International Review of Research in Open and Distributed Learning

Role of AI in Blended Learning: A Systematic Literature Review

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Volume 25, Number 1, February 2024

URI: https://id.erudit.org/iderudit/1110518ar
DOI: https://doi.org/10.19173/irrodl.v25i1.7566

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Publisher(s)

Athabasca University Press (AU Press)

ISSN

1492-3831 (digital)

Explore this journal

Cite this article

Park, Y. & Doo, M. (2024). Role of AI in Blended Learning: A Systematic Literature Review. *International Review of Research in Open and Distributed Learning*, *25*(1), 164–196. https://doi.org/10.19173/irrodl.v25i1.7566

Article 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.

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February – 2024

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

Role of AI in Blended Learning: A Systematic Literature Review

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, such as the lack of immediate feedback from the instructor, the lack of social presence, and low 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

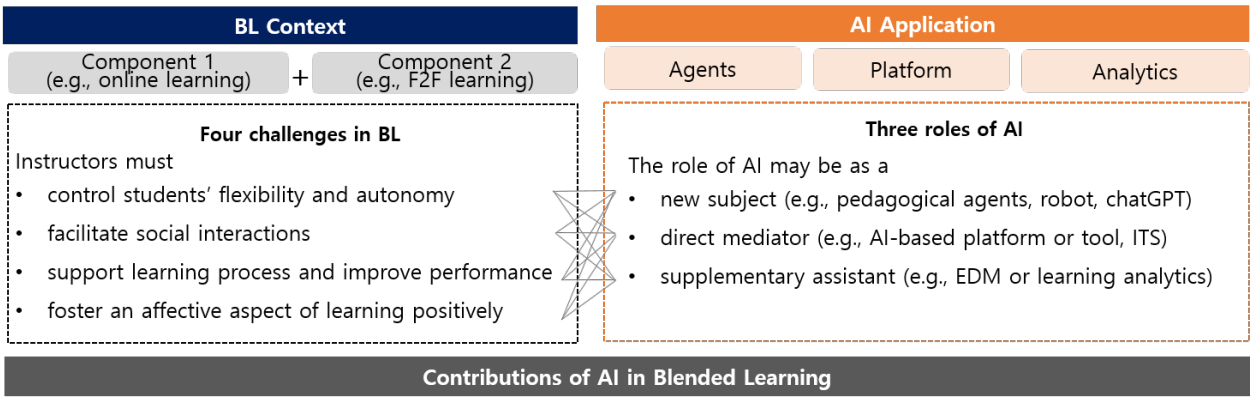
reported that the most researched theme was predicting learners' status (e.g., dropout and retention, student models, academic achievement). Gera and Chadha (2021) focused on demographic and thematic trends of AI in higher education in 29 articles. They suggested future research to increase geographical 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

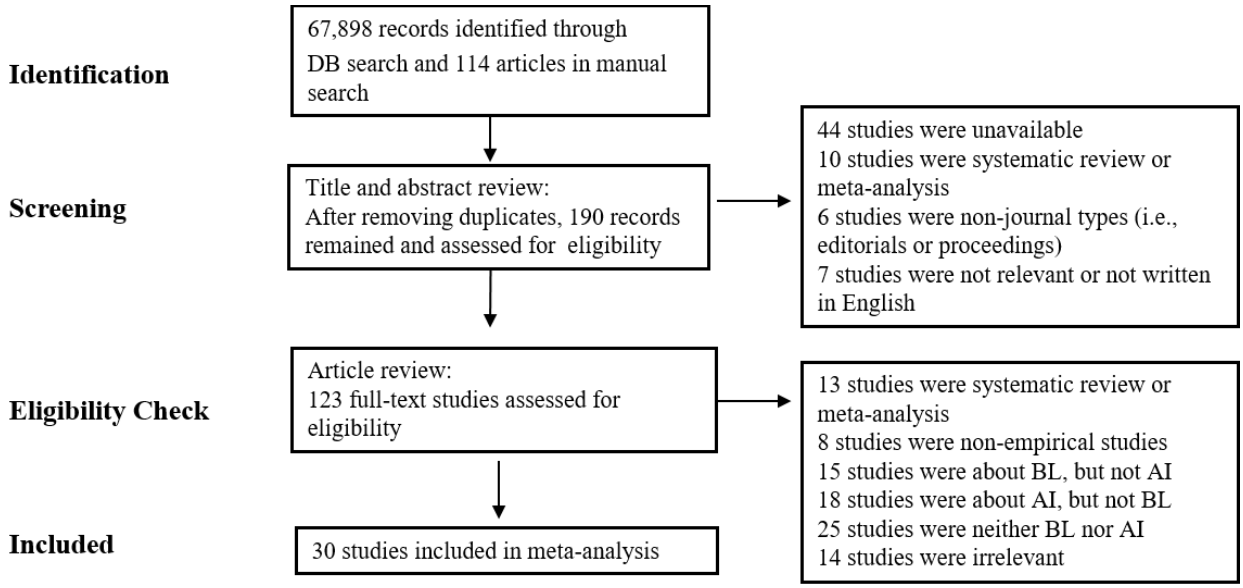
We set the following inclusion criteria to search for eligible studies that (a) discussed AI applications; (b) were confined to blended learning; (c) were empirical studies including quantitative, mixed-method, or qualitative methodologies; (d) were written in English; (e) were peer-reviewed journal 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 Information for Systematic Literature Review

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

Contribution of AI in BL	Flexibility and autonomy, interactions between instructors and students, supports of learning processes and performances, affective aspects of learning
Publication details	Title, author, year, journal name

