational systems experiment with AI in traditional classrooms, online or via mobile learning management systems (e.g., Roschelle et al., 2020; Zhang et al., 2020), it is imperative to balance efficiency, benefits, security and many more (Hagendorff, 2019; Etzioni and Etzioni, 2017; Abrams, Abrams, Cullen, & Goldstein, 2019). About 20 years ago, scholars have already started conversations about AIEd ethics (Aiken and Epstein, 2000), and giant tech companies are forming their own AI ethics panels (Lee, 2019). But new educational AI technology requires specific AI ethics for education. Likewise, privacy is a critical issue yet to be carefully addressed in AIEd. A recent semi-systematic evaluation of 22 AI ethics guidelines has revealed that current guidelines have severe flaws and a range of AI ethics that are critical for AI research, development and implementation are actually missing or overlooked in such guidelines (Hagendroff, 2020). The critical and urgent needs for AIEd ethics also call for collaborative efforts from all stakeholders, including educators, administrators, researchers, technology innovators and all societal members.

4.5. Limitation of this review

As typical with any search engines or strategies, a methodological limitation of this review is tied to the selection of source database and journals, as well as the specific identifiers used in the search efforts, such as “artificial intelligence” or “AI”. Research publications that do not include AI or “artificial intelligence” as a descriptor in its title, abstract, summary or keyword list, as well as those not indexed in the source database thus can be excluded in this review. While conference proceedings may include more recent or even ongoing research projects, considering their very different selection criteria and review processes, conference proceedings are also excluded in this review. Thus, this review is limited in its scope.

4.6. Suggestions for future reviews

Future reviews may extend the search scope to include other reputable databases, specialized journals, or peer-reviewed conference proceedings. Additional key words, such as specific AI technology (e.g., machine learning) or its educational applications may retrieve more relevant publications. However, future reviews should also be mindful of the search results, as sometimes publications on other topics, such as game-based learning also appear in the search results (e.g., Yoon & Kim, 2015), even though they are not AI-related. Another important consideration is to carefully differentiate AIEd studies without human subjects (e.g., Liu, Rus, & Liu, 2017) or otherwise focus on system development or model testing from research with teachers, students or other human participants involved, as such in this review.

As an interdisciplinary field, AIEd has overlaps with a few emerging sub-fields, such as educational data mining, learning analytics and computer-based education (Chen et al., 2020; Romero & Ventura, 2013). Future reviews may also choose to alter the scope by focusing on specific AI technologies or their applications in education, or a sub-field of AIEd, or applying different search strategies and selection criteria, or exploring conference proceedings in addition to peer-reviewed journal articles. Given the integrations of emerging technologies like VR, AR and MR (Zhang & Aslan, 2020) and AI (e.g., Keshav et al., 2017; Ijaz et al., 2017), future reviews may also explore both of them together.

5. Conclusion

AI technology is rapidly advancing and its application in education is expected to grow rapidly in the near future. In the USA, for example, education sectors are predicted with an approximate 48% of growth in AI market in the near future, from 2018 to 2022 (BusinessWire.com, 2018). AI technologies have great potentials in education, in particular, to increase access to learning opportunities, to scale up personally customized learning experiences, and to optimize methods and strategies for desired learning outcomes (Reynolds et al., 2020; Roschelle et al., 2020; Zawacki-Richter et al., 2019). Some scholars have publicly proposed to replace teachers or certain roles of teachers with AI robots ((Edwards & Cheok, 2018). While their article, *Why Not Robot Teachers: Artificial Intelligence for Addressing Teacher Shortage* (Edwards & Cheok, 2018) may cause some uneasiness, discomfort or even fear for many people; it is gradually becoming a reality. In addition to the intelligent tutors and teachable agents in online or blended learning as reported in AIEd studies (e.g., Cheung et al., 2003; Chin et al., 2010, 2013; Cung et al., 2019; Köse & Arslan, 2016; Mclaren et al., 2011), the first AI teaching assistant robots, named *Happy Numbers* have been working in the classrooms in USA already.

