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Role of AI in Blended Learning: A Systematic Literature Review

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Résumé de l'article

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Role of AI in Blended Learning: A Systematic Literature Review

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Abstract

As blended learning moved toward a new phase during the COVID-19 pandemic, advancements in artificial intelligence (AI) technology provided opportunities to develop more diverse and dynamic blended learning. This systematic review focused on publications related to the use of AI applications in blended learning. The original studies from January 2007 to October 2023 were extracted from the Google Scholar, ERIC, and Web of Science databases. Finally, 30 empirical studies under the inclusion criteria were reviewed based on two conceptual frameworks: four key challenges of blended learning and three roles of AI. We found that AI applications have been used mainly for the online asynchronous individual learning component in blended learning; little work has been conducted on AI applications that help connect online activities with classroom-based offline activities. Many studies have identified the role of AI as a direct mediator to help control flexibility and autonomy of students in blended learning. However, abundant studies have also identified AI as a supplementary assistant using advanced learning analytics technologies that promote effective interactions with students and facilitate the learning process. Finally, the fewest number of studies have explored the role of AI as a new subject such as use as pedagogical agents or robots. Considering the advancements of generative AI technologies, we expect more research on AI in blended learning. The findings of this study suggested that future studies should guide teachers and their smart AI partner to implement blended learning more effectively.

Keywords: blended learning, artificial intelligence, systematic review, AI in education

Blended learning, which integrates face-to-face learning and online instruction (Graham et al., 2013), has become an increasingly popular learning format. Many scholars have predicted that blended learning will become the primary instructional approach in the post-COVID-19 era. Mali and Lim (2021) reported that blended learning was perceived more positively during the COVID-19 pandemic. It provided flexibility in learning and often compensated for the weaknesses of online learning engagement (Boelens et al., 2017; Heo et al., 2022; Martin et al., 2022; Wang & Huang, 2018; Zydney et al., 2019). Although blended learning is not a new instructional approach, online learning experiences during the pandemic enabled educators and scholars to take a fresh look at the potential and power of blended learning as an effective instructional approach.

While many researchers have identified the effectiveness and efficiency of blended learning, Boelens et al.'s (2017) systematic review identified four challenges in blended learning: (a) incorporating flexibility, (b) stimulating interaction, (c) facilitating students' learning processes, and (d) fostering an affective learning climate. Despite the effectiveness of blended learning compared to fully online courses, this systematic review highlighted the many challenges and obstacles that still exist with blended learning. On the other hand, Dziuban et al. (2018) pointed out that information communication and technologies (ICT) have made it possible to implement the online learning component of blended learning. Beyond the use of ICT for blended learning, scholars have predicted that artificial intelligence (AI) including learning analytics (LA) techniques, an intelligent tutoring system, and automated essay scoring, will be increasingly adopted in blended learning in the future (Dziuban et al., 2018; Floridi, 2014; Norberg, 2017). Balfour (2013) also predicted that these AI applications will help instructors use their time and resources more efficiently and wisely by reducing their repetitive or recurring tasks. In addition, if AI is properly applied to blended learning, the need for and expense of teaching assistants and technology support personnel for implementing blended learning may no longer be an issue (Zydney et al., 2019). Hwang et al. (2015) emphasized the important role of artificial intelligence in flipped learning as a potential research issue for making flipped learning more effectively.

In the late fall of 2022, the emergence of ChatGPT (generative pre-trained transformer) introduced by OpenAI gained unprecedented attention in society as well as in education (Adiguzel et al., 2023; Halaweh, 2023; Yu, 2023). The use of ChatGPT in education is expected to become a potential tool to support students' personalized learning and to enhance students' engagement in the setting of blended learning (Alshahrani, 2023). Despite the increasing academic interests about the potential of ChatGPT, few scholarly works are currently available in education because it takes time to examine the role of ChatGPT after its extensive application for several years.

With the increasing interest in AI in education (AIEd), numerous systematic literature reviews (SLR) have been published in the past two to three years. While many studies have illustrated general research trends (Chen et al., 2020; Chen et al., 2022; Guan et al., 2020; Li et al., 2022; Song & Wang, 2020; Tahiru, 2021), several examples have emphasized the balance between technology-based applications and theory-based practices. Although many studies have been conducted on AI applications in BL, few systematic reviews have exclusively focused on this topic. Therefore, we conducted a systematic review and provided an overview of the AI applications that can be used in blended learning. As a framework, we used Boelens et al.'s (2017) challenges in blended learning as well as the three roles of AI proposed by Xu and Ouyang (2021). Based on the research findings, we have provided suggestions for applying AI in blended learning formats to enhance the effectiveness and efficiency of blended learning.

Theoretical Framework

Blended Learning

Blended learning refers to a combination of multiple instructional approaches in various dimensions, to find the optimal teaching and learning approach. However, considerable research has emphasized the ambiguity of the term blended learning and its complex nature (Oliver & Trigwell, 2005). Thus, numerous studies have attempted to clarify the various concepts (Caner, 2012; Cronje, 2020; Driscoll, 2002; Friesen, 2012), develop several models (Graham et al., 2013), and categorize the cases of blended learning (Graham, 2006; Horn & Staker, 2014; Margulieux et al., 2016; Park et al., 2016; Singh, 2003).

Blended learning has been defined in different contexts (e.g., ranging from K–12 to higher education) and with different focuses (e.g., formal vs. informal learning), but it can be roughly divided into three phases. In the early phase, when blended learning emerged as a new concept, scholars highlighted the combination of face-to-face (traditional) instruction and computer-mediated (online) activities as the dominant perception of blended learning (Graham, 2006). The second phase was typified by various combinations of modalities, delivery media, pedagogical approaches, instructional technologies, and job tasks, all to answer the question: What is blended? (Driscoll, 2002; Mantyla, 2001; Singh, 2003). The third phase has been characterized by a mix and selection of activities that are thoughtfully integrated in a way to complement each other based on the strengths and weakness of each component (Garrison & Kanuka, 2004; Singh, 2003).

Some scholars have simply recapped the ever changing and evolving definitions of blended learning (Caner, 2012; Friesen, 2012; Hrastinski, 2019), but many scholars have attempted to connect the types of blended learning with practices in the real world (Horn & Staker, 2014; Margulieux et al., 2016). Since blended learning allows limitless combinations, the types of blended learning vary depending on (a) what is blended, (b) in what proportion they are blended, (c) how many instructional components are blended, and (d) in what order they are blended. Allen et al. (2007) classified blended learning into four categories based on the proportion of online learning from traditional (none), Web-facilitated (below 30%), blended learning (between 30% and 79%), to mostly online learning (above 80%). Horn and Stalker (2014) suggested four types of blended learning in the context of K-12 education: (a) the rotation model, (b) the flex model, (c) the self-blending model, and (d) the enriched-virtual model. Among these models, the rotation model was further divided into four types: (a) station-rotation, (b) lab-rotation, (c) flipped learning, and (d) individual rotation. Based on the taxonomy by Horn and Stalker as well as other definitions, Caner (2011) provided a decision tree to determine whether a course is blended or is another type. Margulieux et al. (2016) defined diverse cases combining aspects of face-to-face and online instruction in the context of higher education and categorized them into the mixed instructional experience taxonomy.