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 since the practices were a combination of asynchronous learning and F2F synchronous 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 human-like (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 Selected Studies

Role of AI	*n*	%
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 self-regulation 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

Contributions of AI in Blended Learning

Challenges in BL	Contributions of AI
Control students' flexibility and autonomy	• Provide personalized instruction and scaffolding (Liao & Wu, 2022; Phillips et al., 2020) • 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 between instructor and student, and/or students	• Help teachers form groups of students and identify the content appropriate for differentiated instruction (Lechuga & Doroudi, 2022) • Support instructors to provide meaningful feedback to large student 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 processes and improving performances	• Help beginning learners enhance domain-specific knowledge and skills (e.g., programming language, dance movements, speaking English; Lin & Mubarok, 2021; Lu et al., 2021; Yang et al., 2013)

	• 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 aspects of learning positively	• Make students more relaxed (Lin & Mubarok, 2021), and engaged (Huang et al., 2023) • 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

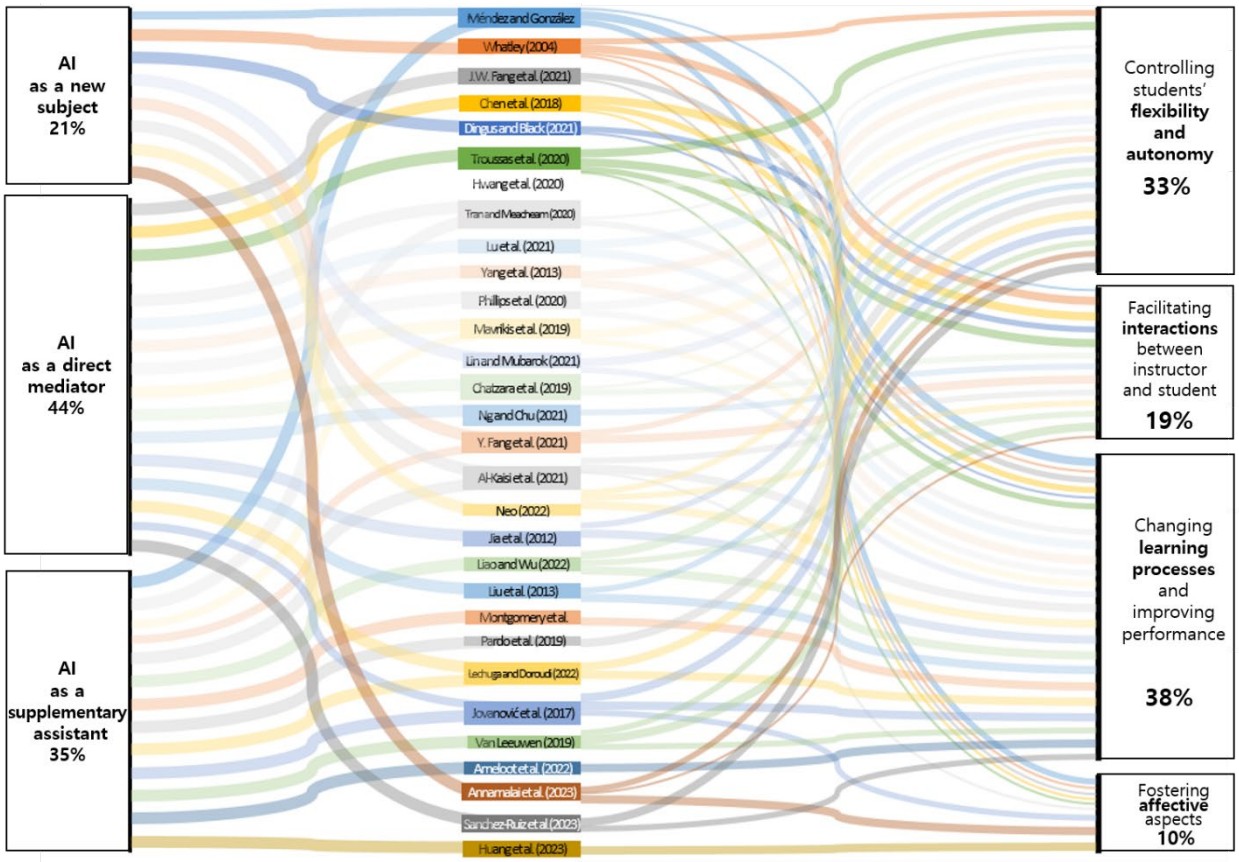
It is important to acknowledge the limitations of this literature review on the use of AI in blended learning in order to help readers understand how to better use AI and to provide meaningful suggestions for extending this research area. Since the scope of this research only analyzed the applications 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.

Acknowledgement

This study was supported by research fund from Honam University, 2022.

References

*References marked with an asterisk indicate studies included in the systematic review.