As Finn has emphasized back in the 1960s, technology is “more than an invention – more than machines. It is a process and a way of thinking” (Fin, 1960, p. 6). The integration of AIEd calls for critical awareness of AI ethics and requires interdisciplinary and transdisciplinary collaborations in large-scaled, longitudinal research. The growing AIEd research would result in more practical guidelines and examples for educators, together with new ways of teaching and learning. Despite skepticism, doubts or fears, AIEd continues to open up new possibilities for innovations in education.

Statements on open data and ethics

This literature review article collected all data (i.e., eligible publications) from selected databases from the internet. The datasets created for the current study (the bibliography of included studies) are available from the corresponding author upon request.

As the research does not involve human participants, there is no need to seek ethical approval from a research review committee in the authors’ affiliations.

Declaration of competing interest

None.

References

Abram, M., Abram, J., Cullen, P., & Goldstein, L. (2019). Artificial intelligence, ethics, and enhanced data stewardship. *IEEE Security & Privacy, 17*(2), 17–30. https://doi-org.proxy.lib.wayne.edu/10.1109/MSEC.2018.2888778.

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

Al Braiki, B, Harous, S., Zaki, N., & Alnajjar, F. (2020). Artificial intelligence in education and assessment methods. *Bulletin of Electrical Engineering and Informatics, 9*(5), 1998–2007.

Andriessen, J., & Sandberg, J. (1999). Where is education heading and how about AI. *International Journal of Artificial Intelligence in Education, 10*(2), 130–150.

Arpaci, I. (2019). A hybrid modeling approach for predicting the educational use of mobile cloud computing services in higher education. *Computers in Human Behavior, 90*, 181–187. https://doi.org/10.1016/j.chb.2018.09.005.

Atilola, O., Valentine, S., Kim, H.-H., Turner, D., Mctigue, E., Hammond, T., et al. (2014). Mechanix: A natural sketch interface tool for teaching truss analysis and free-body diagrams. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 28*(2), 169–192. https://doi.org/10.1017/s0890060414000079.

Bahçeci, F., & Gürol, M. (2016). The effect of individualized instruction system on the academic achievement scores of students. *Educational Research International*, 1–9. https://doi.org/10.1155/2016/7392125, 2016.

Bates, T., Cobo, C., Mariño, O., & Wheeler, S. (2020). Can artificial intelligence transform higher education? *International Journal of Educational Technology in Higher Education, 17*(42). https://doi.org/10.1186/s41239-020-00218-x.

Beck, J., Stern, M., & Haugsjaa, E. (1996). Applications of AI in education. *Crossroads, 3*(1), 11–15.

Burleson, W., & Lewis, A. (2016). Optimists' creed: Brave new cyberlearning, evolving utopias (Circa 2041). *International Journal of Artificial Intelligence in Education, 26*(2), 796–808. https://doi.org/10.1007/s40593-016-0096-x.

Chen, X., Xie, H., Zou, D., & Hwang, G. J. (2020). Application and theory gaps during the rise of artificial intelligence in education. *Computers and Education: Artificial Intelligence, 1*, 100002.

Cheung, B., Hui, L., Zhang, J., & Yiu, S. (2003). SmartTutor: An intelligent tutoring system in web-based adult education. *Journal of Systems and Software, 68*(1), 11–25. https://doi.org/10.1016/s0164-1212(02)00133-4.

Chin, D. B., Dohmen, I. M., Cheng, B. H., Oppezzo, M. A., Chase, C. C., & Schwartz, D. L. (2010). Preparing students for future learning with Teachable Agents. *Educational Technology Research & Development, 58*(6), 649–669. https://doi.org/10.1007/s11423-010-9154-5.

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

Chui, K. T., Fung, D. C. L., Lytras, M. D., & Lam, T. M. (2020). Predicting at-risk university students in a virtual learning environment via a machine learning algorithm. *Computers in Human Behavior, 107*, 105584. https://doi.org/10.1016/j.chb.2018.06.032.

Clancey, W. J., Bennett, J. S., & Cohen, P. R. (1979). *Applications-oriented AI research: Education (No. STAN-CS-79-749). Stanford university, department of computer science*.