Many researchers have conducted systematic reviews and meta-analyses of blended learning to synthesize the findings of the increasing number of studies that have examined the effects of blended learning. Bernard et al. (2014) reviewed 96 studies which compared the effectiveness of blended leaning in higher education. Their meta-analysis indicated that the blended learning conditions exceeded the classroom instruction conditions in terms of learning achievement in higher education (g = .334) and the computer support and presence of one or more interaction treatments enhanced student achievement. Boelens et al. (2017) conducted a systematic review that identified four key challenges when implementing blended learning. The first challenge is that blended learning designers must determine the appropriate amount of learner flexibility and how to incorporate flexibility in blended learning. Zydney et al. (2020) and Boelens et al. (2017) asserted that one of the strengths of blended learning is to give learners flexibility in terms of time, location, learning pace, and learning path. The second challenge is that giving learners more flexibility leads to more autonomy for learners (e.g., high transactional distance), but it reduces the social interaction between the instructor and learners or among learners. Hence, in blended learning, instructors need to stimulate and maintain interaction among learners, and between instructors and learners. Boelens et al. (2017) also emphasized the significance of two-way communication between instructors and learners in blended learning despite the physical separation in the online portion of a course. The third challenge is how to facilitate learning processes in a blended environment. To provide learners with abundant learning autonomy and flexibility, blended learning requires that learners be able to self-regulate. However, not all learners are equipped with sufficient self-regulation skills. Thus, for successful blended learning, it is necessary to help these students succeed. The last challenge of blended learning is the need to address the affective aspects of learning, such as learning satisfaction, motivation, engagement, as well as prevent feelings of isolation, as was the main concern in early distance learning (Gunawardena & Zittle, 1997). Examples of instructional strategies to support affective aspects of learning include enhancing instructors' teaching presence and social presence (Garrison, 2016; Wang & Huang, 2018).

The COVID-19 outbreak accelerated the growth of blended learning. Despite the massive and incalculable damage of the pandemic, one positive outcome was increased opportunities for educational change (Zhao, 2020) and extension of virtual learning (Hoofman & Secord, 2021). However, the quantitative expansion of online learning packages delivered to students' homes, as well as face-to-face learning replaced by video conferencing, both revealed the qualitative limitations of blended learning (Mali & Lim, 2021). Although the sudden change to online learning forced educators and students to adjust and change the status quo, it was still necessary that the components of blended learning be thoughtfully selected and integrated. Thus, educators and designers should carefully re-consider the challenges of blended learning (Boelens et al., 2017) to design effective approaches and conditions.

Artificial Intelligence in Education (AIEd)

As AI programs and applications have flourished, empirical research on their effects has been conducted across diverse domains, including education (Crompton et al., 2022). Systematic literature reviews of AIEd have reflected the significant growth in the application of AI in education and scholarly interest in the trends and patterns of using AI in education. For over 20 years, data-driven studies have also highlighted the increasing number of publications in the field and recent dramatic growth (Chen et al., 2020; Chen et al., 2022; Guan et al., 2020; Li et al., 2022; Song & Wang, 2020; Tahiru, 2021; Xu & Ouyang, 2021). Chen et al. (2020; 2022) investigated the publication trends including major conferences and journals, influential

institutions and researchers, leading countries, frequently cited papers, and research topics. Hwang et al. (2022) identified the distribution of the main research areas, research topics, roles of AI in online learning, and the adoption of AI algorithms. Guan et al. (2020) extended the focus of trends to the major paradigms in the history of AIEd literature. Li et al. (2022) analyzed keywords of studies by using CiteSpace software, and highlighted the most prevalent topics of AIEd research as data mining, virtual reality (VR), agents, intelligent tutoring system (ITS), and online learning. Song and Wang (2020) also applied bibliometric analysis and organized the publication trends into five clusters including ITS, learning system, student-centered learning, labelled training data, and pedagogy. Tahiru (2021) focused on the adoption of AI in education including opportunities, benefits, and challenges through a lens of the technological-organisational-environmental framework.

A large cluster of AIEd studies has focused on personalization for individual learners. In particular, the literature has shown that one of AI's major contributions is its capacity to assess individual students' performance (AlKhuzaey et al., 2021; González-Calatayud et al., 2021; Kurdi et al., 2020) and predict their learning outcomes (Arizmendi et al., 2022) for personalized learning (Bhutoria, 2022; Hashim et al., 2022). González-Calatayud et al. (2021) reviewed 22 papers that demonstrated how educators used AI to assess learners. They noted that formative evaluation has been one of the main uses of AI, such as automatic grading of students' work. In an early AIEd study, du Boulay (2016) mentioned that the AIEd field has existed for about 40 years and the most common application in AIEd has been ITS. Given that it is difficult to explain the AIEd field without referring to the ITS (Holmes et al., 2019), many scholars have conducted SLRs of ITS (Mousavinasab et al., 2021). Mousavinasab et al. (2021) conducted a systematic review with 53 papers and reported that (a) ITS was mostly applied in computer science; (b) the most dominantly applied AI techniques were action-condition rule-based reasoning, data mining, and Bayesian networks; and (c) AI techniques have made it possible to provide adaptive guidance and instruction as well as evaluating learners.

Systematic reviews on AIEd-related topics (e.g., AI applications or learning analytics) have been conducted on e-learning (Tang et al., 2021), blended learning (Bergdahl et al., 2020), and collaborative learning (Tan et al., 2022). Tang et al. (2021) analyzed trends in AI-supported e-learning based on 86 core papers and found that most studies focused on the development and applications of ITS, and AI has been used to facilitate assessment and evaluation in e-learning contexts. Bergdahl et al. (2020) focused on learning analytics (LA) approaches in blended learning and highlighted three themes based on 70 selected papers. They indicated that LA approaches have helped educators (a) understand and predict learners' performance, (b) identify students' behaviors and profiles, and (c) explore and improve the learning environment. Tan et al. (2022) also reviewed 41 studies on using AI for collaborative learning. They identified nine AI techniques (i.e., clustering, ensemble, regression algorithms, deep learning, decision trees, natural language processing, instance-based, fuzzy logic, and agents) for three main purposes for AI applications, namely discovering, learning, and reasoning.