Adiguzel, T., Kaya, M. H., & Cansu, F. K. (2023). Revolutionizing education with AI: Exploring the transformative potential of ChatGPT. *Contemporary Educational Technology, 15*(3), ep429. https://doi.org/10.30935/cedtech/13152

*Al-Kaisi, A. N., Arkhangelskaya, A. L., & Rudenko-Morgun, O. I. (2021). The didactic potential of the voice assistant "Alice" for students of a foreign language at a university. *Education and Information Technologies*, *26*, 715–732. https://doi.org/10.1007/s10639-020-10277-2

AlKhuzaey, S., Grasso, F., Payne, T. R., & Tamma, V. (2021). *A systematic review of data-driven approaches to item difficulty prediction* [Paper presentation]. International Conference on Artificial Intelligence in Education. https://doi.org/10.1007/978-3-030-78292-4_3

Allen, I. E., Seaman, J., & Garrett, R. (2007). *Blending in: The extent and promise of blended education in the United States*. The Sloan Consortium. https://files.eric.ed.gov/fulltext/ED529930.pdf

Alshahrani, A. (2023). The impact of ChatGPT on blended learning: Current trends and future research directions. *International Journal of Data and Network Science, 7*(4), 2029–2040. http://dx.doi.org/10.5267/j.ijdns.2023.6.010

*Ameloot, E., Rotsaert, T., & Schellens, T. (2022). The supporting role of learning analytics for a blended learning environment: Exploring students' perceptions and the impact on relatedness. *Journal of Computer Assisted Learning, 38*(1), 90–102. https://doi.org/10.1111/jcal.12593

*Annamalai, N., Eltahir, M. E., Zyoud, S. H., Soundrarajan, D., Zakarneh, B., & Al Salhi, N. R. (2023). Exploring English language learning via Chabot: A case study from a self determination theory perspective. *Computers and Education: Artificial Intelligence, 5*, 100148. https://doi.org/10.1016/j.caeai.2023.100148

Arizmendi, C. J., Bernacki, M. L., Raković, M., Plumley, R. D., Urban, C. J., Panter, A., Greene, J. A., & Gates, K. M. (2022). Predicting student outcomes using digital logs of learning behaviors: Review, current standards, and suggestions for future work. *Behavior Research Methods, 55*, 1–29. https://doi.org/10.3758/s13428-022-01939-9

Balfour, S. P. (2013). Assessing writing in MOOCs: Automated essay scoring and Calibrated Peer Review™. *Research & Practice in Assessment, 8*, 40–48. https://files.eric.ed.gov/fulltext/EJ1062843.pdf

Bergdahl, N., Nouri, J., Karunaratne, T., Afzaal, M., & Saqr, M. (2020). Learning analytics for blended learning: A systematic review of theory, methodology, and ethical considerations. *International Journal of Learning Analytics and Artificial Intelligence for Education*, *2*(2), 46–79. https://doi.org/10.3991/ijai.v2i2.17887

Bergmann, J., & Sams, A. (2014). *Flipped learning: Gateway to student engagement*. International Society for Technology in Education. https://doi.org/10.1007/s12528-013-9077-3

Bernard, R. M., Borokhovski, E., Schmid, R. F., Tamim, R. M., & Abrami, P. C. (2014). A meta-analysis of blended learning and technology use in higher education: From the general to the applied. *Journal of Computing in Higher Education*, *26*(1), 87–122. https://doi.org/10.1007/s12528-013-9077-3

Bhutoria, A. (2022). Personalized education and artificial intelligence in United States, China, and India: A systematic review using a human-in-the-loop model. *Computers and Education: Artificial Intelligence*, 100068. https://doi.org/10.1016/j.caeai.2022.100068

bin Mohamed, M. Z., Hidayat, R., binti Suhaizi, N. N., bin Mahmud, M. K. H., & binti Baharuddin, S. N. (2022). Artificial intelligence in mathematics education: A systematic literature review. *International Electronic Journal of Mathematics Education*, *17*(3), em0694. https://doi.org/10.29333/iejme/12132

Boelens, R., De Wever, B., & Voet, M. (2017). Four key challenges to the design of blended learning: A systematic literature review. *Educational Research Review*, *22*, 1–18. https://doi.org/10.1016/j.edurev.2017.06.001

Caner, M. (2012). The definition of blended learning in higher education. In P. Anastasiades (Ed.), *Blended learning environments for adults: Evaluations and frameworks* (pp. 19–34). IGI Global. https://doi.org/10.4018/978-1-4666-0939-6.ch002

Celik, I., Dindar, M., Muukkonen, H., & Järvelä, S. (2022). The promises and challenges of artificial intelligence for teachers: A systematic review of research. *TechTrends*, *66*, 616–630. https://doi.org/10.1007/s11528-022-00715-y

*Chatzara, E., Kotsakis, R., Tsipas, N., Vrysis, L., & Dimoulas, C. (2019). Machine-assisted learning in highly interdisciplinary media fields: A multimedia guide on modern art. *Education Sciences*, *9*(3), 198. https://doi.org/10.3390/educsci9030198

*Chen, X., Breslow, L., & DeBoer, J. (2018). Analyzing productive learning behaviors for students using immediate corrective feedback in a blended learning environment. *Computers & Education*, *117*, 59–74. https://doi.org/10.1016/j.compedu.2017.09.013

Chen, X., Xie, H., & Hwang, G.-J. (2020). A multi-perspective study on artificial intelligence in education: Grants, conferences, journals, software tools, institutions, and researchers. *Computers and Education: Artificial Intelligence, 1*, 100005. https://doi.org/10.1016/j.caeai.2020.100005

Chen, X., Zou, D., Xie, H., Cheng, G., & Liu, C. (2022). Two decades of artificial intelligence in education. *Educational Technology & Society*, *25*(1), 28–47. https://www.jstor.org/stable/48647028

Chu, H.-C., Hwang, G.-H., Tu, Y.-F., & Yang, K.-H. (2022). Roles and research trends of artificial intelligence in higher education: A systematic review of the top 50 most-cited articles. *Australasian Journal of Educational Technology, 38*(3), 22–42. https://doi.org/10.14742/ajet.7526