Cung, B., Xu, D., Eichhorn, S., & Warschauer, M. (2019). Getting academically underprepared students ready through college developmental education: Does the course delivery format matter? *American Journal of Distance Education, 33*(3), 178–194.

Cutumisu, M., Chin, D. B., & Schwartz, D. L. (2019). A digital game-based assessment of middle-school and college students' choices to seek critical feedback and to revise. *British Journal of Educational Technology, 50*(6), 2977–3003. https://doi.org/10.1111/bjet.12796.

Dias, S. B., Hadjileontiadou, S. J., Hadjileontiadis, L. J., & Diniz, J. A. (2015). Fuzzy cognitive mapping of LMS users' Quality of interaction within higher education blended-learning environment. *Expert Systems with Applications, 42*(21), 7399–7423. https://doi.org/10.1016/j.eswa.2015.05.048.

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

Etzioni, A., & Etzioni, O. (2017). Incorporating ethics into artificial intelligence. *The Journal of Ethics, 21*(4), 403–418. https://doi.org/10.1007/s10892-017-9252-2.

Finn, J. (1960). Automation and education: III. Technology and the instructional process. *Audio Visual Communication Review, 8*(1), 5–26.

Flogie, A., & Abersek, B. (2015). Transdisciplinary approach of science, technology, engineering and mathematics education. *Journal of Baltic Science Education, 14*(6), 779–790.

Fryer, L. K., Ainley, M., Thompson, A., Gibson, A., & Sherlock, Z. (2017). Stimulating and sustaining interest in a language course: An experimental comparison of Chatbot and Human task partners. *Computers in Human Behavior, 75*, 461–468. https://doi.org/10.1016/j.chb.2017.05.045.

Gao, F., Luo, T., & Zhang, K. (2012). Tweeting for learning: A critical analysis of current research on microblogging in education published in 2008-2011. *British Journal of Educational Technology, 43*(5), 783–801.

Garito, M. A. (1991). Artificial intelligence in education: Evolution of the teaching-learning relationship. *British Journal of Educational Technology, 22*(1), 41–47. https://doi.org/10.1111/j.1467-8535.1991.tb00050.x.

Gonzalez, A. J., Hollister, J. R., Demara, R. F., Leigh, J., Lanman, B., Lee, S.-Y., et al. (2017). AI in informal science education: Bringing Turing back to life to perform the Turing test. *International Journal of Artificial Intelligence in Education, 27*(2), 353–384. https://doi.org/10.1007/s40593-017-0144-1.

Griol, D., Molina, J. M., & Callejas, Z. (2014). An approach to develop intelligent learning environments by means of immersive virtual worlds. *Journal of Ambient Intelligence and Smart Environments, 6*(2), 237–255.

Gulz, A., Londos, L., & Haake, M. (2020). Preschoolers' understanding of a teachable agent-based game in early mathematics as reflected in their gaze behaviors–an experimental study. *International Journal of Artificial Intelligence in Education*, 1–36.

Hagendorff, T. (2019). From privacy to anti-discrimination in times of machine learning. *Ethics and Information Technology, 1–13*. https://doi-org.proxy.lib.wayne.edu/10.1007/s10676-019-09510-5.

Hagendorff, T. (2020). The ethics of AI ethics: An evaluation of guidelines. *Minds and Machines*, 99–120. https://doi.org/10.1007/s11023-020-09517-8.

Hinojo-Lucena, F. J., Aznar-Díaz, I., Cáceres-Reche, M. P., & Romero-Rodríguez, J. M. (2019). Artificial intelligence in higher education: A bibliometric study on its impact in the scientific literature. *Education Sciences, 9*(1), 51.

Hodges, J., & Mohan, S. (2019). Machine learning in gifted education: A demonstration using neural networks. *Gifted Child Quarterly, 63*(4), 243–252.

Hung, J., & Zhang, K. (2012). Examining mobile learning trends 2003-2008: A categorical meta-trend analysis using text mining techniques. *Journal of Computing in Higher Education, 24*(1), 1–17.