SLRs in AIEd have also been conducted according to different target learners. Since AI technology has been applied in diverse education sectors, SLRs on AIEd have been conducted in diverse contexts including higher education (Chu et al., 2021; Gera & Chadha, 2021), K-12 education (Crompton et al., 2022), and teacher education (Celik et al., 2022). Chu et al. (2021) reviewed 50 AI studies in higher education and

reported that the most researched theme was predicting learners' status (e.g., dropout and retention, student models, academic achievement). Gera and Chadha (2021) focused on demographic and thematic trends of AI in higher education in 29 articles. They suggested future research to increase geographical variety, adopt advanced algorithmic approaches, and personalize learning. Crompton et al. (2022) reviewed 169 studies that used AI technology in K-12 education and found three main themes of AIEd applications: pedagogies (e.g., gaming, personalization), administration (e.g., diagnostic tools), and subject content.

Language learning and mathematics are the major subject areas that have frequently utilized AI technologies in education. In terms of the general trends in AIEd, Chen et al. (2020) found that existing educational software with AI technology integration has been mostly developed for mathematics and language learning. This trend has also been supported by other systematic reviews on AIEd that have identified the major areas as language learning (Du, 2021; Liang et al., 2021) and mathematics education (bin Mohamed et al., 2022; Hwang & Tu, 2021). These reviews indicated that using a neural network model has been the dominant method. Liang et al (2021) reported that the primary applications of language learning include writing, reading, and vocabulary acquisition, which are mostly adopted by ITS and natural language processing (NLP). Du (2021), who conducted a bibliometric analysis, added that a neural network has been a dominant method to train machines to learn, read, write, listen to, speak, and assess language. Hwang and Tu (2021) also conducted a bibliometric analysis with 43 articles to identify the trends of AI in mathematics education. They highlighted that AI technology has great potential to promote students' mathematics learning, especially to diagnose learning problems, provide instant feedback, and provide information to help teachers improve learning designs.

In sum, AI applications have contributed as agents, platforms, and analytics in diverse contexts within different disciplines. In a wide perspective, Xu and Ouyang (2021) categorized such roles of AI as (a) a new subject, (b) a direct mediator, and (c) a supplementary assistant to influence instructor-student, student-self, and student-student relationships. In adopting this framework, as shown in Figure 1, this study focused on the empirical studies that presented the contributions of AI to overcome the challenges in blended learning described in the previous section.

Figure 1



Conceptual Framework for This Study

Method

The purpose of this paper was to conduct a systematic review to synthesize the research findings on AI applications in blended learning. This systematic review followed Cooper's (1988) guidelines for conducting a systematic review. The publication period was from January 2007 to October 2023 given that Zawacki-Richter et al.'s (2018) systematic review found that research on AI applications in higher education started increasing in 2007. The three research questions guiding this research were as follows:

- 1. What are the research trends related to AI applications in blended learning?
- 2. What is the role of AI applications in blended learning?
- 3. How can AI applications help mitigate the challenges of blended learning?

Inclusion and Exclusion Criteria

We set the following inclusion criteria to search for eligible studies that (a) discussed AI applications; (b) were confined to blended learning; (c) were empirical studies including quantitative, mixed-method, or qualitative methodologies; (d) were written in English; (e) were peer-reviewed journal articles; and (f) were published between January 2007 and October 2023. Regarding the first inclusion criteria, we did not place limits on the proportion of online learning whereas Müller and Mildenberger's (2021) systematic review defined blended learning as "a course that blends online and classroom learning, with a proportion of between 30 and 79 per cent of the content delivered online" (p.3). We excluded non-empirical studies including conceptual papers and meta-analysis, and systematic reviews. Conference proceedings and technical reports were also excluded.

Search Databases, Strategies, and Process

The keywords we used to search for eligible studies were combinations of blended learning and artificial intelligence (or intelligent). We also included synonyms for blended learning including hybrid learning, flipped learning, and inverted learning, as well as another word for artificial intelligence, namely AIEd. The literature search process included a computer-based database search and manual search. The computer-based database search included Google Scholar, Education Resources Information Center (ERIC), and Web of Science. As an additional step, we conducted manual searches in relevant journals related to educational technology and artificial intelligence in education, including (a) *Computers & Education*, (b) *Educational Technology Research & Development*, (c) *British Journal of Educational Technology*, and (d) *Interactive Learning Environments*. From our computer-based database search findings, we found that these journals produced more studies relevant to our research than did other journals. We conducted the manual search to ensure we did not miss any eligible studies. Figure 2 illustrates the literature search and exclusion process using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

Figure 2

Search and Exclusion Process



From the 30 eligible studies, we extracted information on the (a) types of blended learning, (b) types of learners, (c) learning domains and disciplines, (d) AI applications, and (e) publication details (see Table 1). The authors first developed the coding scheme based on the research questions using Excel. Separately, the two authors manually coded by filling in the Excel spreadsheet. After completing the initial coding, they discussed any disagreement on the initial coding results, including eligibility, missing data, and ambiguous data (i.e., room for interpretation). Finally, the authors cross-checked each other's coding and corrected inaccurately coded items through a series of discussions until they reached a consensus.

Table 1

Coding Inj	formation fo	or Systematic	: Literature	Review
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Category	Coding information
Type of blended learning	Flipped learning, blended learning
Target learners	Kindergarteners, elementary, middle and high schools,
	undergraduates, graduates, adult learners
Learning discipline	Math, English, IT, and others
Research design	Experimental, quasi-experimental, correlational,
	qualitative research
Roles of AI	AI as a new subject, a direct mediator, supplementary assistant

Results and Discussion

This section discusses the research trends related to AI applications in the context of blended learning, the roles of AI in blended learning, and the contributions of AI applications for BL.

Research Trends Related to AI in Blended Learning

In this study, we explored how AI applications have been used in the context of blended learning by analyzing 30 relevant studies. In terms of the types of blended learning, 11 studies (36.7%) identified the context of study as blended learning and seven studies (23.3%) described it as flipped learning (see Table 2). Although flipped learning is a type of blended learning, it is distinctive since the cases involve online activities first followed by face-to-face (F2F) classroom activities. As another unique case, Méndez and González (2013) coined the term reactive blended learning to highlight the reactive feature of AI technology as applied in blended learning. Fang, Lippert, et al. (2021) referred to it as hybrid intervention since their research practice consisted of a human teacher-led session and auto tutor session. Although the context studied by Ng and Chu (2021) was online learning only instead of blended learning, we considered it blended learning. Finally, nine studies (30.0%) did not specify the research context. However, we assumed that those studies were conducted in a blended learning context since the two components of instructional methods included online learning and F2F classroom learning.

We further analyzed how AI technologies have been applied between the two components of blended learning. In 23 studies (76.7%), AI technologies were only applied in the online asynchronous learning portion of the class. In the other seven studies (23.3%), the use of AI technology was found in both the online and offline classroom environments. For example, Lechuga and Doroudi (2022) developed group formation algorithms for classroom-based collaboration activities based on the learning data from the intelligent tutoring system ALEKS. Ameloot et al. (2022) used learning analytics in blended learning to connect students' online activity with the offline workshop.