Cooper, H. M. (1988). Organizing knowledge syntheses: A taxonomy of literature reviews. *Knowledge in Society*, *1*(1), 104. https://doi.org/10.1007/BF03177550

Crompton, H., Jones, M. V., & Burke, D. (2022). Affordances and challenges of artificial intelligence in K–12 education: A systematic review. *Journal of Research on Technology in Education*, 1–21. http://dx.doi.org/10.1080/15391523.2022.2121344

Cronje, J. (2020). Towards a new definition of blended learning. *Electronic Journal of e-Learning, 18*(2), 114–121. https://doi.org/10.34190/EJEL.20.18.2.001

*Dingus, R., & Black, H. G. (2021). Choose your words carefully: An exercise to introduce artificial intelligence to the marketing classroom using tone analysis. *Marketing Education Review*, *31*(2), 64–69. http://dx.doi.org/10.1080/10528008.2020.1843361

Driscoll, M. (2002). Blended learning: Let's get beyond the hype. *E-learning*, *1*(4), 1–4. https://www.academia.edu/download/7691892/blended_learning.pdf

Du, Y. (2021). *Systematic review of artificial intelligence in language learning*. 2021 International Conference on Intelligent Manufacturing Technology and Information Technology. http://166.62.7.99/conferences/AEASR/IMTIT%202021/IMTIT007.pdf

du Boulay, B. (2016). Artificial intelligence as an effective classroom assistant. *IEEE Intelligent Systems*, *31*(6), 76–81. https://doi.org/10.1109/MIS.2016.93

Dziuban, C., Graham, C. R., Moskal, P. D., Norberg, A., & Sicilia, N. (2018). Blended learning: The new normal and emerging technologies. *International Journal of Educational Technology in Higher Education*, *15*(1), 1–16. https://doi.org/10.1186/s41239-017-0087-5

*Fang, J.-W., Chang, S.-C., Hwang, G.-J., & Yang, G. (2021). An online collaborative peer-assessment approach to strengthening pre-service teachers' digital content development competence and higher-order thinking tendency. *Educational Technology Research and Development, 69*(2), 1155–1181. https://doi.org/10.1007/s11423-021-09990-7

*Fang, Y., Lippert, A., Cai, Z., Chen, S., Frijters, J. C., Greenberg, D., & Graesser, A. C. (2021). Patterns of adults with low literacy skills interacting with an intelligent tutoring system. *International Journal of Artificial Intelligence in* Education, *32*, 297–322. https://doi.org/10.1007/s40593-021-00266-y

Floridi, L. (2014). *The 4th revolution: How the infosphere is reshaping human reality*. Oxford University Press.

Friesen, N. (2012). *Report: Defining blended learning*. https://www.normfriesen.info/papers/Defining_Blended_Learning_NF.pdf

Garrison, D. R., & Kanuka, H. (2004). Blended learning: Uncovering its transformative potential in higher education. *The Internet and Higher Education*, *7*(2), 95–105. https://doi.org/10.1016/j.iheduc.2004.02.001

Garrison, D. R. (2016). *Thinking collaboratively: Learning in a community of inquiry*. New York & London: Routledge.

Gera, R., & Chadha, P. (2021). Systematic review of artificial intelligence in higher education (2000–2020) and future research directions. In W. B. James, C. Cobanoglu, & M. Cavusoglu (Eds.), *Advances in global education and research* (Vol. 4, pp. 1–12). USF M3 Publishing https://www.doi.org/10.5038/9781955833042

González-Calatayud, V., Prendes-Espinosa, P., & Roig-Vila, R. (2021). Artificial intelligence for student assessment: A systematic review. *Applied Sciences*, *11*(12), 5467. https://doi.org/10.3390/app11125467

Graham, C. R. (2006). Blended learning systems: Definition, current trends, and future directions In C. J. Bonk & C. R. Graham (Eds.)*, Handbook of blended learning: Global perspectives, local designs* (pp. 3–21). Pfeiffer Publishing.

Graham, C. R., Henrie, C. R., & Gibbons, A. S. (2013). Developing models and theory for blended learning research. In A. G. Picciano, C. D. Dziuban, & C. R. Graham (Eds.), *Blended learning: Research perspective* (Vol. 2). Routledge.

Guan, C., Mou, J., & Jiang, Z. (2020). Artificial intelligence innovation in education: A twenty-year data-driven historical analysis. *International Journal of Innovation Studies*, *4*(4), 134–147. https://doi.org/10.1016/j.ijis.2020.09.001

Gunawardena, C. N., & Zittle, F. J. (1997). Social presence as a predictor of satisfaction within a computer-mediated conferencing environment. *American Journal of Distance Education*, *11*(3), 8–26. https://doi.org/10.1080/08923649709526970

Halaweh, M. (2023). ChatGPT in education: Strategies for responsible implementation. *Contemporary Educational Technology, 15*(2), ep421. https://doi.org/10.30935/cedtech/13036

Hashim, S., Omar, M. K., Ab Jalil, H., & Sharef, N. M. (2022). Trends on technologies and artificial intelligence in education for personalized learning: Systematic literature review. *Journal of Academic Research in Progressive Education and Development*, *12*(1), 884–903. http://doi.org/10.6007/IJARPED/v11-i1/12230

Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial intelligence in education: Promises and implications for teaching and learning*. The Center for Curriculum Redesign. https://doi.org/10.58863/20.500.12424%2F4273108

Hoofman, J., & Secord, E. (2021). The effect of COVID-19 on education. *Pediatric Clinics*, *68*(5), 1071–1079. https://doi.org/10.1016/j.pcl.2021.05.009

Horn, M. B., & Staker, H. (2014). *Blended: Using disruptive innovation to improve schools*. John Wiley & Sons.