Hwang, G., Sung, H., Chang, S., & Huang, X. (2020). A fuzzy expert system-based adaptive learning approach to improving students' learning performances by considering affective and cognitive factors. *Computers and Education: Artificial Intelligence, 1*(1), 100003. https://doi.org/10.1016/j.caeai.2020.100003.

Ijaz, K., Bogdanovych, A., & Trescak, T. (2017). Virtual worlds vs books and videos in history education. *Interactive Learning Environments, 25*(7), 904–929. https://doi.org/10.1080/10494820.2016.1225099.

Kabudi, T., Pappas, I., & Olsen, D. H. (2021). AI-enabled adaptive learning systems: A systematic mapping of the literature. In *Computers and education: Artificial intelligence* (p. 100017).

Kaplan, A., & Haenlein, M. (2019). Siri, siri, in my hand: Who's the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence. *Business Horizons, 62*, 15–25. https://doi.org/10.1016/j.bushor.2018.08.004.

Kelly, A. E., Sleeman, D., & Gilhooly, K. J. (1993). Artificial intelligence in education: Using state space search and heuristics in mathematics instruction. *International Journal of Man-Machine Studies, 38*(4), 725–746. https://doi.org/10.1006/imms.1993.1034.

Keshav, N. U., Salisbury, J. P., Vahabzadeh, A., & Sahin, N. T. (2017). Social communication coaching smartglasses: Well tolerated in a diverse sample of children and adults with autism. *JMIR MHealth and UHealth, 5*(9). https://doi.org/10.2196/mhealth.8534.

Köse, U. (2017). An augmented-reality-based intelligent mobile application for open computer education. *Mobile Technologies and Augmented Reality in Open Education Advances in Educational Technologies and Instructional Design*, 154–174. https://doi.org/10.4018/978-1-5225-2110-5.ch008.

Köse, U., & Arslan, A. (2016). Intelligent e-learning system for improving students' academic achievements in computer programming courses. *International Journal of Engineering Education, 32*, 185–198.

Kurzweil, R. (1985). What is artificial intelligence anyway? As the techniques of computing grow more sophisticated, machines are beginning to appear intelligent - but can they actually think? *American Scientist, 73*(3), 258–264.

Lee, D. (2019, March 26). Google announces AI ethics panel. Retrieved from. https://www.bbc.com/news/technology-47714921.

Lee, H. S., Pallant, A., Pryputniewicz, S., Lord, T., Mulholland, M., & Liu, O. L. (2019). Automated text scoring and real-time adjustable feedback: Supporting revision of scientific arguments involving uncertainty. *Science Education, 103*(3), 590–622. https://doi.org/10.1002/sce.21504.

Legg, S., & Hutter, M. (2007). A collection of definitions of intelligence. *Frontiers in Artificial Intelligence and Applications, 157*, 17–24.

Leony, D., Muñoz-Merino, P. J., Pardo, A., & Kloos, C. D. (2013). Provision of awareness of learners' emotions through visualizations in a computer interaction-based environment. *Expert Systems with Applications, 40*(13), 5093–5100. https://doi.org/10.1016/j.eswa.2013.03.030.

Liu, M., Rus, V., & Liu, L. (2017). Automatic Chinese factual question generation. *IEEE Transactions on Learning Technologies, 10*(2), 194–204. https://doi.org/10.1109/tlt.2016.2565477.

Loup-Escande, E., Frenoy, R., Poplimont, G., Thouvenin, I., Gapenne, O., & Megalakaki, O. (2017). Contributions of mixed reality in a calligraphy learning task: Effects of supplementary visual feedback and expertise on cognitive load, user experience and gestural performance. *Computers in Human Behavior, 75*, 42–49. https://doi.org/10.1016/j.chb.2017.05.006.

Mas-Sanso, R., & Manresa-Yee, C. (2016). Gamifying an artificial intelligence course in engineering education. *International Journal of Engineering Education, 32*, 513–520.

Matsuda, N., Weng, W., & Wall, N. (2020). The effect of metacognitive scaffolding for learning by teaching a teachable agent. *International Journal of Artificial Intelligence in Education*, 1–37.