In terms of research contexts, 20 studies (66.7%) were conducted in higher education, and six studies (20.0%) targeted K–12 students. The remaining studies were in teacher education (10.0%) and lifelong learning contexts (3.3%). The proportion of learning disciplines were diverse, including (a) language learning, (b) computer science or engineering, (c) educational technology or multimedia, (d) natural sciences, (e) physics, (f) electronic engineering, (g) marketing, (h) art, (i) music, and (j) extracurricular activities. The research methods of the selected papers were as follows: quasi-experimental or experimental research (n = 12, 40.0%), quantitative research (n = 8, 26.7%), and design and developmental research (n = 5, 16.7%). A small portion of studies incorporated a qualitative approach, mixed methods, or case study.

Table 2

Research Backgrounds of the Selected Papers

Research background	n	%
Type of blended learning		
Blended learning	11	36.7
Reactive learning	1	3.3
Flipped learning	7	23.3
Hybrid learning	1	3.3
Online learning	1	3.3
Not specified	9	30.0
Application of AI		
Online	23	76.7
Both online and offline	7	23.3
Research context		
K-12	6	20.0
Higher education	20	66.7
Teacher education	3	10.0
Lifelong learning	1	3.3
Learning discipline		
Computer science/Programming	5	16.7
Ed tech/Multimedia	4	13.3
Language/Literacy	6	20.0
Mathematics/Statistics	4	13.3
Natural sciences/Physics	2	6.7
Marketing	1	3.3
Electronic engineering	3	10.0
Dance/Art/Music	1	3.3
Extracurricular activities	2	6.7
Not specified	5	16.7
Research method		
Design and development	5	16.7
Quasi-experimental/Experimental	12	40.0
Quantitative	8	26.7
Qualitative	2	6.7
Mixed methods	2	6.7
Case study	1	3.3

Role of AI

According to Xu and Ouyang (2021), AI has three distinctive roles. We adopted this framework and reviewed the role of AI in the selected papers. The results of the analysis are summarized in Table 3.

The category of AI as a new subject indicated that AI replaced (or did the work of) teachers or instructors, students, or peers. Examples are pedagogical agents for learning or social robots with bionic and humanlike (i.e., anthropomorphic) characteristics. While Xu and Ouyang's (2021) review indicated the role of AI as a tutor, tutee, or peer in this category, we could not find any case where AI played the role of tutee or peer role in our selected studies. Four (16.7%) of the 30 studies presented AI as a guide or a pedagogical agent. For example, in Whatley (2004) study, AI identified students and provided tutoring using a rule based on what they liked or disliked and whether or not they were able to participate in tutoring. In another case, IBM's Watson Tone analyzer was used for students to conduct social listening (Dingus & Black, 2021). In three studies, AI, in the form of a chatbot with a natural language processing (NLP) feature, guided students' language learning and had conversations with them (Annamalai et al., 2023; Lin & Mubarok, 2021; Neo, 2022).

The category of AI as a direct mediator means that AI plays the role of directly bridging the constructs in the educational system. An AI-based platform such as an ITS and interactive learning environment supports the whole process of instruction and learning. AI-based tools such as automatic grading software or translation tools can partially meet the demands of instruction and learning. Participants in the educational process (e.g., instructors, students, parents) choose either an AI-based platform or AI-based tool to meet their instructional demands or learning purposes. In this study, we found that a large proportion of studies (n = 12, 40.0%) fell into this category. In these cases, AI was a technology-integrated platform to support students' self-paced learning during automated lesson generation (Yang et al., 2013), intelligent tutoring (Phillips et al., 2020), multimedia guide on modern art (Chatzara et al., 2019), and ChatGPT (Sanchez-Ruiz, 2023).

Another common role of AI is related to assessment and feedback. For example, Chen et al. (2018) developed a checkable answer feature and immediate simple corrective feedback tool that was integrated in the edX platform. Troussas et al. (2020) developed a mobile game-based learning application that assessed and advanced students' programming knowledge. AI has also functioned as a tool to provide teachers and instructors with practical assistance such as automated question generation (Lu et al., 2021), a question-posing system (Hwang et al., 2020), Moodle-based quiz module (Jia et al., 2012), and online writing tutorial to correct paraphrasing and citations (Liu et al., 2013).

AI as a supplementary assistant indirectly influences educational participants. For example, learning analytics (LA) and educational data mining (EDM) allow instructors and students to better understand and predict learning based on their learning behaviors, characteristics, and learning patterns in instructional and learning processes. We identified six cases (20.0%) in the selected articles. For example, machine learning classification models were used to improve students' academic performance using a multimodal learning analytics approach (Liao & Wu, 2022). AI-enabled personalized video recommendations stimulated students' learning motivation and engagement (Huang et al., 2023). LA approaches have been incorporated to diagnose and intervene in student activities (Van Leeuwen, 2019) and provide personalized

feedback messages based on an algorithm combining the comments related to individual students' activities (Pardo et al., 2019). As a result, LA influences students' self-regulated learning behaviors (Montgomery et al., 2019) and learning performance (Liao & Wu, 2022). The review of the selected studies indicated that a supplementary assistant role has been combined with AI's first role (new subject) and second role AI (direct mediator). For example, in Tran and Meacheam (2020), in the Moodle LMS, the AI-based platform played a role as a supplementary assistant by supporting instructors' decision making in the LA report. Fang, Lippert, et al. (2021) also contended that Autotutor was not only a pedagogical agent but also a conversation-based intelligent tutoring system that supported analytics.

Table 3

Role	of AI	in	the	Sele	peted	Stud	ies
Note	IJЛ	ιπ	ine	Sele	cieu	Stuu	les

Role of AI	п	%
AI works as a new subject (e.g., pedagogical agent, robot, ChatGPT)	5	16.7
AI works as a direct mediator (e.g., AI-based platform or tool)	12	40.0
AI works as a supplementary assistant (e.g., EDM or learning analytics)	6	20.0
AI works as both a direct mediator and a supplementary assistant	4	10.0
AI works as both a new subject and a supplementary assistant	3	13.3

Contributions of AI in Blended Learning

To address our third research question, we analyzed the studies according to the four major blended learning challenges that Boelens et al. (2017) identified. Specifically, we reviewed the selected studies in terms of how AI technology helped mitigate these challenges (See Table 4).