Hrastinski, S. (2019). What do we mean by blended learning? *TechTrends*, *63*(5), 564–569. https://doi.org/10.1007/s11528-019-00375-5

*Huang, A. Y., Lu, O. H., & Yang, S. J. (2023). Effects of artificial intelligence-enabled personalized recommendations on learners' learning engagement, motivation, and outcomes in a flipped classroom. *Computers & Education*, *194*, 104684. https://doi.org/10.1016/j.compedu.2022.104684

Hwang, G.-J., Lai, C.-L., & Wang, S.-Y. (2015). Seamless flipped learning: A mobile technology-enhanced flipped classroom with effective learning strategies. *Journal of Computers in Education, 2,* 449–473. https://doi.org/10.1007/s40692-015-0043-0

Hwang, G.-J., & Tu, Y.-F. (2021). Roles and research trends of artificial intelligence in mathematics education: A bibliometric mapping analysis and systematic review. *Mathematics*, *9*(6), 584. https://doi.org/10.3390/math9060584

Hwang, G.-J., Tu, Y.-F., & Tang, K.-Y. (2022). AI in online-learning research: Visualizing and interpreting the journal publications from 1997 to 2019. *International Review of Research in Open and Distributed Learning*, *23*(1), 104–130. https://doi.org/10.19173/irrodl.v23i1.6319

*Hwang, G.-J., Zou, D., & Lin, J. (2020). Effects of a multi-level concept mapping-based question-posing approach on students' ubiquitous learning performance and perceptions. *Computers & Education*, *149*, 103815. https://doi.org/10.1016/j.compedu.2020.103815

*Jia, J., Chen, Y., Ding, Z., & Ruan, M. (2012). Effects of a vocabulary acquisition and assessment system on students' performance in a blended learning class for English subject. *Computers & Education*, *58*(1), 63–76. https://doi.org/10.1016/j.compedu.2011.08.002

*Jovanović, J., Gašević, D., Dawson, S., Pardo, A., & Mirriahi, N. (2017). Learning analytics to unveil learning strategies in a flipped classroom. *The Internet and Higher Education*, *33*(4), 74–85. https://doi.org/10.1016/j.iheduc.2017.02.001

Kurdi, G., Leo, J., Parsia, B., Sattler, U., & Al-Emari, S. (2020). A systematic review of automatic question generation for educational purposes. *International Journal of Artificial Intelligence in Education*, *30*(1), 121–204. https://doi.org/10.1007/s40593-019-00186-y

*Lechuga, C. G., & Doroudi, S. (2022). Three algorithms for grouping students: A bridge between personalized tutoring system data and classroom pedagogy. *International Journal of Artificial Intelligence in Education, 33*, 1–42. https://doi.org/10.1007/s40593-022-00309-y

Li, Y., Jiang, A., Li, Q., & Zhu, C. (2022). The analysis of research hot spot and trend on artificial intelligence in education. *International Journal of Learning and Teaching*, *8*(1), 49–52. http://www.ijlt.org/uploadfile/2022/0214/20220214024004480.pdf

Liang, J.-C., Hwang, G.-J., Chen, M.-R. A., & Darmawansah, D. (2021). Roles and research foci of artificial intelligence in language education: An integrated bibliographic analysis and systematic review approach. *Interactive Learning Environments, 31*, 1–27. https://doi.org/10.1080/10494820.2021.1958348

*Liao, C.-H., & Wu, J.-Y. (2022). Deploying multimodal learning analytics models to explore the impact of digital distraction and peer learning on student performance. *Computers & Education*, *190,* 104599. https://doi.org/10.1016/j.compedu.2022.104599

*Lin, C.-J., & Mubarok, H. (2021). Learning analytics for investigating the mind map-guided AI chatbot approach in an EFL flipped speaking classroom. *Educational Technology & Society*, *24*(4), 16–35. https://www.jstor.org/stable/48629242

*Liu, G.-Z., Lo, H.-Y., & Wang, H.-C. (2013). Design and usability testing of a learning and plagiarism avoidance tutorial system for paraphrasing and citing in English: A case study. *Computers & Education*, *69*, 1–14. https://doi.org/10.1016/j.compedu.2013.06.011

*Lu, O. H., Huang, A. Y., Tsai, D. C., & Yang, S. J. (2021). Expert-authored and machine-generated short-answer questions for assessing students learning performance. *Educational Technology & Society*, *24*(3), 159–173. https://www.jstor.org/stable/27032863

Mali, D., & Lim, H. (2021). How do students perceive face-to-face/blended learning as a result of the COVID-19 pandemic? *The International Journal of Management Education*, *19*(3), 100552. https://doi.org/10.1016/j.ijme.2021.100552

Mantyla, K. (2001). *Blended e-learning: The power is in the mix*. American Society for Training and Development.