McCarthy, K. S., Likens, A. D., Johnson, A. M., Guerrero, T. A., & McNamara, D. S. (2018). Metacognitive overload!: Positive and negative effects of metacognitive prompts in an intelligent tutoring system. *International Journal of Artificial Intelligence in Education, 28*(3), 420–438.

McKenney, S., & Reeves, T. C. (2018). *Conducting educational design research*. NYC: Routledge.

Mclaren, B. M., Deleeuw, K. E., & Mayer, R. E. (2011). Polite web-based intelligent tutors: Can they improve learning in classrooms? *Computers & Education, 56*(3), 574–584. https://doi.org/10.1016/j.compedu.2010.09.019.

Mirzaeian, V. R., Kohzadi, H., & Azizmohammadi, F. (2016). Learning Persian grammar with the aid of an intelligent feedback generator. *Engineering Applications of Artificial Intelligence, 49*, 167–175. https://doi.org/10.1016/j.engappai.2015.09.012.

Mogil, S. J., Simmonds, K., & Simmonds, J. M. (2009). Pain research from 1975 to 2007: A categorical and bibliometric meta-tend analysis of every research paper published in the journal, pain. *Pain, 142*, 48–58.

Montalvo, S., Palomo, J., & de la Orden, C. (2018). Building an educational platform using nlp: A case study in teaching finance. *Journal of Universal Computer Science, 24*(10), 1403–1423.

Moridis, C. N., & Economides, A. A. (2009). Prediction of student's mood during an online test using formula-based and neural network-based method. *Computers & Education, 53*(3), 644–652. https://doi.org/10.1016/j.compedu.2009.04.002.

Munawar, S., Toor, S. K., Aslam, M., & Hamid, M. (2018). Move to smart learning environment: Exploratory research of challenges in computer laboratory and design intelligent virtual laboratory for elearning technology. *Eurasia Journal of Mathematics, Science and Technology Education, 14*(5), 1645–1662. https://doi.org/10.29333/ejmste/85036.

Okubo, Y. (1997). *Bibliometric indicators and analysis of research systems: Methods and examples, STI working papers 1997/1*. Paris: OECD Science.

Peker, M., Guruler, H., Sen, B., & Istanbullu, A. (2017). A new fuzzy logic based career guidance system: WEB-CGS. *Tehnicki Vjesnik - Technical Gazette, 24*(6). https://doi.org/10.17559/tv-20151105201325.

Rapanta, C., & Walton, D. (2016). The use of argument maps as an assessment tool in higher education. *International Journal of Educational Research, 79*, 211–221. https://doi.org/10.1016/j.ijer.2016.03.002.

Reynolds, T., Reeves, T., Bonk, C., & Zhang, K. (2020). MOOCs and open education: Future opportunities. In K. Zhang, C. J. Bonk, T. Reeves, & T. Reynolds (Eds.), *MOOCs and open education in the Global South: Challenges, successes, and opportunities* (pp. 342–350). NY: Routledge, 2020.

Romero, C., & Ventura, S. (2013). In *Data mining in education. Wiley interdisciplinary reviews: Data mining and knowledge discovery* (Vol. 3, pp. 12–27), 1.

Roschelle, J., Lester, J., & Fusco, J. (Eds.). (2020). *AI and the future of learning: Expert panel report [Report]. Digital Promise*. https://circls.org/reports/ai-report.

Samarakou, M., Fylladitakis, E. D., Früh, W. G., Hatziapostolou, A., & Gelegenis, J. J. (2015). An advanced elearning environment developed for engineering learners. *International Journal of Emerging Technologies in Learning (IJET), 10*(3), 22–33. https://doi.org/10.3991/ijet.v10i3.4484.

Samarakou, M., Tsaganou, G., & Papadakis, A. (2018). An e-learning system for extracting text comprehension and learning style characteristics. *Educational Technology & Society, 21*(1), 126–136.

Santos, F. R. D., & Notargiacomo, P. (2018). Intelligent educational assistant based on multiagent system and context-aware computing. *International Journal of Advanced Computer Science and Applications, 9*(4), 236–243. https://doi.org/10.14569/ijacsa.2018.090437.