The first challenge concerned students' flexibility and autonomy in blended learning. While flexibility is a strength, since students can learn at their preferred time and place, too much autonomy without selfregulation may negatively affect learning. Consequently, BL designers may find it difficult to determine the appropriate amount of flexibility and autonomy students should be given. We believe that AI can help instructors control students' autonomy. In the literature, we found that AI was a direct mediator to provide personalized instruction and scaffolding for individual learners (Lechuga & Doroudi, 2022; Phillips et al., 2020). More specifically, an online learning system powered by AI technology assigned repetitive practice (Lu et al., 2021), provided real-time alerts and feedback to prompt students to participate in daily or weekly discussions (Jovanović et al., 2017; Liao & Wu, 2022), and increased the probability of students achieving learning mastery (Phillips et al., 2020). Further, ChatGPT helped students get easy access to vast information and quick assistance based on their individual needs with the power of natural language processing (Sanchez-Ruiz et al., 2023). As a supplementary assistant, AI helped facilitate class administration and orchestration by tracking students' learning process, classroom dynamics, and goal achievement (Mavrikis et al., 2019). Another positive contribution was that the adoption of AI decreased teachers' workload and saved time (Lechuga & Doroudi, 2022; Lin & Mubarok, 2021). As a result, teachers focused more on helping students and customizing course content to improve the quality of blended learning.

The second challenge is that giving learners more flexibility leads to more autonomy for learners, but it reduces the social interaction between the instructor and learners or among learners. Therefore, blended learning designers need to connect students' individual online learning to collaborative classroom learning. The literature on flipped learning has strongly emphasized the need for connection (Bergmann & Sams, 2014; Straw et al., 2015; Talbert, 2017), and we found that AI can serve as an assistant to support collaborative learning practices (Lechuga & Doroudi, 2022). For example, AI helped teachers create student groups or cohorts (Lechuga & Doroudi, 2022), provided meaningful feedback automatically to large student cohorts (Pardo et al., 2019), and classified clusters of learners so the instructor could adjust the learning environment based on their abilities and characteristics (Fang, Lippert, et al., 2021). In another case, machine learning models helped classify students' discussion content to determine if they were course relevant in an online discussion activity of blended learning using a problem-based learning pedagogy (Liao & Wu, 2022). A typical learning analytics report also encouraged teachers to start interacting with certain students and when intervention was needed (Van Leeuwen, 2019).

The third challenge is a concern about how to facilitate learning processes in a blended learning environment, as this requires learners to self-regulate. We explored how AI applications helped change students' learning process and improved their performance. Several studies found that AI helped beginning learners enhance domain-specific knowledge and skills, such as programming language (Lu et al., 2021), dance movements (Yang et al., 2013), and English-speaking skills (Lin & Mubarok, 2021). The analytic feature of AI has also helped predict students' learning achievement. In a series of studies by Méndez and González (2010, 2013) presented a mechanism on how ControlWeb (i.e., a tool to support learning) analyzed students' behavior and controlled assignment loads to maximize their performance, participation, and motivation. As a unique case, Hwang et al. (2020) developed a concept mapping-based question-posing system that allowed students to observe plants on-site, provided question-posing activities at a shallow level and then at a deep level, and synthesized knowledge of plants. Other studies also found that AI technologies supported individual learners' vocabulary acquisition and assessment (Jia et al., 2012). In addition, it supported students' learning performance as well as critical thinking in a peer assessment activity that called for commenting on peers' work (Fang, Chang, et al., 2021).

The last challenge in implementing blended learning is the need to address the affective aspects of learning, such as satisfaction, motivation, and engagement, as well as prevent feelings of isolation. A few studies revealed affective aspects as additional or partial affordances of incorporating AI in blended learning. For example, Lin and Mubarok (2021) pointed out that their mind map-guided AI chatbot promoted students' English speaking skills in a relaxed manner. Huang et al. (2023) also highlighted that AI-enabled personalized video recommendations stimulated students' learning motivation and engagement. In Jovanović et al. (2017), the learning analytics of an online activity, which was designed as lecture preparation, motivated students to change their learning strategy. As well, AI technology designed with gamification, (e.g., a badge system; Troussas et al., 2020) stimulated students' learning engagement and collaboration.

Table 4

Challenges in BL	Contributions of AI
Control students'	• Provide personalized instruction and scaffolding (Liao & Wu, 2022;
flexibility and	Phillips et al., 2020)
autonomy	• Provide easy access to vast information and quick assistance based on
	individual needs (Sanchez-Ruiz et al., 2023), repetitive practice (Lu et
	al., 2021), and increase mastery of learning (Phillips et al., 2020)
	• Provide real-time alerts or feedback so students can better participate
	in daily and weekly discussions (Jovanović et al., 2017; Liao & Wu, 2022)
	• Augment the school experience (Chatzara et al., 2019)
	• Help class administration (Phillips et al., 2020) and orchestration
	through student tracking, classroom dynamics, and goal achievement
	(Mavrikis et al., 2019)
	• Help instructors customize course content, monitor students' learning
	progress (Phillips et al., 2020), decrease teachers' workload and save
	time (Lechuga & Doroudi, 2022; Lin & Mubarok, 2021)
Facilitate interactions	• Help teachers form groups of students and identify the content
between instructor	appropriate for differentiated instruction (Lechuga & Doroudi, 2022)
and student, and/or	• Support instructors to provide meaningful feedback to large student
students	cohorts (Pardo et al., 2019)
	• Classify clusters of learners and adjust the learning environment to
	learners' abilities and characteristics (Fang, Lippert, et al., 2021)
	• Support various collaborative learning practices (Lechuga & Doroudi,
	2022)
	Classify students' discussion content to determine relevance to the
	course (Liao & Wu, 2022)
	• Encourage teachers to start interaction with students, and inform
	teachers when intervention might be needed (Van Leeuwen, 2019)
Change learning	• Help beginning learners enhance domain-specific knowledge and
processes and	skills (e.g., programming language, dance movements, speaking
improving	English; Lin & Mubarok, 2021; Lu et al., 2021; Yang et al., 2013)
performances	

Contributions of AI in Blended Learning

	٠	Predict students' behavior and control assignment loads to maximize
		performance, participation, and motivation (Méndez & González,
		2010)
	•	Provide question-posing activities at shallow and deep levels, and help
		synthesize knowledge (Hwang et al., 2020)
	•	Allow individualized vocabulary acquisition and assessment so
		students improve reading and listening comprehension (Jia et al.,
		2012)
	•	Impact students' performance and critical thinking through peer
		assessment and commenting on peers' work (Fang, Chang, et al.,
		2021)
Foster affective	٠	Make students more relaxed (Lin & Mubarok, 2021), and engaged
aspects of learning		(Huang et al., 2023)
positively	•	Support students' competence, autonomy, relatedness (Annamalai et
		al., 2023)
	•	Cluster students based on their learning behavior and nudge students
		to change their learning strategy (Jovanović et al., 2017)
	•	Incorporate motivational strategies with a badge system (Troussas et
		al., 2020)

Limitations and Suggestions for Future Research

It is important to acknowledge the limitations of this literature review on the use of AI in blended learning in order to help readers understand how to better use AI and to provide meaningful suggestions for extending this research area. Since the scope of this research only analyzed the applications of AI in blended learning, only 30 articles were examined in our systematic review. However, given the growing interest in AI research in education, it is expected that more studies will examine AI applications for blended learning and will be included in follow-up studies. Above all, since ChatGPT was launched on November 30, 2022, scholars have noted drastic changes in teaching and learning, and expect the use of AI to move into uncharted territory. A generative AI such as ChatGPT offers a range of potential benefits for blended learning in terms of content generation, student engagement and motivation, and personalized learning (Alshahrani, 2023). Despite the increasing interest of ChatGPT in education, the lack of exploration of ChatGPT in the scope of this study is a limitation of this paper. We encourage future researchers to extend this study dealing with this generative AI in the context of blended learning.