Margulieux, L. E., McCracken, W. M., & Catrambone, R. (2016). A taxonomy to define courses that mix face-to-face and online learning. *Educational Research Review*, *19*, 104–118. https://doi.org/10.1016/j.edurev.2016.07.001

Martin, F., Wu, T., Wan, L., & Xie, K. (2022). A meta-analysis on the community of inquiry presences and learning outcomes in online and blended learning environments. *Online Learning*, *26*(1), 325–359. https://files.eric.ed.gov/fulltext/EJ1340511.pdf

*Mavrikis, M., Geraniou, E., Gutierrez Santos, S., & Poulovassilis, A. (2019). Intelligent analysis and data visualisation for teacher assistance tools: The case of exploratory learning. *British Journal of Educational Technology*, *50*(6), 2920–2942. https://doi.org/10.1111/bjet.12876

*Méndez, J. A., & González, E. J. (2010). A reactive blended learning proposal for an introductory control engineering course. *Computers & Education, 54*(4), 856–865. https://doi.org/10.1016/j.compedu.2009.09.015

Méndez, J. A., & González, E. J. (2013). A control system proposal for engineering education. *Computers & Education, 68,* 266–274. https://doi.org/10.1016/j.compedu.2013.05.014

*Montgomery, A. P., Mousavi, A., Carbonaro, M., Hayward, D. V., & Dunn, W. (2019). Using learning analytics to explore self-regulated learning in flipped blended learning music teacher education. *British Journal of Educational Technology, 50*(1), 114–127. https://doi.org/10.1111/bjet.12590

Mousavinasab, E., Zarifsanaiey, N., R. Niakan Kalhori, S., Rakhshan, M., Keikha, L., & Ghazi Saeedi, M. (2021). Intelligent tutoring systems: A systematic review of characteristics, applications, and evaluation methods. *Interactive Learning Environments, 29*(1), 142–163. https://doi.org/10.1080/10494820.2018.1558257

Müller, C., & Mildenberger, T. (2021). Facilitating flexible learning by replacing classroom time with an online learning environment: A systematic review of blended learning in higher education. *Educational Research Review*, 34, 100394. https://doi.org/10.1016/j.edurev.2021.100394

Neo, M. (2022). The Merlin project3: Malaysian students' acceptance of an AI chatbot in their learning process. *Turkish Online Journal of Distance Education*, *23*(3), 31–48. https://doi.org/10.17718/tojde.1137122

*Ng, D. T. K., & Chu, S. K. W. (2021). Motivating students to learn AI through social networking sites: A case study in Hong Kong. *Online Learning*, *25*(1), 195–208. http://files.eric.ed.gov/fulltext/EJ1287128.pdf

Norberg, A. (2017). *From blended learning to learning onlife: ICTs, time and access in higher education* [Doctoral dissertation, Umeå University]. https://umu.diva-portal.org/smash/record.jsf?pid=diva2%3A1068011&dswid=5553

Oliver, M., & Trigwell, K. (2005). Can 'blended learning' be redeemed? *E-learning, 2*(1), 17–26. https://doi.org/10.2304/elea.2005.2.1.17

*Pardo, A., Jovanovic, J., Dawson, S., Gašević, D., & Mirriahi, N. (2019). Using learning analytics to scale the provision of personalised feedback. *British Journal of Educational Technology, 50*(1), 128–138. https://doi.org/10.1111/bjet.12592

Park, Y., Yu, J. H., & Jo, I.-H. (2016). Clustering blended learning courses by online behavior data: A case study in a Korean higher education institute. *The internet and higher education*, 29, 1-11. https://doi.org/10.1016/j.iheduc.2015.11.001

*Phillips, A., Pane, J. F., Reumann-Moore, R., & Shenbanjo, O. (2020). Implementing an adaptive intelligent tutoring system as an instructional supplement. *Educational Technology Research and Development*, *68*, 1409–1437. https://doi.org/10.1007/s11423-020-09745-w

*Sánchez-Ruiz, L. M., Moll-López, S., Nuñez-Pérez, A., Moraño-Fernández, J. A., & Vega-Fleitas, E. (2023). ChatGPT challenges blended learning methodologies in engineering education: A case study in mathematics. *Applied Sciences*, *13*(10), 6039. https://doi.org/10.3390/app13106039

Singh, H. (2003). Building effective blended learning programs. *Educational Technology*, *43*(6), 51–54. https://doi.org/10.4018/978-1-7998-7607-6.ch002

Song, P., & Wang, X. (2020). A bibliometric analysis of worldwide educational artificial intelligence research development in recent twenty years. *Asia Pacific Education Review*, *21*(3), 473–486. https://doi.org/10.1007/s12564-020-09640-2

Straw, S., Quinlan, O., Harland, J., & Walker, M. (2015). *Flipped learning practitioner guide*. National Foundation for Educational Research (NFER) and Nesta. https://media.nesta.org.uk/documents/Flipped_Learning.pdf

Tahiru, F. (2021). AI in education: A systematic literature review. *Journal of Cases on Information Technology*, *23*(1), 1–20. https://doi.org/10.4018/JCIT.2021010101

Talbert, R. (2017). *Flipped learning: A guide for higher education faculty*. Stylus Publishing.