Shih, B.-Y., Chang, C.-J., Chen, Y.-H., Chen, C.-Y., & Liang, Y.-D. (2012). Lego NXT information on test dimensionality using Kolb's innovative learning cycle. *Natural Hazards, 64*(2), 1527–1548. https://doi.org/10.1007/s11069-012-0318-y.

Simmons, A. B., & Chappell, S. G. (1988). Artificial intelligence-definition and practice. *IEEE Journal of Oceanic Engineering, 13*(2), 14–42. https://doi.org/10.1109/48.551.

Tang, K. Y., Chang, C. Y., & Hwang, G. J. (2021). Trends in artificial intelligence-supported e-learning: A systematic review and co-citation network analysis (1998–2019). *Interactive learning environments*, 1–19.

Tärning, B., Silvervarg, A., Gulz, A., & Haake, M. (2019). Instructing a teachable agent with low or high self-efficacy–does similarity attract? *International Journal of Artificial Intelligence in Education, 29*(1), 89–121.

Thelwall, M. (2008). Bibliometrics to webometrics. *Journal of Information Science, 34*(4), 605–621.

Walkington, C., & Bernacki, M. L. (2019). Personalizing algebra to students' individual interests in an intelligent tutoring system: Moderators of impact. *International Journal of Artificial Intelligence in Education, 29*(1), 58–88.

Wei, Y., Yang, Q., Chen, J., & Hu, J. (2018). The exploration of a machine learning approach for the assessment of learning styles changes. *Mechatronic Systems and Control (Formerly Control and Intelligent Systems), 46*(3), 121–126. https://doi.org/10.2316/journal.201.2018.3.201-2979.

Xiao, Y., & Hu, J. (2019). Assessment of optimal pedagogical factors for canadian esl learners' reading literacy through artificial intelligence algorithms. *International Journal of English Linguistics, 9*(4), 1–14. https://doi.org/10.5539/ijel.v9n4p1.

Xie, T., Zheng, Q., Zhang, W., & Qu, H. (2017). Modeling and predicting the active video-viewing time in a large-scale e-learning system. *IEEE Access, 5*, 11490–11504. https://doi.org/10.1109/access.2017.2717858.

Xu, D., & Wang, H. (2006). Intelligent agent supported personalization for virtual learning environments. *Decision Support Systems, 42*(2), 825–843. https://doi.org/10.1016/j.dss.2005.05.033.

Yoon, D.-M., & Kim, K.-J. (2015). Challenges and opportunities in game artificial intelligence education using angry birds. *IEEE Access, 3*, 793–804. https://doi.org/10.1109/access.2015.2442680.

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

Zdenek, S. (2003). Artificial intelligence as a discursive practice: The case of embodied software agent systems. *AI & Society, 17*(3–4), 340–363. https://doi.org/10.1007/s00146-003-0284-8.

Zhang, K., & Aslan, A. B. (2020). Preparing industry-ready engineers with virtual reality: Recent research and future directions. *International Journal of Smart Technology and Learning, 2*(2–3), 136–150. https://doi.org/10.1504/IJSMARTTL.2020.112130.

Zhang, K., Bonk, C., Reeves, T., & Reynolds, T. (2020). MOOCs and open education in the Global South: Successes and challenges. In K. Zhang, C. J. Bonk, T. Reeves, & T. Reynolds (Eds.), *MOOCs and open education in the Global South: Challenges, successes, and opportunities* (pp. 1–14). NY: Routledge, 2020.

Zheng, J., Zhang, Q., Xu, S., Peng, H., & Wu, Q. (2018). Cognition-based context-aware cloud computing for intelligent robotic systems in mobile education. *IEEE Access, 6*, 49103–49111. https://doi.org/10.1109/ACCESS.2018.286788.

Zhu, M., Liu, O. L., & Lee, H.-S. (2020). The effect of automated feedback on revision behavior and learning gains in formative assessment of scientific argument writing. *Computers & Education, 143*, 103668. https://doi.org/10.1016/j.compedu.2019.103668.

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