Conclusion and Implications

This systematic literature review of studies examining the use of AI in blended learning explored how AI applications can help instructors and designers implement blended learning more effectively. We examined 30 journal articles in the domain of AI and blended learning to determine how AI helps advance blended learning practices. Figure 3 presents the connections of each article to the role of AI and the challenges of blended learning based on the description in the Appendix. The major research findings provide the following implications for the design and implementation of effective blended learning and for the future research directions of the use of AI in BL.

Figure 3



Sankey Diagram Showing Roles of AI for the Advances of Blended Learning

The first implication is that AI applications have been used mainly for the online individual learning component in blended learning, and, specifically, in an asynchronous mode. Contrary to our expectation, very few studies have focused on the connection between online and offline activities in blended learning using AI applications. A few exemplar studies (Lechuga & Doroudi, 2022; Whatley, 2004) explored the contribution of AI applications to group formation for the classroom-based collaboration and to connect students' online individual learning and offline activities. This systematic review also revealed that few cases explored how to use AI to enhance F2F classroom activities based on students' learning traces in the LMS

and analytic approaches involving AI (e.g., machine learning, deep learning techniques). These applications are promising areas for future research. Bergdahl et al. (2020) conducted a systematic review found a similar result. In their research, comparatively few studies revealed how students' behaviors (e.g., video viewing patterns, resource utilization, order of activities) informed instructors on how to enhance classroom teaching and resources. Thus, future studies need to incorporate learning analytics techniques as well as AI algorithms to identify the systematic connections of diverse activities when constructing blended learning.

Another implication is related to the roles of AI. A large proportion of the studies (40%) identified the role of AI as a direct mediator. AI-based platforms or tools played a mediator role for students and helped them be more engaged in the personalized learning environment. Automated lesson generation (Yang et al., 2013), adaptive intelligent tutoring (Phillips et al., 2020), and multimedia guides (Whatley, 2004) enhanced students' autonomy by allowing them to learn in the AI-based platform or Website at their preferred time. The AI-based platform also helped instructors control students' autonomy by guiding them through tailored lessons, providing scaffolding (e.g., adjusted questions, hints, or resources), and connecting them to peers for collaboration or further discussion. Since autonomy and flexibility could negatively influence students' learning performance, an AI-based interactive system, compared to video-based lectures, would be beneficial, especially for students with low levels of self-regulation. AI-based tools that incorporated the feature of generating questions (Hwang et al., 2020; Jia et al., 2012; Lu et al., 2021) and provided immediate feedback (Liu et al., 2013) can also contribute to students' mastery of learning and deeper learning.

Studies also revealed that AI as a supplementary assistant indirectly impacted student learning. AI technologies involving educational data mining or learning analytics helped instructors or teachers decide how best to administrate and orchestrate blended learning. In around 34.7% of the studies, AI played a major role in predicting students' behavior (Méndez & González, 2010), classifying students based on their learning behavioral patterns (Jovanović et al., 2017; Liao & Wu, 2022), and providing personalized feedback (Pardo et al., 2019). These features helped teachers effectively interact with their students (Van Leeuwen, 2019) and to make changes in students' learning strategies (Jovanović et al., 2017). However, very few studies discussed how AI analytic support can help teachers prepare or revise the offline activities in a blended learning environment. One recent exception, (Lechuga & Doroudi, 2022) discussed three types of group formation algorithms based on students' learning data, which supported various pedagogical and collaborative learning practices. More practical studies are needed that present pedagogical approaches utilizing AI technologies to help teachers blend diverse learning activities and adjust activities for individual students.

The least number of studies (20.4%) discussed the role of AI as a new subject. This role, implying the replacement of agents such as teachers or instructors, is a sensitive issue from teachers' perspectives. Discussing the role of AI and human teachers is not the focus of this study, but we believe this category will be the final feature of AI in education. Future studies can explore how this new subject with bionic and anthropomorphic characteristics can be successfully combined with the roles of AI as a direct mediator and supplementary assistant. However, we only found a few cases for this review, perhaps because this study focused on blended learning. Nevertheless, several studies in this review presented the partial function as

pedagogical agents (Whatley, 2004) such as a Chatbot (Annamalai et al., 2023; Lin & Mubarok, 2021; Neo, 2022), auto tutor (Fang, Lippert, et al., 2021), and voice assistant (Al-Kaisi et al., 2021), which allowed students to communicate and facilitated their learning with immediate feedback and scaffolding. It also helped teachers save time and reduce their workload. These studies indicated that this type of AI can effectively foster the affective aspects of learning. However, it should be noted that these affective aspects of AI in blended learning were discussed the least, accounting for only 10% of the studies. This suggests that future research needs to be extended by investigating not only students' learning processes or outcomes but also the affective aspects such as changes in their learning motivation, attitudes, and satisfaction. Given that we are no long in the COVID-19 pandemic, blended learning is expected to expand in scope, with growing use of AI in education. This study is a stepping stone for research and practices to design blended learning more effectively with the creative use of AI.