Tan, S. C., Lee, A. V. Y., & Lee, M. (2022). A systematic review of artificial intelligence techniques for collaborative learning over the past two decades. *Computers and Education: Artificial Intelligence, 3*, 100097. https://doi.org/10.1016/j.caeai.2022.100097

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*, *31*(4), 2134–2152. https://doi.org/10.1080/10494820.2021.1875001

*Tran, T. P., & Meacheam, D. (2020). Enhancing learners' experience through extending learning systems. *IEEE Transactions on Learning Technologies*, *13*(3), 540–551. https://doi.org/10.1109/TLT.2020.2989333

*Troussas, C., Krouska, A., & Sgouropoulou, C. (2020). Collaboration and fuzzy-modeled personalization for mobile game-based learning in higher education. *Computers & Education*, *144,* 103698. https://doi.org/10.1016/j.compedu.2019.103698

*Van Leeuwen, A. (2019). Teachers' perceptions of the usability of learning analytics reports in a flipped university course: When and how does information become actionable knowledge? *Educational Technology Research and Development, 67,* 1043–1064. https://doi.org/10.1007/s11423-018-09639-y

Wang, Q., & Huang, C. (2018). Pedagogical, social and technical designs of a blended synchronous learning environment. *British Journal of Educational Technology, 49*(3), 451–462. https://doi.org/10.1111/bjet.12558

Whatley, J. (2004). An agent system to support student teams working online. *Journal of Information Technology Education: Research*, *3*(1), 53–63. https://www.learntechlib.org/p/111440/

Xu, W., & Ouyang, F. (2021). A systematic review of AI role in the educational system based on a proposed conceptual framework. *Education and Information Technologies*, *27*(3), 4195–4223. https://doi.org/10.1007/s10639-021-10774-y

*Yang, Y., Leung, H., Yue, L., & Deng, L. (2013). Generating a two-phase lesson for guiding beginners to learn basic dance movements. *Computers & Education*, *61*, 1–20. https://doi.org/10.1016/j.compedu.2012.09.006

Yu, H. (2023). Reflection on whether ChatGPT should be banned by academia from the perspective of education and teaching. *Frontiers in Psychology, 14,* 1181712. https://doi.org/10.3389/fpsyg.2023.1181712

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), 1-27. https://doi.org/10.1186/s41239-019-0171-0

Zhao, Y. (2020). COVID-19 as a catalyst for educational change. *Prospects*, *49*(1), 29–33. https://doi.org/10.1007/s11125-020-09477-y

Zydney, J. M., Warner, Z., & Angelone, L. (2020). Learning through experience: Using design based research to redesign protocols for blended synchronous learning environments. *Computers & Education*, *143*, 103678. https://doi.org/10.1016/j.compedu.2019.103678

Appendix

Analysis and Summary of Selected Papers

No	Citation	BL Contexts		AI Applications			Contributions of AI in BL				Target learners/ research participants	Learning discipline	Evaluation method
		Component 1	Component 2	Agent	Platform	Analytics	F	I	P	A			
1	Méndez and González (2010)	Reactive blended learning		Fuzzy Controller measuring the activity level of student in the class			Predicting students' behaviour and control assignment loads to maximize the performance, participation, and motivation				Higher Ed/ 91 undergraduate students	Electronic engineering	Quasi-experimental design with a control group
		F2F lectures	Online resources	◎		●		○	●	◎			
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 students	Not specified	Development of prototype / survey and group interviews
		F2F team project	Online learning with software agents	●			◎	●	○	○			
3	Fang, Chang, et al. (2021)	Not specified		Collaborative feedback-based peer-assessment (CFPA) learning system			Impacting students' performance, self-efficacy, and critical thinking via peer assessment and commenting on peers' work				Teacher Ed/ 97 pre-service teachers	Educational technology	Quasi-experimental design with a control group
		F2F (introduction)	Online collaboration, peer assessment		●				◎	○			
4	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				Higher Ed/ 474 undergraduate students	Physics	Quantitative analysis, data mining with three data sources (demographics, tracking logs, and performance metrics)
		F2F lectures	Problem-solving with online resources		●			●	◎	○			

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 students	Marketing	Experimental design with pre-test and post survey
		Online video, interactions	F2F or online Discussion	●				◎	○				
6	Troussas et al. (2020)	Not specified		Quiz time!: a mobile game-based learning application which assess and advance students' knowledge on programming			Recommending other learners of the same or higher current knowledge level (CKL) for a balanced or challenging play. Promoting collaborative learning and incorporating motivational strategies via a badge system				Higher Ed/ 20 experts 80 undergraduate students	Computer science (C# programming)	Development research, evaluation population A (Computer science experts), population B (learners)
		F2F classroom	Online resources Mobile game		●		●	●	◎	○			
7	Hwang et al. (2020)	Not specified		Concept mapping-based question-posing system			After watching videos of target plants and observing the plants on-site, providing question-posing activities at a shallow level and deep level, and allowing them to synthesize knowledge of the plants				K–12, primary school/ 90 students	Natural science (Plants)	Quasi-experimental design with a control group
		Field trip	Online system		●		◎		●				
8	Tran and Meacheam (2020)	Flipped learning		Moodle-based LMS: (a) quiz making, (b) LA reports, (c) automating course admin, (d) 4-in-1 for flipped learning			Improving LMS users' productivity and enhancing students' learning experience via innovative use of web tech and learning analytics				Higher Ed/ instructors, learners, and administrators	NA	Development research (4 projects)
		Extended LMS	F2F classroom		●	●	◎		◎				
9	Lu et al. (2021)	Not specified		Automatic question generation (AQG) solution, a combined semantics-based and syntax-based analysis			Providing repetitive practice of short-answer questions, and enhancing students' long-term memory of course knowledge				Higher Ed/ 91 undergraduate students	Computer science (basic Python programming)	Experimental design with control group Evaluating the question and grading quality
		F2F Classroom	Online system		●		●		●				
10	Yang et al. (2013)	Blended learning		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		●		●		●				