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Appendix

Analysis and Summary of Selected Papers

No	Citation	BL C	ontexts	A	AI Applicati	ons	Cont	ribution	s of AI i	n BL	Target learners/	Learning discipline	Evaluation method
100	Citation	Component 1	Component 2	Agent	Platform	Analytics	F	Ι	Р	А	research participants	•	
1	Méndez and González	Reactive blended learning		Fuzzy Controller measuring the activity level of student in the class			Predicti and con to maxi particip	ng stude trol assi mize the ation, a	ents' bel gnment e perforr nd motiv	naviour loads nance, vation	Higher Ed/ 91 undergraduate	Electronic engineering	Quasi- experimental design with a
	(2010)	F2F lectures	Online resources	Ø		•		0	•	0	students		control group
2	Whatley (2004)	Not specified		Guardian agent to allocate and tutor students using the rules based on what students like/dislike, and what student are good at.			Allowing students access to a project site at different times, communicating with other students and the guardian agent				Higher Ed/ 55 undergraduate	Not specified	Development of prototype / survey and group
		F2F team project	Online learning with software agents	•			Ø	•	0	0	students		interviews
3	Fang, Chang,	Not specified		Collaborative feedback- based peer-assessment (CFPA) learning system		Impacti perform critical assessm on peer	ng stude nance, se thinking nent and s' work	ents' elf-effica g via pee comme	ncy, and r nting	Teacher Ed/ 97	Educational	Quasi- experimental	
	et al. (2021)	F2F (introduction)	Online collaboration, peer assessment		•				Ø	0	teachers	teennology	control group
	Chen et al. (2018)	Blended learning		Checkable answer feature (CAF), a computer-based immediate simple corrective feedback tool, powered by edX platform			Providing immediate feedback so students interact with the CAF, and impacting students' study strategies and performance			edback 1 the 1 dents'			Quantitative analysis, data
4		F2F lectures	Problem- solving with online resources		•			•	Ø	0	Higher Ed/ 474 undergraduate students	Physics	mining with three data sources (demographics, tracking logs, and performance metrics)

5	Dingus and Black (2021)	Not specified		IBM's Watson Tone Analyser conducting social listening			Enhancing students' communication skills and deepening critical thinking through AI and the role of technology via discussion				Higher Ed/ 107 undergraduate	Marketing	Experimental design with pre- test and post survey
		Online video, interactions	F2F or online Discussion	•				Ø	0		students		survey
6	Troussas et al. (2020)	Not specified		Quiz time!: a mobile game- based learning application which assess and advance students' knowledge on programming			Recom of the s knowle balance Promot learnin motiva badge s	mending same or f edge leve ed or cha ting colla g and inc tional str system	y other le nigher cu el (CKL) Illenging aborative corporat rategies	earners urrent for a g play. g ing via a	Higher Ed/ 20 experts 80 undergraduate students	Computer science (C# programming)	Development research, evaluation population A (Computer science experts), population B
		F2F classroom	Online resources Mobile game		•		•	•	Ø	0			(learners)
7	Hwang et al. (2020)	Not specified		Concep question	t mapping-t n-posing sy	oased stem	After v plants a on-site posing level an allowir knowle	vatching and obse , providin activitie nd deep l ng them t edge of th	videos o rving the ng quest s at a sha level, an to synthe ne plants	of target e plants ion- allow d esize	K–12, primary school/ 90 students	Natural science (Plants)	Quasi- experimental design with a control group
		Field trip	Online system		•		Ø		•				
8	Tran and Meacheam (2020)	Flipped learning		Moodle making automat (d) 4-in learning	-based LMS , (b) LA rep ting course -1 for flippo g	S: (a) quiz oorts, (c) admin, ed	Improv produc student via inn and lea	ving LMS tivity and ts' learnin ovative u trning an	S users' d enhand ng expense use of we alytics	cing rience eb tech	Higher Ed/ instructors, learners, and administrators	NA	Development research (4 projects)
		Extended LMS	F2F classroom		•	•	Ø		Ø				
9	Lu et al. (2021)	Not specified		Automa generati combin and syn	Automatic question generation (AQG) solution, a combined semantics-based and syntax-based analysis			ing repet nswer qu ing stude y of cour	itive pra lestions, ents' lon rse knov	and and g-term vledge	Higher Ed/ 91 undergraduate	Computer science (basic Python	Experimental design with control group Evaluating the
		F2F Classroom	Online system		•		•		•		students	programming)	grading quality
10	Yang et al. (2013)	Blended learn	ing	An auto generati dance n motion	An automated lesson generation system for basic dance movements based on motion capture technology			Helping beginners learn dance in two phases: (a) learning from small, divided pieces of movement to the arranged patterns; (b) guiding students to incorporate all of the patterns in the full dance			Higher Ed/ 52 undergraduate students	Dance	Experimental design with three groups (treatment 1, 2, and control group)
		Classroom learning	Computer- mediated learning		•		•		•				una controi group)

11	Phillips et al. (2020)	Blended learning		ALEKS (assessment of learning in knowledge spaces): an intelligent tutoring system for mathematics			Providing students with personalized instruction to support increased mastery, supporting class administration, instruction, customizing course content and progress monitoring				K-12/9 High schools/ 24 teachers 2494 students	Mathematics (algebra)	Experimental evaluation with 3 models (a) Integration of ALEKS by teacher (b) use of ALEKS only, (c) teacher-	
		Teacher instruction	Online/digital learning		•		•		Ø		students		led (no use of ALEKS)	
10	Mavrikis et	Not specified		MiGen system: mathematical microworld called the eXpresserm and a teacher assistance (TA) tool		Supporting classroom orchestration through student tracking (ST), classroom dynamics (CD), and goal achievement (GA)			tudent m al	K-12/	Mathematics	Contextual design approach,		
12	al. (2019)	Classroom	Online system (AI-based exploratory learning environment)		•	Ø	•		Ø		26 teachers	(algebra)	formative evaluation	
13	Lin and Mubarok (2021)	Flipped learning		Mind map-guided AI Chabot		Decrea worklo more ro student skills, a issues o EFL (e	workload, making students more relaxed, promoting students' English speaking skills, and overcoming the issues of flipped classroom for EFL (extra workload)			Higher Ed/ EFL (English as a foreign language) 50 students	English (speaking)	Quasi- experimental design with a control group		
		Online resources	F2F Classroom	•			•		Ø		50 students		Broup	
14	Chatzara et al. (2019)	Machine-assisted blended learning		Istoriat: a WSeb/multimedia guide on modern art			Promot schooli algorith paintin crowds annotat	ing augr ng exper mic rec g styles ourcing- ion	nented rience vi ognition and driven i	ia of the ndirect	47 undergraduate /graduate students who	e Modern art (inter- disciplinary	Developmental research, usability evaluation and UX	
		In-class demonstration	Self-training with crowdsource users' feedback		•		0	Ø			are interested in modern art	course)	analysis	
15	Ng and Chu	Online learnin	g	Games for Oce model t	(e.g., Code. an, Image s rainer, Face	org, AI tylizer, Al -AI)	Extend via soc blended the pan	ing stud ial medi l techno demic	ents' exp a and ot logies d	perience her uring	K-12/ 98	Extracurricular	Case study investigating	
	(2021)	Asynchronous learning	F2F synchronous learning		•			Ø			students	activities	perception	
16	Fang, Lippert, et al. (2021)	Hybrid interve	ention	Autotut based I tutoring	or: a conver TS (intellige system)	rsation- ent	Providi enviror varying charact	ng learn ments tl gabilitie eristics (ing hat adap s and of users,	t to the	Adults with low reading literacy	Reading (literacy)	Quantitative research, cluster analysis	