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-led (no use of ALEKS)
		Teacher instruction	Online/digital learning		●		●		◎				
12	Mavrikis et al. (2019)	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)				K–12/ 26 teachers	Mathematics (algebra)	Contextual design approach, formative evaluation
		Classroom	Online system (AI-based exploratory learning environment)		●	◎	●		◎				
13	Lin and Mubarok (2021)	Flipped learning		Mind map-guided AI Chabot			Decreasing teachers' 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	●			●		◎				
14	Chatzara et al. (2019)	Machine-assisted blended learning		Istoriat: a WSeb/multimedia guide on modern art			Promoting augmented schooling experience via algorithmic recognition of the painting styles and crowdsourcing-driven indirect annotation				47 undergraduate /graduate students who are interested in modern art	Modern art (inter-disciplinary course)	Developmental research, usability evaluation and UX analysis
		In-class demonstration	Self-training with crowdsource users' feedback		●		○	◎					
15	Ng and Chu (2021)	Online learning		Games (e.g., Code.org, AI for Ocean, Image stylizer, AI model trainer, Face-AI)			Extending students' experience via social media and other blended technologies during the pandemic				K–12/ 98 secondary students	Extracurricular activities	Case study investigating students' perception
		Asynchronous learning	F2F synchronous learning		●			◎					
16	Fang, Lippert, et al. (2021)	Hybrid intervention		Autotutor: a conversation-based ITS (intelligent tutoring system)			Providing learning environments that adapt to the varying abilities and characteristics of users, and				252 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%)	●		◎	◎	●					
17	Al-Kaisi et al. (2021)	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				Higher Ed/ 24 undergraduate students	Language learning (Russian)	Experimental design with a control group
		Online learning with Alice	Electronic teaching aides in the classroom	●		●		◎	●	○			
18	Neo (2022)	Blended learning		Merin: a virtual learning assistant (chatbot that simulates human-like conversation with NLP feature)			Providing scaffolding and supporting asynchronous online learning, and encouraging students' engagement in content				Higher Ed/ 102 undergraduate students	Multimedia (3-point lighting in 3D modelling course)	Mixed methods
		Classroom	Online learning with a chatbot	●			◎	◎	●				
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 students	Language learning (English vocabulary acquisition)	Experimental design with a control group
		F2F in multimedia computer lab	Online individual learning system		●		◎		●				
20	Liao and Wu (2022)	Blended learning under PBL pedagogy		ML classification models with Facebook datasets, multimodal LA on students' academic performance			Classifying student discussions into course relevant and course-irrelevant, and providing real-time alerts or personalized scaffolding to help students' learning based on their daily/ weekly peer learning engagement				Higher Ed/ 51 graduate students	Advanced statistics	Quantitative research
		On-campus/ F2F synchronous	Off-campus/ Web-based Asynchronous			●	●	◎	●				
21	Liu et al. (2013)	Not specified		Dwright: A Chinese-interface online writing tutorial for paraphrasing and citing English (ITS)			Extending knowledge to avoid plagiarism and enhancing their paraphrasing and writing skills				35 Chinese-speaking volunteering participants	English (writing)	Quantitative and qualitative analysis
		F2F class or workshop	Online writing practice		●		◎		●				
22	Montgomery et al. (2019)	Flipped learning (regular biweekly rotation of 50% online and 50% F2F)		Learning analytics approaches collecting self-			Helping instructors consider how to support students' regularity of online access and				Higher Ed/ 157	Music education	Quantitative analysis (log data by the Moodle

				regulated learning (SRL) behaviours			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. (2019)	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				Higher Ed/ 1020 undergraduate students	Computer engineering	Quantitative analysis (log data by LMS, self-reported survey, and academic performance)
		F2F classroom	Online resources (video, formative evaluation, exercise in LMS)			●	●						
24	Lechuga and Doroudi (2022)	Blended learning		3 group formation algorithms that leverage learning data from ALEKS ITS			Supporting various pedagogical and collaborative learning practices and saving teachers' time in forming groups as well as identifying content that is most appropriate for differentiated instruction				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		●	●	●		●				
25	Jovanović et al. (2017)	Flipped learning		Lecture preparation activities: Video with MCQs (multiple-choice questions), documents with embedded MCQs			Providing students real-time feedback on their level of engagement, clustering students based on their learning behaviour; and nudging students to change their learning strategy				Higher Ed/ 290 undergraduate students	Computer engineering	Quantitative analysis (exploratory sequence analysis, clustering analysis)
		Online learning (videos with MCQs)	F2F learning (active session)		◎	●	●		●	◎			
26	Van Leeuwen (2019)	Flipped learning		LA reports for diagnosing and intervening during student activities			Encouraging teachers to start interaction with students, and informing teachers of when intervention might be needed				Teacher Ed/ 7 teachers	Designing educational materials	Qualitative analysis (teacher logbooks, interviews)
		Online materials	F2F meeting (teacher-guided practice)			●	◎	●	◎				

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, mixed method
		Online learning	Classroom-based interventions			●			●				
28	Annamalai et al., (2023)	Not Specified		Chatbots (Students choose any chatbots among Duolongo, Mondly, & Andy)			Supporting competence, autonomy, and relatedness				Higher Ed/ 25 students	English	Qualitative study with semi-structured interview
		Use of Chatbots	Classroom-based lecture	●			◎	○		●			
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/ 102 first-year students	Mathematics I	Experimental design with a control group
		Autonomous learning and online knowledge assessment	In-class reinforcement using dEERs(digital educational escape rooms)		●		●		◎				
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				Higher Ed	Programming	Quantitative research (survey)
		Online self-learning	F2F teaching in the classroom			●				●			

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, ◎ for partially connected, and ○ 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), ●, ◎, and ○ are employed to represent the most closely, partially, and slightly connected scenarios, respectively.