					allowing researchers classify the clusters of adults								
		Human teacher-led session	AutoTutor session (25%)	•		Ø	Ø	•			-		
17	Al-Kaisi et	Flipped learning		Alice: Voice assistant as an interesting interlocutor who can make interactions playful		Helping foreign students develop their pronunciation and intonation, and practice basic speech patterns			ts ition ctice	Higher Ed/	Language learning	Experimental design with a	
1,	al. (2021)	Online learning with Alice	Electronic teaching aides in the classroom	•		•		Ø	•	0	undergraduate students	(Russian)	control group
18	Neo (2022)	Blended learning		Merin: a assistan simulato convers feature)	a virtual lea t (chatbot th es human-li ation with Y	rning nat ke NLP	Providi support online encoura engage	ng scaff ing asyn learning, aging stu ment in o	olding a achronou and andsidents'	nd 1s	Higher Ed/ 102 undergraduate	Multimedia (3-point lighting in 3D modelling	Mixed methods
		Classroom	Online learning with a chatbot	•			Ø	Ø	•		students	course)	
19	Jia et al. (2012)	Blended learning		Intelligent feature of the Moodle quiz module			Allowing individualized vocabulary acquisition and assessment so students improve reading and listening comprehension				K–12 (junior middle school)/768	Language learning (English vocabulary	Experimental design with a control group
		F2F in multimedia computer lab	Online individual learning system	-	•		Ø		•		students	acquisition)	eenner group
20	Liao and Wu (2022)	Blended learning d Wu 22)		ML clas with Fa multimo academ	ML classification models with Facebook datasets, multimodal LA on students' academic performance			ying stud urse relevan ng real-t alized sca idents' la r daily/ v g engage	lent disc vant and int, and ime aler affoldin earning veekly p ement	ts or ts or g to based beer	Higher Ed/ 51 graduate students	Advanced statistics	Quantitative research
		On-campus/ F2F synchronous	Off-campus/ Web-based Asynchronous			•	•	Ø	•				
21	Liu et al.	Not specified	1	Dwrigh interfac tutorial citing E	t: A Chines e online wr for paraphr nglish (ITS	e- iting asing and)	Extend plagiari paraphi	ing knov ism and casing an	vledge te enhancin d writin	o avoid ng their g skills	35 Chinese- speaking	English	Quantitative and qualitative
	(2013)	F2F class or workshop	Online writing practice		•		Ø		•		volunteering participants	(writing)	analysis
22	Montgomery et al. (2019)	Flipped learnin (regular biwee 50% online an	ng kly rotation of d 50% F2F)	Learnin approac	g analytics hes collecti	ng self-	Helping how to regular	g instruc support ity of on	tors con students line acc	sider s' ess and	Higher Ed/ 157	Music education	Quantitative analysis (log data by the Moodle

				regulate behavio	ed learning ours	(SRL)	Institutions design BL environments to support their SRL				undergraduate students	(basic music theory)	LMS and students' academic achievement)
		Online learning (theory)	F2F learning (practice)			•			•				,
23	Pardo et al	Blended learning		Personalized feedback messages based on the algorithm combining the comments related to individual students' activities			Supporting instructors in BL contexts to provide meaningful feedback to large student cohorts			in BL aningful nt	Higher Ed/	Computer	Quantitative analysis (log data by LMS self-
	(2019)	F2F classroom	Online resources (video, formative evaluation, exercise in LMS)			•	•				undergraduate students	engineering	reported survey, and academic performance)
24	Lechuga and Doroudi (2022)	Blended learning		3 group formation algorithms that leverage learning data from ALEKS ITS			pedagogical and collaborative learning practices and saving teachers' time in forming groups as well as identifying content that is most appropriate for differentiated instruction			orative aving 1g fying tiated	K–12/ 86 students	Algebra	Evaluating three grouping methods (within-module, curriculum-wide, reciprocal paring)
		Online learning in ALEKS	Activity in group formed by ALEKS data		•	•	•		٠				
25	Jovanović et al. (2017)	Flipped learning		Lecture preparation activities: Video with MCOs (multiple-choice questions), documents with embedded MCQs			Providi feedbac engage student learning nudging their lea	ng stude ck on the ment, cl s based g behavi g studen arning st	ents real- eir level ustering on their our; and ts to cha trategy	-time of I inge	Higher Ed/ 290 undergraduate	Computer engineering	Quantitative analysis (exploratory sequence analysis, custering
		Online learning (videos with MCQs)	F2F learning (active session)		Ø	•	•		٠	Ø	students		analysis)
		Flipped learnii	ng	LA repo and inte student	orts for diag rvening du activities	nosing	Encour interact informi interver	aging te ion with ng teach ntion mi	achers to student ers of w ght be n	start s, and hen eeded			
26	Van Leeuwen (2019)	Online materials	F2F meeting (teacher-guided practice)			•	Ø	•	Ø		Teacher Ed/ 7 teachers	Designing educational materials	Qualitative analysis (teacher logbooks, interviews)

27	Ameloot et al. (2022)	Blended learning		LA approaches with three types of LMS data (general, content, background)			Optimizing educational processes and course design and providing extra information about particular topics that might still be unclear				Teacher Ed/ 257 students	Educational technology	Quasi- experimental intervention study,
		Online learning	Classroom- based interventions			•			•				mixed method
28	Annamalai et al., (2023)	Not Specified		Chatbots (Students choose any chatbots among Duolongo, Mondly, & Andy)			Supporting competence, autonomy, and relatedness				Higher Ed/	English	Qualitative study with semi-
		Use of Chatbots	Classroom- based lecture	•			Ø	0		•	25 students	6	interview
29	Sanchez- Ruiz et al. (2023)	Blended learning		GPT-3.5, GPT-4 problem- solving capabilities			Providing easy access to vast information, quick assistance based on individual needs and clarifying doubts				Higher Ed/		Experimental
		Autonomous learning and online knowledge assessment	In-class reinforcement using dEERs(digital educational escape rooms)		•		•		Ø		102 first-year students	Mathematics I	design with a control group
30	Huang et al. (2023	Flipped classroom		AI-enabled personalized video recommendations			Helping improve the learning performance and engagement of students with a moderate motivational level			earning gement derate el	Higher Ed	Programming	Quantitative
		Online self- learning	F2F teaching in the classroom			•				•		6 6	research (survey)

Note: The table illustrates the degree of connection among the subtypes of AI applications (agent, platform, Analytics). It utilizes • to denote the most closely connected, \otimes for partially connected, and \circ for slightly connected cases. Additionally, concerning AI's contributions to BL in terms of F (controlling students' flexibility and autonomy), I (facilitating interactions between instructor and students, and/or students), P (changing learning process and improving performance), and A (fostering an affective aspect of learning positively), •, \otimes , and \circ are employed to represent the most closely, partially, and slightly connected scenarios, respectively.



